Pressure Reactive Electronic Solar Stones

P.R.E.S.S.

Group # 20

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Sponsors:
Duke Energy
Leidos

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1 – Executive Summary

Our project will be a lighted solar powered landscape stepping stone. The stones will be made of a waterproof solid Plexiglas material that can withstand significant amounts of force. Inside these Plexiglas units, will be an array of LEDs, a solar panel and power management circuitry, a Microcontroller Unit (which controls the sequencing of the LEDs according to what pattern the user prefers), a pressure sensor, and a Bluetooth module that can make wireless connections between a user, a master and slave module stones.

Since the stepping stones will also be pressure sensitive, one of the modes of operation is when a stone is stepped on, the stone will light up. It can be programmed to make it so that the next stone in the path as well as the previous stone light up in order to show you the next step in your path. This also helps to conserve energy by not having all of them on all the time. However, if desired you will be able to turn on all of the stones at once for a fully illuminated walkway. A light intensity mode will also be available to select how bright you would like the path to be. Using multicolored LED lights a multitude of colors will be available for any preference, occasion, or theme.

As an added feature users will be able to control and program various lighting arrangements via their mobile phone. The phones will use Bluetooth to create a communication connection since Bluetooth does not consume large amounts of power and makes connecting wireless devices almost effortless. The program being used to create the communication platform is called jQuery. The jQuery framework allows for connection regardless of whether the smartphone being used is an Android or an Apple product since it does not discern. The application will have settings to choose the color variation of the lights and how bright you want them to be. Besides color patterns, this application will control all other aspects of the P.R.E.S.S. as well including sleep mode.

The technical approach for this project is going to formulated by doing research on multiple similar projects that have been accomplished and by taking the most relevant and efficient aspects from several reference designs. Texas Instruments products are preferred for the means of this design since Texas Instruments integrated circuits and semiconductors are much more prevalent in the electrical engineering industry versus Arduino which is more of a hobbyist platform. Texas Instruments products are also backed by a large online support community where any question can be asked and an engineer that knows the product will be able to help. The Microcontroller Unit that will be used will be of the MSP430 variety and it will hook up to an LED driver. The MSP430 is ideal for this project because it is widely used in LED applications and is a product that the group is familiar with. Overall, the final design is reached by a compilation of multiple similar design tactics used in various comparable applications. By conducting in-depth research on what products to use and how to integrate them, it’s easy to ensure the design is plausible and efficient.

2 – Detailed Description

2.1 – Motivation

Walkways are a part of almost every home's outside landscaping. The objective of our project is to provide the user an easy way to brighten an outdoor pathway while also being energy efficient. Walkway lighting is an important part to making a pathway visible in the dark. Imagine being able to give light to the pathway you are about to walk on at your home before even pulling into the driveway. A basic principle in pedestrian walkway safety is having a bright lit even-leveled place to travel. Our goal by creating a solar powered pressure sensitive light up walkway system will help provide safety and assurance for the user when traveling outside at night.

This design will also be applicable to commercial applications seeing as most outdoor parks or recreational areas try to abide by lighting specifications set by the Illuminating Engineering Society when they are bringing in anything new. A foot-candle measurement (or a lumen) is a metric for brightness. There are also set values in the United States for how bright certain areas should be in terms of lumens or foot-candles when construction documents are being laid out. Our project will assist designers in engineering a safely lit outdoor area by acting as a primary or supplementary light shedding solution.

2.2 – Specifications and Requirements

2.2.1 – Weather Proofing

A key aspect of the project is going to be ensuring that the devices can function in varying temperatures and with varying amounts of humidity. Seeing as rain, snow, hail, and flooding are a concern in most parts of the United States, it is important to cover the base to prevent water intrusion. After reviewing the existing standards for Ingress Protection Marking (IP Code) developed by the International Electrotechnical Commission (IEC), it was established that the devices would need to endure liquid ingress protection of up to level four. Testing procedures will be covered in a broader manner in the Design and Test sections but from the information gathered about weatherproofing standards, it was decided that the devices be required to meet the following standards regarding their environments.

- Stones shall be outdoor rated and waterproof in order to withstand rain and harsh weather.
- Stones shall be able to withstand high amounts of humidity.

- Stones shall be able to function in hot environments and relatively cold conditions (between 95 degrees Fahrenheit maximum and 50 degrees Fahrenheit minimum).

2.2.2 – Solar Powered

Seeing as the use of these stones will be for the user to place them in their yard and use them only at night to be able to see one's way into the house, the user will be expecting to perform little to no maintenance on the devices. This means it is expected that the design allows for internal power generation, storage and usage without an external power source being attached. The stones must be self-sufficient so the best suited answer to accommodate this need would be to implement solar panels within the stones for outdoor power generation. Because of this, there are certain requirements that need to be established for this aspect:

- Stones shall obtain 100% of the necessary power by means of solar acquisition.
- Stones shall have a photo resistor that plays into the power management circuitry and only allows power to the circuit when ambient light from the outdoor environment has been detected as absent.
- Stones shall have a solar panel that hooks into a battery and will charge all day as the photo resistor senses that light is present and once light is absent, the lighting circuitry (which could be on a set timer) will be activated.
- Stones shall be able to acquire the necessary amounts of power needed for a full night's worth of activity and will not run out of power prematurely.

2.2.3 – Pressure Sensitivity

If it is necessary that the stones light up when stepped on, a pressure sensing system is needed to evaluate loads being imparted on the stones at any given moment. The structural integrity of the stones must be considerably steadfast in order to support the weight of the user and still be able to use an accelerometer (or another related sensor) to sense the load. Also, as discussed in the section prior to this one, power is not an infinite resource to the devices once the sun has set. It is imperative that the devices be able to function on very low amounts of power and not waste functionality when they are not being stepped on (unless a light up pattern has been pre-defined by the user via the smartphone interfacing application). This creates a need that the group evaluate exactly what the stones should be expected to handle when it comes to pressure sensing.

- Stones shall be pressure sensitive to a minimum of 30 pounds and to a maximum of 300 pounds.

- Stones shall light up upon sensing the pressure and can be programmed to light up the next stone in the array or the previous stone in the array in order to guide the path of the user in dark situations.
- Stones will not be susceptible to lighting up for smaller outdoor creatures that will waste the available power.

2.2.4 – LED Coloring

These requirements are a little less stringent. It was still found to be necessary that our group come up with an idea of how we wanted the devices to light up, in which colors, and at what brightness variations. It was also necessary that the stones be able to light up brightly enough to give the user the ability to see the pathway or stone in front of them. The following specifications outline the manner in which the stones are to be expected to light up:

- Stones shall be made to be able to light up in a variety of different red, green and blue combinations.
- An LED driver will be used to drive the specific color combinations needed to activate user-specified hues.
- User shall be able to specify the amount of light being output from each stones as well as any color that is portrayed in the user-interface application.
- Stones shall be capable of lighting up in multiple different user-specified patterns and will be capable of repetitive blinking, fading in and out of different colors as well as timed pulses of light.

2.2.5 – Wireless Communication

Not only will the stones be functioning on solar power and lighting up in the dark but they will also be programmable by the user. This means that it is necessary to give the project certain specifications for how the stones will communicate with one another and about what types of tools the user can employ to be able to speak with the stones and give them commands on how to function. These specifications are listed below:

- The stones shall be able to interface with smartphones and receive commands from the user about how to light up.
- The stones shall use Bluetooth communication capabilities via a Bluetooth Serial Module embedded within each stone.
- The Bluetooth serial module will hook up to the Microcontroller Unit and send it signals on how to drive the lights.
- The stones shall be able to interface with both Apple smartphones and Android phones alike.
- The stones will communicate with each other in a Slave and Master format. There will be one Master stone that processes commands from the

application user interface and sends signals out to each of the Slave stones to light up at specific times in the patterns given.

- The application that is used to communicate with the stones is going to be made with a framework called jQuery (which is written in Hyper Techs Markup Language 5 but also uses Cascading Style Sheets 3 and JavaScript).
- The application shall be able to communicate flawlessly with the stones from a distance of at least thirty feet away.

2.3 – Roles

2.3.1 – LED Driving Design and Lighting Protocols

One of the important aspects of the project is understanding how to drive the Light Emitting Diodes to output different colors at different times. This will entail selection of an LED driver that best fits the given situation. It is also importance to select the proper high output, low power consumption Light Emitting Diodes. This means one of the roles of a group member is to focus solely on lighting and the types of circuitry that is required for making the stones do as they are told by the user. This means looking up a variety of different lighting protocols such as I-squared C and Digital Multiplexing 512 to better understand what is best applicable to this project.

2.3.2 – Communications Circuitry and Microcontroller Selection

Another important role is the focus of communications. This member need to understand the difference between different wireless communication methods such as Wi-Fi or Bluetooth. They must also understand how each of these different communication methods plays into working with a Microcontrollers Unit so they must also do the research on Microcontroller selection. Some Microcontrollers are better for mechanical uses while some are better for driving LEDs. Some microcontrollers are capable of storing larger amounts of information which may be a necessity for the need of this project since multiple lighting commands must be stored, processed and sent out at any given time so it is important to find the right controller to accomplish that goal.

2.3.3 – User Interface Application Production

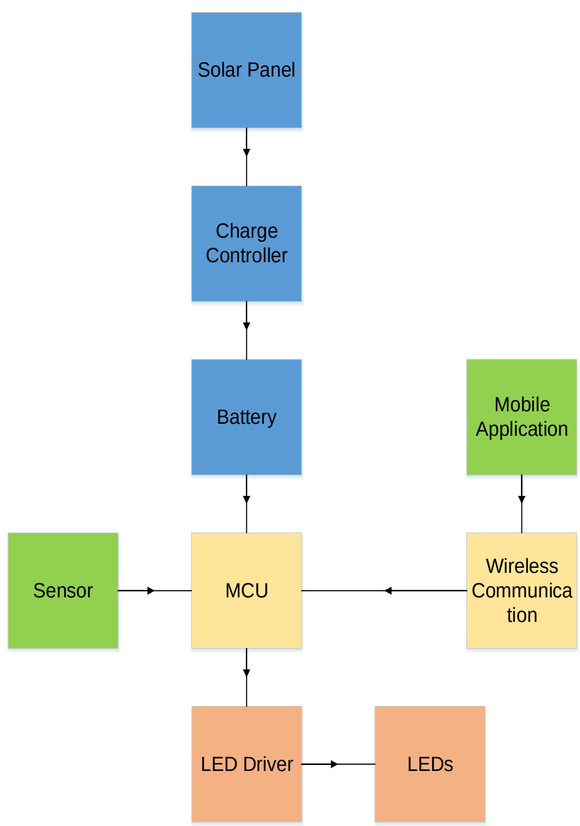
There is also the role of creating an application that allows the user to speak to the stones in plain English and tell them how and when he/she wants them to light up. This role requires a lot of knowledge of coding and language research. As long as the person in this role has a relevant understanding of how to code in C, they will have the building blocks for understanding other languages and will be able to create the platform through which all commands are passed.

2.3.4 – Solar Power Management Circuitry Design

Last but not least, a very pivotal role lies within the individual(s) who will be mapping out the power circuitry and deciding which types of solar panels to go with in order to be able to harness the necessary amount of power for the Microcontroller Unit, Bluetooth Transmitter/Receiver, Light Emitting Diodes, Driver and pressure sensor to all be functioning simultaneously. It is the role of this individual to also present power saving solutions when selecting certain electrical components.

2.4 – Block diagram

The solar panel emits a voltage to a charge controller within the main board. The charge controller regulates that voltage and outputs to a battery. The battery sends voltage to a voltage regulation board which boosts and drops voltage as necessary for specific needs of LEDs, Bluetooth module, and pressure sensor.



3 – Research

3.1 – Hardware

3.1.1 – Microcontroller Unit

3.1.1.1 – Texas Instruments Based Solutions

Before starting any project, a designer needs to have a solid grasp on the inner workings of all the pieces and parts used so that they can create an optimal system and be able to correct issues easily. A microcontroller basically acts as the brain of any electrically operating system. It is composed of Analog to Digital Converters, Memory (Static Random Access Memory, Flash memory, Electronically Erasable Programmable Read Only Memory), Timers, pins for input and output and possibly some type of debugging platform.

It starts out by the designer writing a program in a simple language such as C which is then taken by the programming interface and converted into assembly language which is comprised of AND, XOR, OR and MOV commands which explain where to look for inputs, what arithmetic operations to execute to the values stored in different addresses of the memory and where to pull output from. Once the assembly version of the software has been produced, one can upload the instruction set onto the microcontroller using a development board which gets plugged into a computer via USB. By pressing the on button to activate the unit, it immediately disables all other operations in order to get the system up and running. Power supply voltage gets to its max value and oscillator frequency becomes steady. The oscillator's main ingredient is a quartz-crystal which maintains a certain stabilizing resonant frequency. The frequency of operation within the circuit is not the same as the oscillator but is actually several times slower (which is still pretty fast from our perspective!). Then Special Function Registers are being packed with bits which show the state of all smaller systems inside the microcontroller. All pins are aligned as inputs. The overall unit begins to operate in sync with a pulsing clock sequence. The program counter begins at the first address in memory and sends whatever is at that address to be processed in the instruction decoder which executes it. The program counted continues counting from address to address executing instructions until it reaches the bottom at which point it starts all over again like clockwork. It will continue this pattern until a user turns it breaks off power supply of powers the MCU down. When you are dealing with products in today's market, it is definitely best to choose semiconductors and MCU's that are widely used on an industrial platform rather than a hobbyist platform. That is why Texas Instruments products are a wonderful option when trying to choose what type of ICs can accomplish the goals of the project.

The project may end up dealing with Wi-Fi connectivity or Bluetooth for communication purposes but on Texas Instruments website there exists an IC that perfectly meets all the right requirements. This microcontroller unit is called the CC3200 and it is a single chip wireless MCU. Inside of this chip, there is an ARM® Cortex®-M4 for Wi-Fi networks processing, power management subsystems and an ARM® Cortex®-M4 Core which acts as the Micro processing Unit.

Elaborating further on the application microcontroller subsystem within the CC3200 one may see that the ARM® Cortex®-M4 features a Nested Vector Interrupt Controller which means that rather than holding instructions in the vector table, it holds address values of the Interrupt Service Routine (a portion of the operating system that takes over when it receives an interrupt and executes the necessary operations to fix that interrupt) rather than regular instructions as the other ARM® Cortex®-M4 versions do [1]. The Wake-up controller interface is used to force exit and bring the chip out of any lower power hibernation modes it may be in. The chip incorporates a Central Processing Unit with Single Instruction Multiple Data instructions and a special architecture for DSP applications. Another section of this chip has the architecture for data input, transfer, storage and memory protection. The RAM is static and does not need refreshing. The memory protection aspect is accomplished by utilizing up to 8 regions (with sub-regions and background regions) of the Microprocessor unit. A Floating Point Unit is used as a specialized coprocessor used to perform complex mathematical computations in a more efficient manner than the general processing unit.

The following information mostly outlines the methods the processor uses to do debugging. It includes a Data Watchpoint and Flash Patch and Breakpoint features stop the coding simulation when memory is trying to be accessed so as to keep the debug program running smoothly. The ITM trace stands for Instrumentation Trace Macrocell and is used to send data to the debugger. The ITM memory retains data written into its registers and when the debugger is ready, it access that data through a trace interface to display or process it. This method is similar to Joint Test Action Group yet it is faster and more proficient. The ETM traces stand for Embedded Trace Macrocell which sends trace information using the Trace Port Interface Unit and the debug host uses external trace recognizing hardware to retain these instructions. The Debug Access Port bus interface resides at the core level and allows outside debugging software to access registers to debug memory and hardware while information is being processed. The Serial Wire Viewer Trace port controls that bus interface inside the Debug Access Port and can support both serial-wire protocol as well as regular JTAG protocol. A block diagram of the Microprocessor Unit is shown below in Figure 3.1.1.1.1.

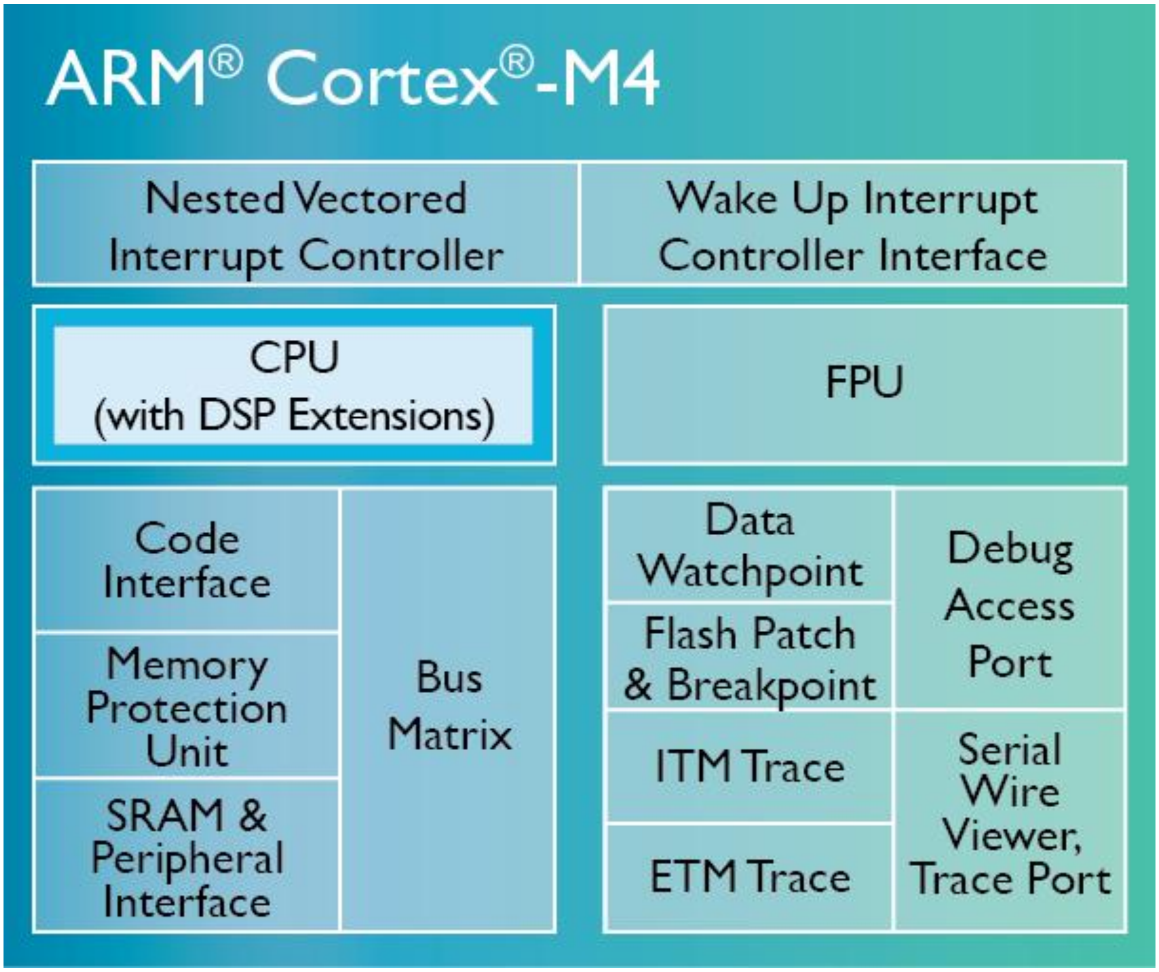


Figure 3.1.1.1.1 - Block Diagram of the Capabilities of the ARM® Cortex®-M4.

The CC3200's Wi-Fi network processor is an ARM® Cortex®-M4 and supports Station (this means that it is capable of using 802.11 protocol and can be fixed, mobile or portable), Access Point (this means Wi-Fi is being used to connect wireless devices to a router nearby which can then transmit the information to a destination point located on a broader scale) and Wi-Fi Direct Modes (Wi-Fi Direct Mode surpasses the need of an access point and connects wireless devices directly to one another without any go-between). The Wi-Fi RX current for this module is 53mA and its TX current is 223mA at 54 Orthogonal Frequency Division Multiplexing (a specific method of encoding digital information within a number of different carrier frequencies). The Wi-Fi RX sensitivity for this module is -95.7dBm and its TX power is 18dBm using Direct Sequencing Spread Spectrum as the modulating technique. The embedded internet system inside the chip includes Transport Layer Security and Secure Sockets Layer protocols which are used to ensure secure internet communications. It is also capable of understanding earlier internet protocols such as Transmission Control Protocol and Internet Protocol which are both less secure than the former two protocols. The embedded Wi-Fi system includes supplicant (this program is responsible for making log-on requests to a secure wireless network), Wi-Fi Driver, Wi-Fi Baseband (manages all Wi-Fi functions that require an antenna), and Wi-Fi Radio [2].

3.1.1.2 – Arduino™ Based Solutions

Although Arduino™ is mostly used on a hobbyist platform there are still many benefits to choosing to go with an Arduino™ based setup for the microcontrollers which are meant to go into each stone. There is a lot of open source code as well as many similar projects that can be used as references when attempting to come to a final product. The setup specifically requires a microcontroller, an LED driver to drive the LEDs with some sort of wireless communication attachment in order to be programed remotely. For the needs of this project, one could use an Arduino™ Uno (one of the latest revisions to the Arduino™ product line). This type of product uses an 'AT mega328' microcontroller at a 5V operating voltage. More about the Uno itself and its capabilities are expanded upon in the PCB section of the hardware research.

The 'ATmega328' showcases made by Atmel is a high performance 8-bit Reduced Instruction Set Computing based microcontroller that uses read-while-write abilities and a 32KB of self-programming flash memory and can operate between 1.8V and 5.5V. This product has 23 general purpose input/output lines with 32 general purpose registers. It uses serial programmable Universal Synchronous Receive/Transmit capacities alongside a 2 wire serial interface and a serial peripheral interface port in order to successfully communicate with outside devices. A very large benefit to going with a microcontroller like this one is how quickly it can execute commands since it can almost execute 1 million instructions per second per 1 MHz. The CPU is made by AVR. The product does not have a USB interface but that is where we would start incorporating the Arduino™ schematic in order to program the microcontroller. It's possible it may even be best to program the chip within the original Arduino™ Uno and then extract it for use within our PCB.

The overall comparison between the two Microcontroller Units is shown in this Table 3.1.1.2.1:

	ATMega328	**CC3200**
Flash Memory	32 KB	256 KB
Operating Voltage	1.8V -5.5V	2.1V - 3.6 V
Max Operating Frequency	20 MHz	80 MHz
Maximum I/O Pins	23	27
General Purpose Timers	3	4
ADC Channels	8	4
ADC Resolution	10 bits	12 bits
FPU	No	Yes
MPU	No	Yes
Debug Interface	debugWIRE	Serial Wire Debug & JTAG
UARTs	1	2
SPI	2	1
Wi-Fi Capable	No	Yes

Table 3.1.1.2.1 - Comparison of the benefits of the ATMega328 Microchip versus the CC3200 chip.

3.1.2 – Communication

3.1.2.1 – Bluetooth vs. Wi-Fi

When it comes to information transmission speed, Wi-Fi has it all. Bluetooth is much slower coming in at a rate of around 2.1 Megabits per second in comparison to Wi-Fi's more impressive 600 Megabits per second. Blue tooth is primarily used for making solid point-to-point connections while Wi-Fi is capable of communicating with multiple different devices at once which is ideal for our needs since we have a series of stones which will all be waiting for the "go-ahead" in order to execute lighting sequences. Bluetooth range usually varies from 5 meters to 30 meters while with Wi-Fi one could do the programming from anywhere they like as long as they are located near a router and can obtain a Wi-Fi signal which may be challenging seeing as the stones will be located in the yard of a home while the router could be located all the way across the property on the other side of the home where connectivity could be hard to come by. Bluetooth is very simple to use for interfacing since it just uses key matching while Wi-Fi is more complex and necessitates specific configuring of both hardware and software. Lastly, when we look at overall power consumption, since Wi-Fi is able to function over a much longer distance, it also requires more power in order to maintain those connections [3] [4].

Bluetooth is a short range technology used to eliminate the use of RS-232 cabling. Bluetooth devices occupy the unlicensed ISM (Industrial Scientific and Medical) band in the 2.4GHz range which is the same range as occupied by microwaves and Wi-Fi signals. All devices undergoing the exchange of information in a Bluetooth scheme comprise a “piconet”. This piconet has one master and can have up to seven slaves. The master can send messages to the slaves and the slave can respond to the master but there is no direct communication between the slaves when they are acting as secondary devices. A positive attribute to Bluetooth technology is how easily slave devices can reconfigure themselves as the masters in a new piconet while still remaining slaves in the previous piconet. This reconfiguration is very dynamic and can occur quickly without difficulties.

Bluetooth uses timeslots with frequency hopping in order to ensure robustness of communications transmissions. By picking a specific frequency in the given Industrial Scientific and Medical band for which to transmit a packet in a time slot (packets usually occupy one time slot but can cover up to five if necessary) and then immediately switching the transmission frequency for the next package transmission, the devices incurs less noise transmission from other RF source disturbances sharing the same frequency band. Bluetooth is superior to most competing designs because it hops from frequency to frequency faster and transmits smaller packets. A telecommunication theory called Forward Error Correction or channel coding allows for vigor over a longer transmission line. Forward Error Correction occurs when the sender encodes the message in a redundant manner which permits the receiver to perceive a small number of errors that could occur anywhere within the message (and often can fix these errors without having to receive the message a second time) [5].

Wi-Fi is a wireless local area network (WLAN) technology which utilizes 2.4 Ghz UHF (Ultra-High Frequency) to 5 GHz SHF (Super High Frequency) radio waves to make an internet connection. WLAN connection specifications are outlined in the Institute of Electrical and Electronics Engineers 802.11 Specifications. The 802.11 family consists of over-the-air modulation techniques that use the same given protocol. These techniques outline that communication can occur in both directions yet two devices cannot transmit data to one another simultaneously. 802.11-1997 was the first wireless networking standard to be output. This protocol had the following specifications: (1) Two net bit rates of 1 or 2 Mbit/s (2) Employs Forward Error Correction Code (which is the same FEC as was discussed for Bluetooth in section 4.1.4.2) (3) Calls out 3 similar physical layer technologies – diffused infrared at 1 Mbit/s, Frequency Hopping Spread Spectrum or Direct Sequence Spread Spectrum functioning at 1 or 2 Mbit/s. 802.11b was more widely accepted and it standardizes a maximum raw data rate of 11 Mbit/s while still maintaining all the same former specifications. One of the limitations of functioning in only the 2.4 GHz range is that there can only be one network in the area in order to avoid interference from Wireless Local Area Network surrounding signals. In order to solve this issue a newer standard of

802.11 was put out that states one can function in the 5GHz band of a multi-station WLAN with a transmission rate of 1 GBit/s. This new standard is reducing issues with connectivity and is spreading rapidly. Wi-Fi has a range of 115 ft indoors and a larger range outdoors. You can then use Wireless routers or Wireless Access points to connect within that range. Routers or Access Points with internal Ethernet switches or router firmware applications can provide internet protocol (IP) Routing, network Address Translation (NAT) and domain name system (DNS) forwarding to access a wide area network (WAN) interface in order to transmit data over very large ranges by accessing a cable/DSL Modem.

Lastly, another method of long-distance transmission is the use of wireless range-extenders or wireless repeaters. It is worthy to note that connections through repeaters will still undergo an amplified latency with each additional hop. The connection will also suffer a reduction in the maximum overall data throughput.

3.1.2.2 – Arduino™ Based Solutions

Depending on whether or not one wants to use Bluetooth or Wi-Fi for wireless communication between the mobile device and the controllers within each of the stones, there are Arduino™ compatible solutions for both scenarios. Starting with Bluetooth, connecting a wireless device to an Arduino™ based PCB is very simple. By using an inexpensive Bluetooth Serial Module which only has four simple pins (5V supply, GND, Receive/RX, and Transmit/TX) and connecting it to the appropriate ports on the PCB, this module allows wireless connectivity to be almost effortless. Use '1234' as the pairing key so one can pair the PCB with your Bluetooth capable device and some simple code for this pairing is also provided in the Communication section of Software Research. The PCB replaces the regular serial Receive and Transmit cables with the RX and TX on the Module.

Pairing devices via Wi-Fi is not as simple but definitely allows the user more freedom when trying to execute commands at more than one point. For this we would use the Wi-Shield product from Async labs. This board uses a PCB antenna, 9 pin breakout for prototyping, uses serial peripheral interface in order to communicate with host at speeds as fast as 25MHz. Uses 6 Arduino™ ports: (4) for SPI- Slave Select on pin 10, clock on pin 13, Master in Slave out on pin 12, and Master out Slave in on pin 11. (1) for interrupts – either INT0 on pin 2 or DIG8 on pin 8, (1) for LED on pin 9 which is not entirely necessary but does help with troubleshooting. The Wi-Fi module is also small with dimensions of 1.9 x 2.1 x .5 inches and can easily be connected to any Arduino™ based devices [6].

3.1.2.3 – Texas Instruments Based Solutions

The best option for communication if one decides to go with Texas Instruments products would be their newest CC3200 chip which integrates a Microcontroller Unit with a built-in Wi-Fi network processor. This built-in Wi-Fi Networks processor's internal structure was laid out in section 2.1.1.2 of this document during the evaluation of the Microcontroller Unit since the Wi-Fi network and the MCU chip are one in the same. The Wi-Fi subsystem features a Wi-Fi Internet-on-a-Chip and utilizes an ARM® Cortex®-M4 which is completely separate from an addition ARM® Cortex®-M4 used for applications within the chip. This subsystem comprises an 802.11 compliant radio, baseband, and media access control (MAC). Fast connectivity and security are ensured through the chip's encrypting engine with 256-bit encryption. Both WPA2 for personal and enterprise security and WPS 2.0 are each supported through this device as well. WPA2 stands for Wireless Protected Access and WPS 2.0 stands for Wi-Fi Protected Setup which is a standard that tries to enhance security of wireless network set up and connection by making the process for connectivity more systematic.

3.1.3 – Solar Power

There are multiple ways to power electronic devices. Power supplies take electrical energy and convert that energy into usable energy for that specific device. Renewable energy sources take energy from a source that cannot be depleted such as wind power, hydropower, solar power, and natural gas. The sun is an incredible renewable energy source that produces an incredible amount of energy that is turned electrical power. There are a few things to be considered when dealing with the power solar produces. Solar energy has some advantages and disadvantages to be discussed. Different types of panels have different efficiency rates while also having different ways of turning the suns energy into electrical power. The suns radiation plays a significant part in the efficiency of solar energy.

3.1.3.1 – Advantages and Disadvantages of Solar Power

Solar energy is considered to be one of the cleanest sources of energies on the planet. It creates absolutely no pollution which makes it much more practical compared to the most used energy source, oil. The burning of oil for energy creates harmful greenhouse gasses, carcinogens and carbon dioxide that gets released into the air [7]. Solar energy emits zero greenhouse gasses which makes it incredibly eco-friendly and could help eliminate some of the serious future climate changes our planet will endure.

Another advantage of solar energy is that it can be harnessed from almost anywhere in the world the sun can reach. Solar farms are becoming more and more popular throughout the United States. Orlando Utilities Company out of Central Florida finished construction on its own solar farm in 2011 called the Stanton Solar Farm. The solar farm provides more than 600 homes with power generated from renewable energy with its 6 Mega Watt facility [8]. Labor costs for solar farms are significantly lower compared to a fossil fuel plant. Fortunately for solar farms the sun and the light and energy emitted from it do most of the work. Since the sun is unlimited and free, it makes solar energy less vulnerable to price manipulations from the politics. The cost of fossil fuels is constantly increasing as wars rage across the world and relationships with countries who mine the raw materials for these fossil fuels rigid. Within the last decade the cost of fossil fuels have doubled, when the price per watt of solar energy production has more than halved [9].

Although solar power energy has many of advantages, it also has some disadvantages. One of the major disadvantages is that it does not work at night, during storms, or on a cloudy day. On days that the sun is shining the solar panel device then needs to store energy in another device that can access the stored energy at a further time. This can limit the amount of power that can be saved from day to day making it not completely reliable. As a society that depends on electrical power on a daily basis this can be quite discerning, making society depend on more readily available energy sources. Unfortunately solar panels can also be quite expensive depending on the type of materials used in the panel itself. This can come across as a disadvantage at first, but with tax breaks for using solar energy for businesses and homeowners makes investing in solar power a benefit investment wise. With new technologies being developed daily, what used to be expensive, bulky, and inefficient in the early days of solar power energy is ever becoming cheaper, more accessible, and more efficient [7].

3.1.3.2 – Harvesting Solar Energy

The energy the sun gives is converted into electrical power by the photovoltaic effect. The term “photo” means light and “voltaic,” electricity. Energy is generated by materials that absorb photons of light from the sun and release electrons. The types of material used in solar panels are primarily made of crystalline silicon semiconductor. Most generally the materials are called PV cells, PV standing for photovoltaic. The PV cells can be connected in both parallel and series combinations to produce different voltages and currents. The PV cells create DC current which is then converted into AC current by an inverter so the energy can be used in homes and businesses [10].

There are two types of solar power generating systems: grid-connected systems and stand-alone systems. Grid connected systems are connected to the commercial power infrastructure and distribute energy back and forth between the solar system and the power companies. During a sunny day the grid connected solar panel collects energy from the sun and actively uses that electrical power throughout the day. The extra power collected is either stored for later use, like at night time or on cloudy days, or is sold back to the power companies for them to use and distribute. If the solar system does not generate enough power, electricity can also be purchased from the power company to use until the solar power system collects enough energy to sustain itself again. Stand-alone systems solely depend on themselves and are mostly used for emergency power. In other cases they are also used as power supplies in remote areas for places that are off the utilities companies' power grid.

3.1.3.3 – Solar Cells and Manufacturing Technology

There are various types of solar cells that all use different materials to make them unique. Each type of solar cell varies in cost of production, efficiency of light absorption, energy conversion efficiency, and the semiconductor material used. Most PV cells that are currently in use today are silicon based although; they can also be made of other semiconductor materials that are not silicon as well. There are the new up and coming PV solar cells are using what is considered a second generation technology called thin films. More research and tests have been produced for silicon PV solar cells, but it is predicted that the thin film PV solar cells are eventually going to surpass silicon PV cells in performance and cost within the next decade [10]. Both types of PV solar cells can be split mono-crystalline or polycrystalline subcategories. The most commonly used material in mono-crystalline thin film panels is gallium arsenide (GaAs). Some of the more common materials used to create polycrystalline thin film panels are copper indium gallium selenide (CIGS), cadmium telluride (CdTe), and amorphous silicon (A-Si).

3.1.3.3.1 – Mono-crystalline Silicon Panel

Mono-crystalline silicon panels or single-crystalline silicon cells are one of the most commonly used PV panels used in industry. The have been proved to be one of the most reliable and dependable technologies in the solar industry. Mono-crystalline silicon panels are made from a technique called the Czochralski method. This method takes a mono-crystalline silicon seed and dips it into a melted mass of high-purity poly-crystalline. The mono-crystalline seed is slowly pulled to form a single-crystal ingot [11]. The ingots then get sawed into extremely small wafers. These types of silicon wafers are used for semiconductor device fabrication.

Single-crystalline silicon is extremely reliable because it has a uniform molecular structure making it have 15-18% efficient, which is higher energy conversion efficiency than other types of solar panels [11]. Having high efficiency means the mono-crystalline will get the most watts of power per square foot which is ideal. Unfortunately this type of PV cell is one of the more expensive types of PV cells due to its high pure silicon content and its lack of imperfections in the cellular structure. These types of PV solar panels can also be quite difficult to install because of how fragile they are. Since they have been around the longest it is proven that single-crystalline solar panels have a long life span. With the fast growing solar industry, online retailers have had mono-crystalline silicon solar panels slowly on the decline making them in an affordable price range for the project.

3.1.3.3.2 – Polycrystalline Silicon Panel

Poly-crystalline silicon panels are made from a less pure form of silicon. They are manufactured in two different ways, either sliced from polycrystalline silicon blocks or in a more advanced approach called ribbon growth. To form the polycrystalline blocks an ingot casting process is used and then the raw material is heated under a vacuum. The silicon blocks are sawed into bars and then into the polycrystalline wafers used inside the PV solar panels [11]. The ribbon growth meth requires no sawing of the silicon wafers making it cheaper to manufacture. The silicon is grown as thin sheets at the thickness need for making the PV cells. Compared to the mono-crystalline PV solar panels, polycrystalline is much stronger and can be cut into a third less of the size of the mono-crystalline material [10]. The price per watt of the polycrystalline material is cheaper compared to other PV cells but is also less efficient because the silicon is less pure. The efficiency of the polycrystalline PV cell is about 13-16% which is slightly lower than the monocrystalline material. The online solar panel market has polycrystalline PV solar panels rated at the lowest priced solar panel currently available. This being said, it makes it a highly considerable option for our project. The tradeoffs we will have to consider are price over efficiency.

3.1.3.3.3 – Amorphous Silicon (a-Si) Thin Film Panel

Amorphous Silicon solar cells, (a-Si) is a new technology for solar energy. Starting in the early 90's has become revolutionary in thin-film solar technology. Amorphous silicon is applied as thin layers to glass substrate. Amorphous silicon has an extremely high light absorption rate making the entire material able to be extremely thin [11]. The thin material is then usually placed between two thick glass panels to protect it making the entire product heavy in weight. A newer way thin film is being produced is with a thin laminate material instead of glass outer shell. The laminate makes the amorphous silicon incredibly thin and flexible and easy to mount on surfaces that are not flat.

Unfortunately the energy conversion efficiency is low in amorphous silicon thin film panels ranging between 5-9% [10]. Meaning twice the amount of these thin panels would be needed to generate the same amount of energy are mono-crystalline and polycrystalline panels. Efficiency has also been known to degrade after long exposure to sunlight as well, making this type of thin film solar panel not a good choice for the project.

3.1.3.3.4 – Copper Indium Gallium Diselenide (CIGS) Thin Film Panel

Another type of thin film solar panel is the CIGS which is made up of the elements copper, indium, gallium, and selenium. Like other thin film type panels the complex combination of materials is layered on a glass substrate. The combination of all of these materials has an incredibly high light absorption rate. At 0.5 micrometers it can absorb 90% of the solar spectrum of light [10]. Since it isn't necessary to have as much of this material for optimum light absorption it is very light and thin in comparison to crystalline silicon panels. The energy conversion efficiency rate for this type of thin film panel has PV cells reaching maxing out at 19.9% remarkably achieved in the National Renewable Energy Lab [12]. Although the efficiency rate is very high, it is extremely dangerous to produce requiring more than 500 degrees Celsius of heat to produce the film. The production also requires the use of hydrogen selenide which is an extremely toxic gas if inhaled making it a dangerous manufacturing environment. Due to the complexity of the material it is extremely expensive and hard to accumulate so it will not be considered for the project. Below in figure (3) is the structure of a CIGS thin film solar panel.

3.1.3.3.5 – Cadmium Telluride CdTe Thin Film Panel

Another thin film type of solar panel is the Cadmium Telluride (CdTe) which is made up of the materials cadmium and tellurium. Similar to the CIGS solar cell it has a high absorption rate being able to absorb 90% of the solar spectrum at one micrometer of thickness [10]. The energy conversion efficiency for this type of thin film ranges between 7%-12%. The best lab efficiency produced thus far has been maxed out at 16.5%. The solar cell is typically formed by using a chemical bath technique to deposit the Cadmium Sulfide (CdS) and then a space vacuum process to deposit the Cadmium Telluride (CdTe) [12]. Both processes are relatively cheap making it the most cost effective thin film solar panel and the most popular one on the market. A disadvantage to the CdTe thin film panel is that the cell itself is not very stable in performance. This type of PV cell usually performs best in high temperature and low light situations. Another disadvantage is the material Cadmium is an extremely toxic substance. Only a little amount is actually used in the manufacturing process but some extra precautions do need to be made. CdTe are the most cost effective and efficient thin film panel, but the toxicity and the manufacturing cost outweigh those factors making it not an option for the project.

3.1.3.3.6 – Gallium Arsenide GaAs Thin Film Panel

The final type of thin film solar panel is made up of the materials gallium and arsenic or Ga and As. Gallium is such a rare element it is harder to come by than Gold (Au). Arsenic on the other hand is not rare at all but is extremely poisonous. The combination of these elements makes it a very expensive and very dangerous thin film solar panel. Human exposure to a broken panel could result in serious illness and even death. One of the greatest barriers of success of GaAs PV cells has been the cost of a single-crystal GaAs substrate [13]. This thin film panel has energy conversion efficiency rates between 25%-30% making it among the highest among the group of thin film panels discussed. GaAs has an ideal band gap which is what makes it have such a high efficiency rate. GaAs is also resistant to radiation damage making it a prime choice for space applications [10]. Since the project will not be conducted in space and the budget does not have abilities to support such an expensive thin film solar panel, GaAs will not be considered for the project.

3.1.3.4 – Photovoltaic Effect in Solar Cells

To really get a grasp on the photovoltaic effect it is needed to dig deeper into the actual process of how solar panels convert solar energy into electricity. A better understanding of this process will give the user a better understanding of which solar panel will be most efficient for the project. Some solar cells are considered to be multi-junction photovoltaic cells or cells with multiple p-n junctions. P-n junctions can be thought of positively and negatively charged materials that come in contact with each other. The contact between the positive and negative materials causes an electric field to form. The charge that is built up in the electric field makes the photovoltaic cells have a built in potential difference that is usually less than 1 eV. When voltage is applied to the cells across the p-n junction it creates a current. The incoming light from the sun is thought as the applied voltage adding energy to the system. The incoming light then creates a current as the n type materials accelerate towards the p type materials, and when the p type materials accelerate towards to the n type materials at the junction. The current is produced from the potential difference between to the two regions [14].

The potential difference between the lowest energy level on the conduction band E_c and the highest level on the valence band E_v of the specific semiconductor device is called the band gap. Each solar cell is made up of typically one p-n junction that has a specific band gap that lets different types of light through depending on the energy levels of the light [14]. The sun’s light is made up of different energy levels including: high energy ultra violet light, intermediate energy which is visible light, and low energy infrared light. The junction of the solar cell will be able to absorb the energy if it is equal or greater than the energy of the band gap. If it has more energy than necessary, the excess energy is dissipated and if the light doesn't have a high enough energy it will not be able to get absorbed at all by the solar cell. A large band gap means high energy can be absorbed, a small band gap means lower energies can be absorbed. No single semiconductor has a band gap that can respond to the suns full spectrum of light but different combinations in layers can create higher efficiency rates by being able to absorb multiple variations of light [15]. The popular solar cells of today for consumer use are usually made up of one or two semiconductor materials varying in band gap size with Silicon and Germanium being the most popular. Since each semiconductor device has its own band gap it is important to choose a material that has a band gap near the middle of the energy spectrum for optimal energy consumption.

3.1.3.5 – Photovoltaic Panel Performance

Solar cells in general have very low efficiency rates which can make them inefficient in some cases. This is one of the major issues solar panels have therefore increasing the panel performance is vital. The main downfalls in solar panel performance stem from temperature, light absorption efficiency, and electron-hole recombination rates. The electron-hole recombination rate is directly related to the purity of the semiconductor material. Previously discussed, mono-crystalline are uniform in molecular structure which decreases the electron-hole rate. The lower the electron-hole rate the more efficient the panel will be. Considering this it is one of the main contributing factors to why mono-crystalline panels have better panel performance then polycrystalline solar panels.

3.1.3.6 – Solar Radiation

Solar radiation is the energy photovoltaic panels collect from the sun to produce power. The solar radiation produced from the sun is the total frequency spectrum of electromagnetic radiation including high energy ultra violet light, intermediate energy which is visible light, and low energy infrared light [16]. Solar radiance is measured by kilowatt-hours per square meter per day ($kW/m^{2)}$ which is an instantaneous power density. In the figure displayed below, it shows the solar radiation absorption rates across the United States. This project will be designed in tested in the Central Florida area and according to this map (Figure 3.1.3.6.1); Florida has a high UV exposure rate at about 5kW per square kilometer.

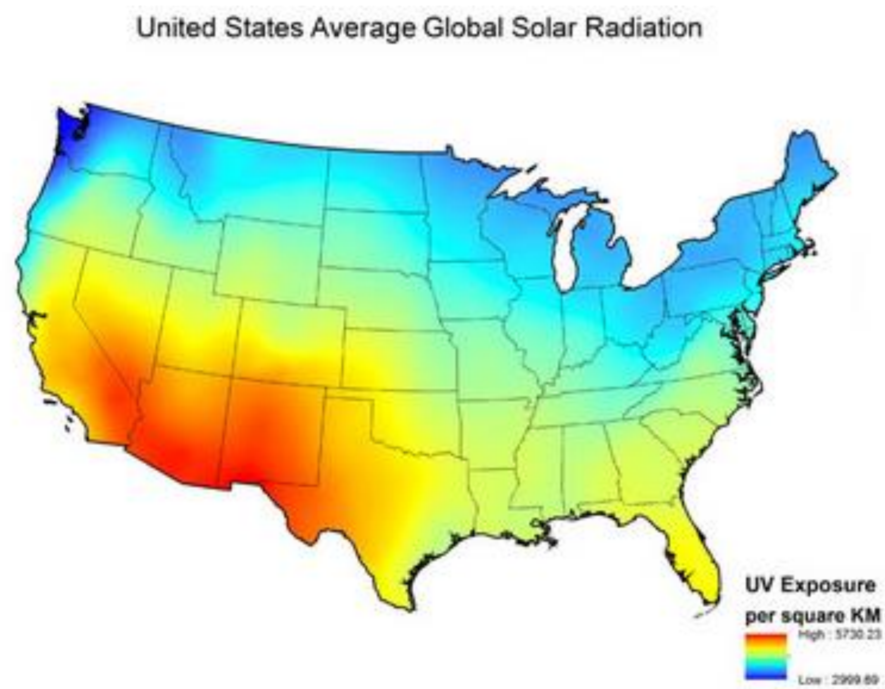


Figure 3.1.3.6.1 - Average Global Solar Radiation
Permission requested from the National Cancer Institute

Although Florida has a high UV average exposure rate, there is still some other flaws that can make solar panel performance not function at optimal rates. There are multiple ways to maximize the collection of solar radiation including solar and light tracking, preprogramed angles for each hour of the day, and maximum power point tracking. The solar method being considered for this project is Maximum Power Point Tracking or MPPT. This method is an indirect approach that controls the amount of photovoltaic output voltage and output current to optimize efficiency. The system recognizes when the battery that the PV panel is charging requires a larger voltage and manually increases the output voltage to maintain power levels.

3.1.4 – Battery Power

In P.R.E.S.S the battery will serve as a container for the electrical energy the photovoltaic panel will produce from the sun. Since P.R.E.S.S will predominately be used at night when there are no rays from the sun to create that energy, the battery is needed to store the energy absorbed during the day. For the purpose of this project research will predominately focus on lead acid and lithium ion batteries. Below in Table 3.1.4.1 illustrates different types of batteries and the important characteristics they each depict.

	NiCd	NiMH	Lead Acid	Li-ion	Li-ion polymer	Reusable Alkaline
Gravimetric Energy Density(Wh/kg)	45-80	60-120	30-50	110-160	100-130	80 (initial)
Internal Resistance (includes peripheral circuits) in mΩ	100 to 200[1] 6V pack	200 to 300[1] 6V pack	<100[1] 12V pack	150 to 250[1] 7.2V pack	200 to 300[1] 7.2V pack	200 to 2000[1] 6V pack
Cycle Life (to 80% of initial capacity)	1500[2]	300 to 500[2,3]	200 to 300[2]	500 to 1000[3]	300 to 500	50[3] (to 50%)
Fast Charge Time	1h typical	2-4h	8-16h	2-4h	2-4h	2-3h
Overcharge Tolerance	moderate	low	high	very low	low	moderate
Self-discharge / Month (room temperature)	20%[4]	30%[4]	5%	10%[5]	~10%[5]	0.3%
Cell Voltage(nominal)	1.25V[6]	1.25V[6]	2V	3.6V	3.6V	1.5V
Load Current - peak - best result	20C 1C	5C 0.5C or lower	5C[7] 0.2C	>2C 1C or lower	>2C 1C or lower	0.5C 0.2C or lower
Operating Temperature(discharge only)	-40 to 60°C	-20 to 60°C	-20 to 60°C	-20 to 60°C	0 to 60°C	0 to 65°C
Maintenance Requirement	30 to 60 days	60 to 90 days	3 to 6 months[9]	not req.	not req.	not req.
Typical Battery Cost (US$, reference only)	$50 (7.2V)	$60 (7.2V)	$25 (6V)	$100 (7.2V)	$100 (7.2V)	$5 (9V)
Cost per Cycle(US$)[11]	$0.04	$0.12	$0.10	$0.14	$0.29	$0.10-0.50
Commercial use since	1950	1990	1970	1991	1999	1992

Table 3.1.4.1 – Battery Characteristics
Permission requested from Battery University.

3.1.4.1 – Lead-Acid Batteries

Lead-acid batteries historically were the first rechargeable battery for commercial use. There are two variations to lead-acid batteries small sealed lead acid (SLA) and large valve regulated lead acid (VRLA) batteries [17]. Valve regulated lead acid batteries are considered to be a starting type design battery, most commonly used in cars to help start engines. VRLA batteries have a maximum high current output because of their large surface areas. They are useful for applications that need a high current increase in a small amount of time. Unfortunately they cannot be charge and recharged without damaging the battery itself giving it a short lifespan. Small sealed lead acid batteries are considered to be deep cycle lead acid batteries and are the most commonly used rechargeable batteries used in power applications [18]. SLA batteries can be recharged after being discharged without losing its large capacity. SLA batteries have a low output current due there small surface areas and are most commonly used on Photovoltaic systems.

There are three different types of deep cycle lead acid batteries; wet cell (flooded), gel cell, and absorbed glass mat (AGM) [19]. Wet cell, better known as flooded lead acid batteries are filled with electrolytes and water. These are the most common among the three types of deep cycle lead acid batteries because they are the cheapest compared to the other two. The construction of absorbed glass mat lead acid batteries allows a layer of electrolytes to be suspended close to the surface of the charging plates inside the battery. This enhances the discharge and recharging capabilities. Gel cell batteries are similar to absorbed glass mat batteries except for the fact they have a silica additive to the chemical components inside the battery. Gel cell batteries are best used in extremely deep cycle applications and even last longer in hot temperatures. Although lead acid batteries are most commonly used, there is both good and bad qualities they portray [19].

3.1.4.1.1 – Advantages

One of the key reasons lead acid batteries are so popular and most commonly used is because they are extremely inexpensive to manufacture. For a consumer, what is most important is getting high caliber performance without having to purchase an extremely expensive product. Some of the key advantages to lead acid batteries include [17].

- The battery itself is low maintenance and low in manufacturing cost. In terms of cost per watt hours small sealed lead acid batteries are considered to be the least expensive.
- They offer exceptional performance for everyday applications and can be recharged up to 1000 cycles.
- The most mature battery technology has developed from using lead acid batteries. They are the most studied and the most commercial used.
- Has an extremely low self-discharge rate at about 5 hours. The longer the time the battery takes to discharge the higher the capacity rating.

3.1.4.1.2 – Limitations

A significant disadvantage to lead acid batteries is its low energy density. Lead acid batteries can be big and bulky making them not ideal for small applications that demand a compact size. The following limitations of lead acid batteries are below:

- When charged excessively it can cause gassing and water depletion and contains electrolyte and lead which is harmful to the environment.
- Lead acid batteries can never be charged to their full potential. Most batteries only reach up to 75% of their potential charge.
- Has a long charging time ranging anywhere from 8-16 hours depending on the size of the lead acid battery.
- The battery cannot be stored at its discharged state. It causes a chemical reaction where sulfation occurs making it difficult to impossible to recharge [17].

3.1.4.2 – Lithium Ion Batteries

Lithium Ion (Li-ion) batteries are made from lithium which is the lightest of all metals. After many failed attempts of making the lithium ion battery rechargeable, Sony Corporation commercialized the first Li-ion battery in 1991. After becoming commercialized, Li-ion batteries took over one-third of the entire global battery market. Li-ion batteries are used in small electrical applications like cell phones and computers since they are light in weight. They have a high cell voltage making it possible for Li-ion batteries to use only one cell which makes the battery design simpler [17]. Rechargeable Li-ion batteries use the migration of liquid electrolytes to carry charge between each anode and cathode located inside batteries structure. Different types of cathodes and anodes offer different safety specifications and longer lifetimes for the battery. Although Lithium Ion batteries are small and light weight they have some disadvantages as well [20].

3.1.4.2.1 – Advantages

Lithium ion batteries have unbelievable entities that make it an ideal choice for P.R.E.S.S. The battery chosen for this project needs to be able to fit into a small structure making weight and size a key contributing factor when making decisions.

- Lithium ion batteries have high energy densities which give them a high capacity. This makes them incredibly efficient.
- Relatively low self-discharging rates making it long lasting. Li-ion batteries can have a shelf life of 5-10 years.
- Low maintenance with simple chemical make-up that does not require any cell conditioning [20].

3.1.4.2.2 – Limitations

Although there are outstanding qualities that lithium ion batteries have, there are also some key disadvantages that need to be considered when choosing the energy storing battery for this project.

- Lithium ion batteries are expensive to manufacture because of the safety precautions needed. This makes Li-ion batteries retail value also expensive.
- Require a charge controller or protection circuit to regulate voltages and current. The Li-ion battery can become unsafe and rupture if over charged.
- Extremely sensitive chemically with water, long exposure can exponentially degrade batteries lifespan.
- These batteries need to be partially charged for storage purpose to prevent the aging process from increasing [20].

3.1.4.3 – Charge Controllers

Charge controllers in photovoltaic charging systems are used to regulate the amount of voltage and current that travels from the panel to the battery. Charge controllers are used to prevent over charging to the battery being charged and to optimize panel performance. Different size batteries require a certain voltage to charge and the charge controller will either increase or decrease the output voltage from the PV panel to get the voltage to the optimal value. Aside from just preventing overcharging in a battery, charge controllers also block reverse current from the battery back to the PV panel [21]. There are a few different types of charge controllers that prevent over charging with different algorithms. They all have the same basic parameters given on spec sheets which give limits for load current, losses, and set points. All of those things are usually dependent on temperature of the controller itself and how large the battery voltage and current is.

To regulate the flow of energy to the battery from a photovoltaic panel there are a few different methods to control the energy. Some charge controllers regulate the flow of energy by using a switch that lets all of the current flow or none of the current flow. It is better known as an on/off switch. When the battery reaches its maximum charge the charge controller will completely “turn off” and stop all energy flowing to the battery. Another type of voltage regulating charge controller is called a Pulse Width Modulation controller. This controller holds the voltage most constant [21]. Typically Pulse Width Modulation controllers are a two stage controller that will keep a constant high voltage until the battery is fully charged and then decrease the input voltage of the battery to a very low voltage to keep it a constant fully charged rate. The voltage at which the controller changes its rates of flow is called the voltage set point. Some charge controllers have adjustable set points, while most on the market do not.

A system that is made up entirely of all DC loads will need a low voltage disconnect. This is generally already inside most charge controllers and prevent over discharging from the battery. Mostly used in deep cycle batteries to make sure discharging does not surpass the maximum depth of discharge and ruin the battery. Like discussed in previous sections, lead acid deep cycle batteries cannot be recharged if they are completely discharged. LVD is an effective type of set point designed to control the voltage distribution in charge controllers [21].

There are two types of charge controllers to be considered shunt controllers and series controllers. Shunt controllers are typically used for photovoltaic panel systems design that has currents less than 20A. The algorithm for a shunt controller is both linear and interrupting. Shunt controllers regulate the charging of the battery by short circuiting the array or like described in above sections the "on/off" method [22]. Shunt controllers cut off the energy distributed to the battery at the predetermined set point. The most common shunt regulator used in solar applications is the LM431 three terminal adjustable zener shunt. It operates similar to a zener diode and can be adjusted by choosing different resistor values for R1 and R2 in the circuit below (Figure 3.1.4.3.1) to get the desired output voltage need to charge the battery [23].

$$Vo = \left(1 + \frac{R1}{R2}\right) Vref$$

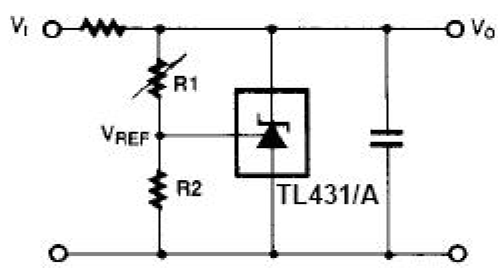


Figure 3.1.4.3.1 - Zener Shunt Charge Controller using LM431

The Zener Shunt controller is a linear charge controller that keeps the battery at a fixed voltage that has the control element in parallel with the battery as shown above. This is a relatively simple design but including the LM431 element can up the charge costs and limits power ratings of the controller itself. The other types of shunt controller use an interrupting algorithm uses pulse charging to actually short circuit the array. The interrupting method has the capability of short circuiting the battery as well which is not ideal. All shunt charge controllers also need a heat sink to dissipate all the extra energy that is collected from the PV panel and is not being directed towards the battery itself [23].

The other type of charge controller is the series controller which can also be broken down into two types; interrupting and linear. A series controller regulates the charging of the battery from the PV panel by open circuiting the solar panel which interrupts the charging current. An interrupting series controller uses pulse width modulation as a control strategy to turn on and off the variable frequency with a variable duty cycle. Pulse width modulation then maintains the battery at the voltage regulation set point [22].

There are also two other methods of using series interrupting charge controllers including 2-step constant currents and 2-step with dual set points. The 2-step constant current design is similar interrupting charge controller with one minor difference. When the set point voltage is reached instead of completely open circuiting and cutting off all current, the 2-step constant voltage linear charge controller will remain at a very low constant current allowing for trickling charging for a predetermined amount of time. The 2-step dual set point interrupting design has 2 separate charging cycles the first to charge the battery at a high voltage and the second to keep it consistently charging. This method is best used in flooded deep cycle lead acid batteries. The series linear charge controller has a regulation element that dissipates the balance of power that is not used while charging the battery. The element is generally acts as variable resistor that allows the voltage to drop across it while regulating current [24].

3.1.4.3.1 – Maximum Power Point Tracking (MPPT)

Maximum power point tracking has the ability to boost the charging current coming from the solar photovoltaic panels. The current boost is produced from the excess voltage developed from the solar panels and converting it into higher charging amperage [22]. The MPPT varies with sunlight intensity and with solar cell temperatures within the panel itself. Maximum power point tracking tracks the voltages and currents being outputted from the solar panel and adjusts the ratios leaving the controller accordingly. Solar cells have nonlinear output voltages due to the complex relationship between the solar cells, solar irradiation, temperature and total resistance. The MPPT system tracks the output of the solar cells and applies the proper load to obtain the maximum power for a given environmental conditions. MPPT systems are most effective when extra power is needed for instance in the winter, on cloudy days, or on hazy days where the solar radiance isn’t at an ideal rate [25].

3.1.5 – Heat Control

An initial design option for the system were heated elements that were included into the structure of the case. The purpose of these elements was to, in appropriate climates, melt accumulated snow and ice on the surface of the stones. Although this would be a useful feature for the project by increasing safety during the winter months, along with other improvements, there were concerns that this type of system would pull too much power for it to be viable on what will be a generally low power project. Research was conducted in order to determine if the heat and power costs of this feature would be acceptable to the overall design considerations and limitations of the project.

3.1.5.1 – Pros for Heat Control System

This system was under consideration to be added to the project for a number of reasons. These reasons include added safety, usability improvements, and finally an opportunity to incorporate automation into the system. The first and most major reason that this system was considered was the increase in safety to the user. At the most basic level this project will be used as a pathway either to a user's front door or through their yard. For this reason it should be more convenient to walk on the stones than on the normal ground. During the winter months normal pavers can be coated with ice and/or snow causing hazardous conditions should someone walk carelessly on them. Our stones would not be exempt from this fact. Snow and/or ice buildup on our stones would be just as hazardous. Since the safety of the user is of great concern, the addition of a heating system was considered. This system would be able to generate enough heat in order to melt off the snow and/or ice in order to create safe conditions for use.

Another reason for the consideration of the addition of this system to the project was usability improvements to the user. Since they can rely on their P.R.E.S.S stones to be ice free in the winter months they will have greater confidence to install them in their own home. Knowing that it will always be safe for themselves and their children to use the stones free from ice and snow increases the chances that they will be satisfied by the product. Also, the buildup of ice and snow on top of the stones may have adverse effects to the lighting features of the system. A primary feature of the system to is to light up when pressure activates them as well as when specified via the mobile application. The luminosity of the stones may be affected by a buildup of snow and ice. Doing this would diminish the usability of the system by handicapping one of its primary features. Furthermore a buildup of material on top of the stones may also affect the power system of the stones. Since these stones are powered by using solar panels any extra barrier between the sun and the panels could reduce power generation and therefore reduce the overall battery charge and time that the system can be used. By including the heat control system both the diminishment of luminosity and reduction of battery charge by the presence of ice can be avoided. This would increase the reliability and usability of the system making it of greater value to the user.

The final reason for the consideration of the addition of this system to the project was the opportunity it created to add a level of automation to the project. The coldest time of a given day occurs during the night hours when most people are inactive; therefore the highest chance of encountering hazardous conditions on the path is during the early morning hours. This is typically when people leave for work and will use their paths to exit their homes. For this reason it would be beneficial to create a timer so the P.R.E.S.S system will automatically defrost itself at the time chosen by the user to best suit their needs. This could be when they leave for work or perhaps when their children leave for school. This way once the time is set they no longer have to worry about it, they can be assured that their walkway will be safe for use. This level of automation would not be difficult to add and could be very beneficial to the user.

3.1.5.2 – Cons for Heat Control System

When deciding whether or not to include this heat control system a number of negative effects it could have on the project as a whole were considered. These included power usage and added cost. The first and most major concern with the addition of this system was the amount of power it would draw from the P.R.E.S.S project. The project is powered solely by solar panels in an attempt to be both self-contained and environmentally friendly. For this reason power is a large limitation when considering what features and components to choose. The type of heating element that was being considered for this project was a resistive heating element for its small footprint making it simple to incorporate into the surface of the project. When calculating how much power would be needed the following best case conditions were used.

Specific Heat of Material (Plastic)	1.25 J/g/°C
Mass (Only of Top Surface)	952.54 g
Initial Temperature	0°C
Final Temperature	10°C
Time	300s

Table 3.1.5.2.1 - Power Calculation Specifications

Using the specification in Table 3.1.5.2.1 we can use the power calculation in Figure 3.1.5.2.1 to solve for the total power needed to adequately heat the surface of the system.

$$P = \frac{mC_p(T_f - T_i)}{t}$$

Figure 3.1.5.2.1 – Power Equation

Given the specifications stated this will result in a power need of 40watts. This would be a significant drain on the power availability of the system. And since the project is operating using solar power if the system runs out of power it will take a significant amount of time to build up enough charge to continue to use the system. Given that the primary location for the system to be used is Florida, large parts of the day can be inflicted by thunderstorms creating less sun for the solar panel to absorb. Even further reducing the amount of power the stone will be able to generate. This greatly reduces usability and would not be beneficial to the project.

Another factor in the decision of not including the heating system to the project was added cost that would need to be accounted for. Since a total of eight stones are going to be made for the project what seems to be a relatively low cost for a component is increased greatly by the repetition of that component. In the case of the heating system the price for the resistive heating component was conservatively estimated at $20. This would lead to a total cost of $160 dollars. This would mean the low end prediction of the heating system would cost more than both the amount budgeted for the solar panels and the amount budgeted for the load sensors. The inclusion of this system would greatly increase the total budget for the project. Since we are seeking funding from Duke Energy the lowest possible budget is required. The inclusion of this system would increase costs while not substantially increasing the usefulness of the project.

The final factor in the decision of not including the heating system to the project was the possible interference with the solar panel caused by the resistive heating film. Since the film would need to be mounted on the interior surface of the top of the stone in order to effectively heat the surface it would in the direct way of the solar panel. This could reduce the amount of light that would reach the solar panel therefore reducing the amount of charge produced. This compounded with the additional power usage mentioned previously this could greatly impact the total power available to the system. This would make the system able to operate for a shorter amount of time than if the heating system was not included.

Next, this section further discusses the pros and cons simultaneously when deciding whether to include the heating system for our project. While the safety concern of ice and/or snow build up is valid, it is not a large concern considering that location of this projects use will be in Florida for the foreseeable future. However, if the system does need protection from snow and ice similar more cost effective solutions do exist. For example using a waterproof coating on the surface of the stones will prevent moisture from collecting on the surface and frost from forming. This method can be applied at the user’s discretion or during production depending on the site that the project will be used. For these same reasons the usability will not be negatively affected. The ability for the solar panels to collect light and the luminosity of the stone will not be affected by this solution.

Finally, the opportunity for automation that is given by adding the heating system does not outweigh drain required on power and the added cost of materials. These costs would surely drive our system to be over budget which is not an option. Also the reduction in power will greatly increase the difficultly and cost of picking the components for our circuit board in order for them to draw the least amount of power possible. Although it would a possible useful feature, it should not be added with the possibility of negatively affecting the main functions of the project. The current main functions of the project will be of great enough challenge that introducing further complexities is ill advised. For all of these reasons the decision was made to not include the heating system in the project.

3.1.6 – Communication

3.1.6.1 – Bluetooth vs. Wi-Fi

When it comes to information transmission speed, Wi-Fi has it all. Bluetooth is much slower coming in at a rate of around 2.1 Megabits per second in comparison to Wi-Fi's more impressive 600 Megabits per second. Blue tooth is primarily used for making solid point-to-point connections while Wi-Fi is capable of communicating with multiple different devices at once which is ideal for our needs since we have a series of stones which will all be waiting for the "go-ahead" in order to execute lighting sequences. Bluetooth range usually varies from 5 meters to 30 meters while with Wi-Fi one could do the programming from anywhere they like as long as they are located near a router and can obtain a Wi-Fi signal which may be challenging seeing as the stones will be located in the yard of a home while the router could be located all the way across the property on the other side of the home where connectivity could be hard to come by. Bluetooth is very simple to use for interfacing since it just uses key matching while Wi-Fi is more complex and necessitates specific configuring of both hardware and software. Lastly, when we look at overall power consumption, since Wi-Fi is able to function over a much longer distance, it also requires more power in order to maintain those connections [3] [4].

Bluetooth is a short range technology used to eliminate the use of RS-232 cabling. Bluetooth devices occupy the unlicensed ISM (Industrial Scientific and Medical) band in the 2.4GHz range which is the same range as occupied by microwaves and Wi-Fi signals. All devices undergoing the exchange of information in a Bluetooth scheme comprise a "piconet". This piconet has one master and can have up to seven slaves. The master can send messages to the slaves and the slave can respond to the master but there is no direct communication between the slaves when they are acting as secondary devices. A positive attribute to Bluetooth technology is how easily slave devices can reconfigure themselves as the masters in a new piconet while still remaining slaves in the previous piconet. This reconfiguration is very dynamic and can occur quickly without difficulties.

Bluetooth uses timeslots with frequency hopping in order to ensure robustness of communications transmissions. By picking a specific frequency in the given Industrial Scientific and Medical band for which to transmit a packet in a time slot (packets usually occupy one time slot but can cover up to five if necessary) and then immediately switching the transmission frequency for the next package transmission, the devices incurs less noise transmission from other RF source disturbances sharing the same frequency band. Bluetooth is superior to most competing designs because it hops from frequency to frequency faster and transmits smaller packets. A telecommunication theory called Forward Error Correction or channel coding allows for vigor over a longer transmission line. Forward Error Correction occurs when the sender encodes the message in a redundant manner which permits the receiver to perceive a small number of errors that could occur anywhere within the message (and often can fix these errors without having to receive the message a second time) [5].

Wi-Fi is a wireless local area network (WLAN) technology which utilizes 2.4 Ghz UHF (Ultra-High Frequency) to 5 GHz SHF (Super High Frequency) radio waves to make an internet connection. WLAN connection specifications are outlined in the Institute of Electrical and Electronics Engineers 802.11 Specifications. The 802.11 family consists of over-the-air modulation techniques that use the same given protocol. These techniques outline that communication can occur in both directions yet two devices cannot transmit data to one another simultaneously. 802.11-1997 was the first wireless networking standard to be output. This protocol had the following specifications: (1) Two net bit rates of 1 or 2 Mbit/s (2) Employs Forward Error Correction Code (3) Calls out 3 similar physical layer technologies – diffused infrared at 1 Mbit/s, Frequency Hopping Spread Spectrum or Direct Sequence Spread Spectrum functioning at 1 or 2 Mbit/s. 802.11b was more widely accepted and it standardizes a maximum raw data rate of 11 Mbit/s while still maintaining all the same former specifications. One of the limitations of functioning in only the 2.4 GHz range is that there can only be one network in the area in order to avoid interference from Wireless Local Area Network surrounding signals. In order to solve this issue a newer standard of 802.11 was put out that states one can function in the 5GHz band of a multi-station WLAN with a transmission rate of 1 GBit/s. This new standard is reducing issues with connectivity and is spreading rapidly. Wi-Fi has a range of 115 ft indoors and a larger range outdoors. You can the use Wireless routers or Wireless Access points to connect within that range. Routers or Access Points with internal Ethernet switches or router firmware applications can provide internet protocol (IP) Routing, network Address Translation (NAT) and domain name system (DNS) forwarding to access a wide area network (WAN) interface in order to transmit data over very large ranges by accessing a cable/DSL Modem.

Lastly, another method of long-distance transmission is the use of wireless range-extenders or wireless repeaters. It is worthy to note that connections through repeaters will still undergo an amplified latency with each additional hop. The connection will also suffer a reduction in the maximum overall data throughput.

3.1.6.2 – Arduino™ Based Solutions

Depending on whether or not one wants to use Bluetooth or Wi-Fi for wireless communication between the mobile device and the controllers within each of the stones, there are Arduino™ compatible solutions for both scenarios. Starting with Bluetooth, connecting a wireless device to an Arduino™ based PCB is very simple. By using an inexpensive Bluetooth Serial Module which only has four simple pins (5V supply, GND, Receive/RX, and Transmit/TX) and connecting it to the appropriate ports on the PCB, this module allows wireless connectivity to be almost effortless. Use '1234' as the pairing key so one can pair the PCB with your Bluetooth capable device and some simple code for this pairing is also provided in the Communication section of Software Research. The PCB replaces the regular serial Receive and Transmit cables with the RX and TX on the Module.

Pairing devices via Wi-Fi is not as simple but definitely allows the user more freedom when trying to execute commands at more than one point. For this we would use the Wi-Shield product from Async labs. This board uses a PCB antenna, 9 pin breakout for prototyping, uses serial peripheral interface in order to communicate with host at speeds as fast as 25MHz. Uses 6 Arduino™ ports: (4) for SPI- Slave Select on pin 10, clock on pin 13, Master in Slave out on pin 12, and Master out Slave in on pin 11. (1) for interrupts – either INT0 on pin 2 or DIG8 on pin 8, (1) for LED on pin 9 which is not entirely necessary but does help with troubleshooting. The Wi-Fi module is also small with dimensions of 1.9 x 2.1 x .5 inches and can easily be connected to any Arduino™ based device [6].

3.1.6.3 – Texas Instruments Based Solutions

The best option for communication if one decides to go with Texas Instruments products would be their newest CC3200 chip which integrates a Microcontroller Unit with a built-in Wi-Fi network processor. This built-in Wi-Fi Networks processor's internal structure was laid out in section 2.1.1.2 of this document during the evaluation of the Microcontroller Unit since the Wi-Fi network and the MCU chip are one in the same. The Wi-Fi subsystem features a Wi-Fi Internet-on-a-Chip and utilizes an ARM® Cortex®-M4 which is completely separate from an addition ARM® Cortex®-M4 used for applications within the chip. This subsystem comprises an 802.11 compliant radio, baseband, and media access control (MAC). Fast connectivity and security are ensured through the chip's encrypting engine with 256-bit encryption. Both WPA2 for personal and enterprise security and WPS 2.0 are each supported through this device as well. WPA2 stands for Wireless Protected Access and WPS 2.0 stands for Wi-Fi Protected Setup which is a standard that tries to enhance security of wireless network set up and connection by making the process for connectivity more systematic.

3.1.7 – Lighting

There are multiple options available for lighting sources including: tungsten, arc, fluorescent, and LED lamps. Within all of these different lighting sources there are also multiple configurations within each lamp to consider. Aside from the physical format of the lighting source we need to consider their technical qualities such as energy consumption, luminous density, luminous flux, viewing/beam angle, operating life, and operating temperature.

3.1.7.1 – Tungsten Lamps

Tungsten lamps are the oldest and most common type of lamp. These lamps typically require a minimum power of 40 W which would output about 505 lumens. [26] Table 3.1.7.1.1 is a list of typical luminous output associated with common tungsten lamp wattages.

Watts	Lumens
40	505
60	870
75	1190
100	1750

Table 3.1.7.1.1 – Tungsten Luminous Output

A type of tungsten lamp considered for the project was the Sylvania 57025. The particular specifications of our concern are listed in Table 3.1.7.1.2. Viewing/beam angle information was not available for this particular lamp. [27]

Wattage	40 W
Bulb type	T4
Base	G9 looped
Length	1.61 in
Diameter	0.5 in
Life Hours	2,000
Lumens	480

Table 3.1.7.1.2 – Specifications for a Tungsten Lamp

After further consideration this type of lamp is not practical to the overall design needs of the stepping stones, as its power consumption exceeds the low power consumption requirement, it has a physical footprint is large, and the color temperature (kind of light) is only white, any color changing capabilities will have to designed externally of the lamp further exceeding the low power specification.

3.1.7.2 – Arc Lamps

Arc Laps create light by electrical discharge in an ionized gas chamber between two electrodes typically made of carbon. Arc lamps were the first commercially successful form of electrical lamps. Created by Sir Humphrey Davy in 1809, the arc lamp was first used for street, and theater lighting [28]. The Osram Sylvania 69231 arc lamp was considered and
Table 3.1.7.2.1 – Arc Lamp Specifications. This table contains the general information of main concern to the project.

Wattage	75 W
Bulb type	XBO
Base	NA
Length	3.54 in
Diameter	NA
Life Hours	400
Lumens	26000
View/Beam Angle	NA

Table 3.1.7.2.1 – Arc Lamp Specifications

Operating this type of lamp off a battery is impractical because of the high current demand of the arc [29]. Also like the tungsten incandescent lamp, the light output is only white, which would require an external device to change colors using some kind of lighting gel filter.

3.1.7.3 – Fluorescent Lamps

Fluorescent lamps are a sealed low pressure tube with a small amount of mercury and an inert gas such as argon. The inside part of the tube is coated a phosphor powder, with electrodes on either end of the tube. When electricity is sent through the electrodes it excites the gas, which eventually releases photons that hit the phosphor coated glass which glow producing the light. Colored light can be produced by using different phosphor combinations in the coating. [30] This type of lamp requires the use of a ballast to channel current through both electrodes. Fluorescent lamps were quickly excluded from further research, once it was discovered that the lamps require an alternating current power source and typically require 120 V to operate. While it is possible to use a DC to AC inverter the voltage requirement for these lamps makes use of it impractical.

3.1.7.4 – LED Lamps

A fairly new light source compared to the others, LEDs have shown the most promise for efficient use. Typically they have been used as indicators, only recently have LEDs been used for lighting. Because LEDs are a semiconductor device they can be manufactured into shape or purpose, however through-hole and surface mount designs (smd) are typically used for designing lighting systems. Through-hole LEDS can be easier to solder on to a board, however to fully direct the light they would need to be placed in a reflector mount, smd chips already have a reflector built into to them. LEDs can also be designed to output a certain color, sometimes combining different colored LEDs into one device to give users the chance to make their own color. Figure 3.1.7.4.1 show a datasheet example of a multi-color LED device.

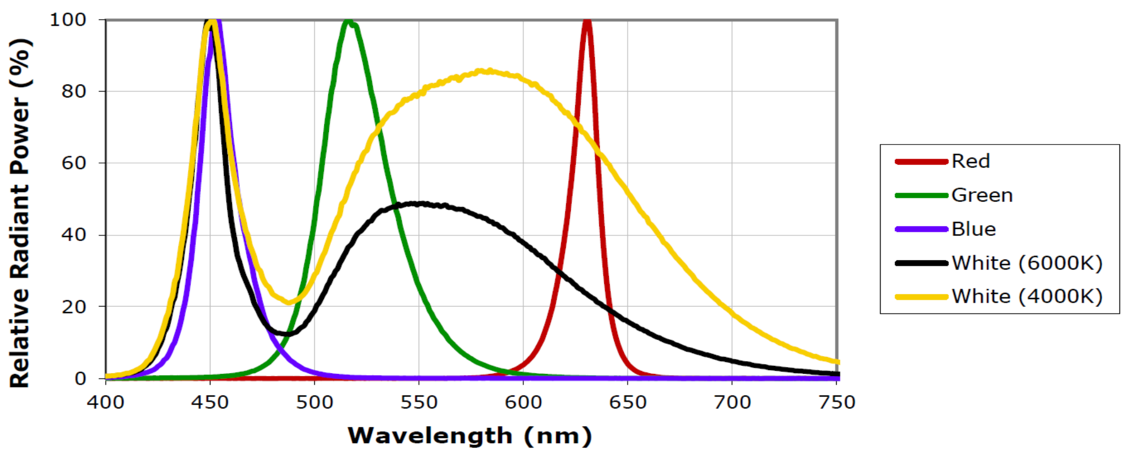


Figure 3.1.7.4.1 – Spectral Output of CREE XLamp MC-E Color LED

LED intensity is typically listed in units of micro-candela (mcd) instead of lumens. A candela is the SI base unit for luminous intensity, which is the power emitted by a light source at a certain angle, weighted by the luminous efficiency. To have a better understanding of what kind of light output these LEDs produce use the Figure 3.1.7.4.2 to convert mcd to lumens.

$$\phi_{V(lm)} = I_{V(cd)} * (2\pi(1 - \cos(\frac{\theta}{2}))$$

Figure 3.1.7.4.2– Candela to Lumen

- Where $I_{V(cd)}$ is the candela number given in the datasheet and θ is the viewing angle also available in the datasheet.

Since the candela is dependent on frequency of the light luminous flux will also be dependent of the frequency, and thus consideration of the discrepancy between the lowest and highest light frequency should be considered if just red, green, blue (RGB) LEDs are used. This is because in order to make white light, the three primary light colors need to be close to equal intensity. A possible design to accommodate a pure white design would be to use red, green, blue, white (RGBW) LEDs or purchase RGB units and a separate white unit.

3.1.8 – LED Drivers

LED Drivers are used when the circuit becomes complex, and are especially used when driving high-powered LEDs for illumination. Their purpose is to regulate the current being sent to the LED. For this reason if LEDs are to be used in the design phase a LED driver must be used, this section talks about certain LED drivers.

Texas Instruments LP5562 LED Driver offers four channels with programmable lighting sequences. It offers programmable memory that can operate independently of the processor, and can enter a power save mode when LEDs are not on. Current output is an 8-bit setting from 0 mA to 25.5 mA at 100 µA increments. The LP5562 has four pin-selectable I^2C addresses, which allows connecting up to four parallel devices in one bus. The packaging of this IC is a 12 pin DSBGA format. [31] Maximum ratings and recommended operating conditions can be found in Table 3.1.8.1 and Table 3.1.8.2 respectively.

Parameter	Unit
V(VDD, Ven, R, G, B, W)	-0.3V to +0.6V
Voltage on Logic Pins	-0.3V to VDD+0.3V with 6.0 Vmax
Continuous Power Dissipation	Internally Limited
Junction Temperature	125°C
Storage Temperature Range	-65°C to 150°C

Table 3.1.8.1– Maximum Condition for LP 5562 LED Driver

Parameter	Unit
VDD	2.7V to 5.5V
Ven/vcc	1.65 V to VDD
Junction Temperature	-40°C to +125°C
Ambient Temperature	-40°C to +85°C

Table 3.1.8.2 – Recommended Operating Conditions for LP5562

The Texas Instruments TLC5971 LED driver is a 12-channel, 16-bit, PWM, RGB driver with a 3.3 V linear regulator. This driver offers 12 constant-current sink outputs capable of providing 60 mA per channel, with a 16-bit PWM grayscale control. There is also a global brightness control of 7-bits for each color group.

The grayscale and global brightness are accessible via a two-wire signal interface. Maximum current for each channel is set by a signal external resistor. This device can be cascaded as many times as needed with minimal loss. This IC comes in two styles of packaging a 20 pin PWP package and a 24 pin RGE package. [32] Table 3.1.8.1 and Table 3.1.8.2 show the maximum and recommended operating conditions for this device.

Parameter	Name	Min	Max	Unit
Supply Voltage	Vcc	-0.3	+18	V
Input Voltage	IREF	-0.3	Vreg+0.3	V
	SDIT, SCKI	-0.3	Vreg+0.6	V
Output Voltage	OUTR0 to OUTR3	-0.3	+18	V
	OUTG0 to OUTG3	-0.3	+18	V
	OUTB0 to OUTB3	-0.3	+18	V
	SDTO, SCKO	-0.3	Vreg+0.3	V
	Vreg	-0.3	+6	V
Output Current	OUTR0 to OUTR3		75	mA
	OUTG0 to OUTG3		75	mA
	OUTB0 to OUTB3		75	mA
	Vreg		-30	mA
Operating Junction temp	Tj(max)		150	°C
Storage Temp	Tstg	-55	150	°C

Table 3.1.8.1 – Maximum Ratings for TLC 5971

		TLC5971			UNIT
		MIN	NOM	MAX	
DC CHARACTERISTICS					
VCC	Supply voltage, internal voltage regulator used	6		17	V
VREG	Supply voltage, VREG connected to VCC	3	3.3	5.5	V
V_O	Voltage applied to output (OUTR0 to OUTR3, OUTG0 to OUTG3, OUTB0 to OUTB3)			17	V
V_{IH}	High-level input voltage (SDTI, SCKI)	0.7 × VREG		VREG	V
V_{IL}	Low-level input voltage (SDTI, SCKI)	GND		0.3 × VREG	V
V_{IHYS}	Input voltage hysteresis (SDTI, SCKI)		0.2 × VREG		V
I_{OH}	High-level output current (SDTO)			–2	mA
I_{OL}	Low-level output current (SDTO)			2	mA
I_{OLC}	Constant output sink current (OUTR0 to OUTR3, OUTG0 to OUTG3, OUTB0 to OUTB3)			60	mA
I_{REG}	Voltage regulator output current (VREG)			–25	mA
T_A	Operating free temperature range	–40		+85	°C
T_J	Operating junction temperature	–40		+125	°C

Table 3.1.8.2 – Recommended Operating Conditions for TLC 5971
Reprinted with Permission from Texas Instruments

3.1.9 – PCB Vendor and Assembly

For the project each stone will have several IC's inside of the stone in order to function properly. This includes a MCU for communication and processing purposes, a Wi-Fi enabled IC to connect the stones together, an array of LEDs, a pressure sensor, and various other elements. All of these components will need to work together and therefore must be mounted on a Printed Circuit Board (PCB). The process of designing and producing a PCB is not taught in the curriculum; as a result this section is dedicated to the research of various PCB vendors and the process of designing a PCB. This will be vital to the project as without a well-designed and functioning PCB the project will not operate as intended.

There are a multitude of PCB vendors out there from all across the globe. There will be several factors when considering which PCB vendor to order from. These factors include: manufacturing cost, shipping cost, location of business, customer reviews, and estimated time of order fulfillment. The PCB vendors that have been considered include: PCB-Pool, OSH Park, Express PCB, 4PCB, Kejie PCB, Sunstone Circuits, Our PCB, My RO PCB, PCB International, Sierra Circuits, and Gold Phoenix PCB. In order to estimate the cost of PCB manufacturing some considerations need to be made. This includes to total number of PCBs that need to be printed, the total area of each PCB, and the number of layers used in each PCB. For research purposes these numbers will be overestimated. The figure for the PCB budget ($528) will also be brought into consideration when comparing the various PCB suppliers.

There are going to be a maximum of eight stones for the project. Two different general PCB layouts have been considered. The first being that each stone will have one large motherboard like PCB that all the components and LEDs will mount to and the board will need to be large in order to arrange the LEDs in a way to get maximum light dispersion throughout the surface of the stone in order to give the project a uniform glow. This will increase the surface area of each PCB which could add to cost, however the total number of boards that will need to be printed will only be eight.

The other layout considered is many smaller boards per stone. Perhaps one very small board for each LED that would then interface with the control board to receive the lighting commands. For the purpose of this research it will be considered that each stone will use five LEDs. This makes the total number of boards per stone six stones. Therefore the total amount of boards for the project will be 48. This greatly increases the total amount of boards that will need to be ordered, but the area of each board will be greatly reduced.

Both of these possible layouts will be considered when comparing PCB vendors. This is because if one method cost much more than another to implement that will greatly impact our design decisions. The area of each stone will be roughly 146.14 in^2. As a result for the single board situation the board will have an estimated side length of 7.44 inches, producing an area of 55.35 in^2. For the multi-board situation each board will have an estimated side length of 2 in, producing an area of 4 in^2 per board. These are the values that will be used to estimate cost for each vendor listed .

	Manufacturing Cost	Shipping Cost	Location of Business	Customer Reviews	Estimated Time of Order Fulfillment
PCB-Pool	$774.46	Included in manufacturi ng	Ireland	Positive	12 days
OSH Park	$2214	$0	USA	Positive	18 days
Express PCB	$378.96	$40	USA	Positive	4 days
4PCB	$264	$136	USA	Positive	7 days
Kejie PCB	Quoted Per Design	$200	China	Not Found	14days
Sunstone Circuits	$619.85	$0	USA	Positive	5 days
Our PCB	$161.44	$200	China	Positive	7 days
My RO PCB	$88.92	$100	Canada	Not Found	5 days
PCB International	$497.60	$100	USA	Not Found	5 days
Sierra Circuits	$447.68	$40	USA	Positive	8 days
Gold Phoenix PCB	$231	$100	China	Positive	7 days

Table 3.1.9.1 - PCB Vendor Comparison for Single Board per Stone

As you can see from the above table costs can vary by a significant margin between manufacturers. The four cheapest manufacturers being, in order from least to most expensive: My RO PCB, Our PCB, Gold Phoenix PCB, and 4PCB. When considering these manufacturers being located in North America is preferred for shipping costs, shipping speed, and customer service. For this reason Gold Phoenix PCB and Our PCB may not be used. Then considering the customer reviews My RO PCB will not be considered because of the lack of reviews. From this table the preferred manufacturers will be 4PCB or if cost is an issue, Our PCB.

	Manufacturing Cost	Shipping Cost	Location of Business	Customer Reviews	Estimated Time of Order Fulfillment
PCB-Pool [1]	$313.24	Included in manufacturing	Ireland	Positive	12
OSH Park [2]	$960	$0	USA	Positive	18 days
Express PCB [3]	$243.40	$236.40	USA	Positive	4 days
4PCB [4]	$129.08	$50	USA	Positive	7 days
Kejie PCB [5]	Quote Per Design	$200	China	Not Found	14days
Sunstone Circuits [6]	$601	$0	USA	Positive	5 days
Our PCB [7]	$110.97	$200	China	Positive	7 days
My RO PCB [8]	$52.64	$100	Canada	Not Found	5 days
PCB International	$437.28	$100	USA	Not Found	5 days
Sierra Circuits	$375.84	$40	USA	Positive	8 days
Gold Phoenix PCB	$126	$100	China	Positive	7 days

Table 3.1.9.2 - PCB Vendor Comparison for Multiple PCB per Stone

Based on the information collected in Table 3.1.9.1 and Table 3.1.9.2 you can see that generally the multi-board layout is more cost effective. However this can increase in shipping costs because of the increased amount of boards that need to be shipped, as some companies only ship a certain amount of boards at once. Taking into account all of the fields researched the recommended vendors are Express PCB, 4PCB, and Gold Phoenix PCB. Gold Phoenix has lower costs as the boards are manufactured in China, though this will lead to greater shipping costs. Express PCB and 4PCB are recommended for their location in the USA, free design software, reasonable prices, and fast shipping.

3.1.9.1 – Arduino™ Based Solutions

Understandably one would not be able to use the exact Arduino™ Uno board for our project since the project requires a printed PCB. Arduino™ provides all of their product's reference designs and schematics on an open-source platform. By making a few modifications and using the boards found online as a basis for the design, making a new PCB could end up being simpler than it may seem. This helps the designer understand the intricacies and necessities of a PCB while still manufacturing their very own final product.

All one would need to do is revise a given schematic to fit the needs of our specific project and hook it up to the computer in order to program it in the same manner that you would a regular Arduino™ Uno. In the given source schematic, the board shows that it has 7-12V recommended input voltage with 14 digital I/O pins and of those pins 6 of them are capable of Pulse Width Modulation. The DC current that each I/O pin can handle is 40mA and the DC current that the 3.3V pins can handle is 50mA. The product can hold 31.5 additional KB of memory with another .5 KB being used the boot loader which helps one program their board. There is 2 KB of Static RAM and 1 KB of Electronically Erasable Programmable Read-Only Memory all at a clock speed of 16 MHz. This PCB would then be compatible with either a Wi-Fi add-on pack like the Wi-Shield 2.0 or maybe a simple Bluetooth Serial Module (both of which will be discussed further in the communications section of the hardware research) [34].

Inside the PCB the microcontroller would then link into an LED driver such as the MAX6969 16 port, 5.5V Constant-Current LED Driver. This LED driver helps to be able to control a very large amount of LEDs with a limited number of pins. This LED driver uses an input voltage of 5V at the V+ input. It needs to be connected to an external clock to work. This means that the clock would be brought in from the nearby microcontroller unit. The DIN is driven by a 'Master Output Slave Input' signal coming from the microcontroller and the DOUT is an output that is sent back to the microcontroller. This signal being sent back is a 'Master Input, Slave Output' value. The DIN and DOUT pins are used for serial communication between the LED driver and the controller unit. Lastly, there is a latch value which waits for a signal coming from the microcontroller to activate the latch internal to the driver and an 'Output Enable Not' signal that comes from the controller to the driver. This means that the driver would be enabled by a microcontroller and would help modulate the output of the LEDs. The schematic shown below, in Figure 3.1.9.1.1, was taken from the Maxim Integrated© website as a reference schematic for their MAX6969 LED driver [35].

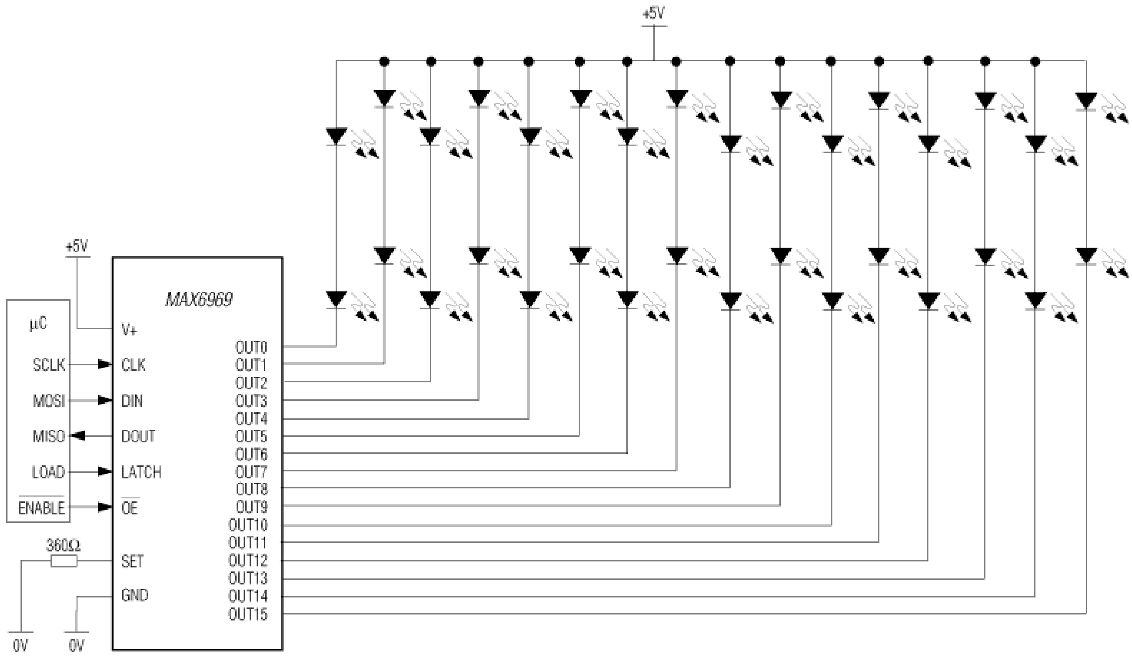


Figure 3.1.9.1.1 – LED Driver Schematic
Drawing courtesy of Maxim Integrated. © 2014.

The supply voltage for the LEDs is shown as +5V but in order to regulate the intensity of the LEDs for the purposes of the project (color changing) the 5V supply would be switched to be the output of a voltage regulator which allows us to transmit varying voltage intensities into the anodes of the diodes in order to achieve varied amounts of luminosity [36] [5].

3.1.10 – Structure

3.1.10.1 – Structure Breakdown

The structure of P.R.E.S.S. can be broken down into three key components the top, bottom, and the adhesives used to hold them together. Looking at P.R.E.S.S. from an aerial view it is in the shape of a hexagon with a slight view of the components shown through the clear or semi-opaque material. The material located on the top of each stepping stone in P.R.E.S.S. needs to be a material that is hard enough to hold up to three hundred pounds without collapsing onto the components inside the stone. The bottom of the structure will be encasing all of the key components that will make P.R.E.S.S. work properly including the PCBs, solar panel, sensors, and LEDs. The bottom casing material also needs to be able to withstand up to a three hundred pound weight limit. Throughout the center of the entire structure there will be two hollow screw posts connecting the bottom encasing to the top material. The screws will make for easy access to inside of the stone making the top and bottom detach from one another when unscrewed revealing the components. All of the materials needed for P.R.E.S.S. need to be water proof and hermetically sealed so that no water or air can reach the inside of the stones while being used. The electrical components inside can be damaged if exposed to the elements making the outside structure of P.R.E.S.S of high importance. The figures below show the general structure for each stone in P.R.E.S.S.

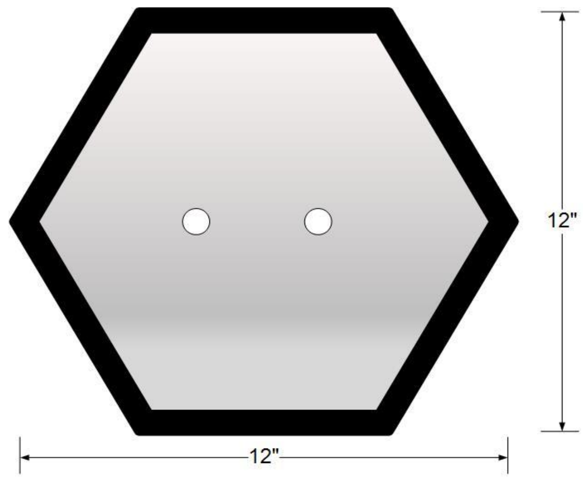


Figure 3.1.10.1.1 - Top View of P.R.E.S.S

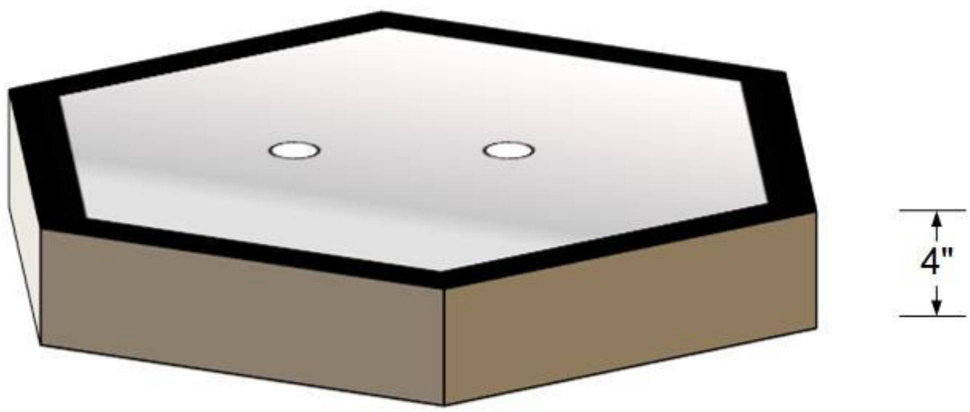


Figure 3.1.10.1.2 - Side view of P.R.E.S.S

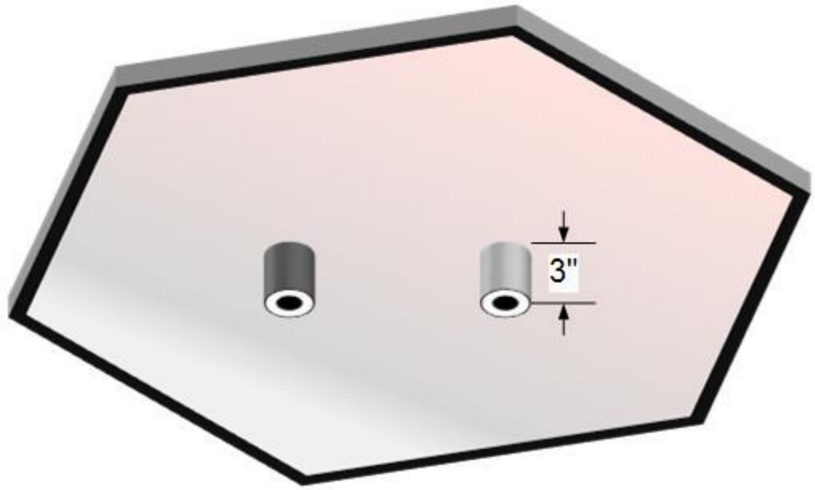


Figure 3.1.10.1.3 - Bottom view of the top of the structure of P.R.E.S.S

The keys things that need to be considered for building the structure of press include the material the top of the structure will be made out of, the material the bottom of the structure will be made of, and the sealants and adhesives needed to weather proof the entire structure.

3.1.10.2 – Material of Top Structure

3.1.10.2.1 – Fiber glass

Fiber glass is better known as fiberglass reinforced plastic or (FRP). The term fiber glass itself refers to a thermoset plastic resin that is reinforced with glass fibers. Fiberglass reinforced plastic is considered a composite material made of a polymer and a ceramic. The polymer material is usually resin and the ceramic material is usually glass. Since it is a composite the shape of fiberglass can be modified somewhat easily. There are two classes of plastic resins that can be used in FRP one being thermosets and the other thermoplastics. Thermosets will maintain their molded shape up to very high temperatures and cannot be melted and reshaped. Thermoplastics have lower melting points and be melted and re-solidified into different shapes. The glass fibers used inside this composite structure is what provides strength, stability and heat resistance [37].

Fiberglass reinforced plastic have superior mechanical properties to be considered. FRP's do not corrode, rust, or breakdown easily from industrial and household chemicals. The material is also very sturdy and provides a high strength to weight ratio making it able to bear a lot of weight on a small area. FRP does not absorb moisture easily and is a great electrical insulator [37]. It is also relatively inexpensive to produce depending on the amount of ceramic material used in the composite material. The more ceramic material like glass, carbon, or other man made material inside the composite fiberglass reinforced plastic the more expensive the material is. The top of the stepping stones in P.R.E.S.S. need to be strong and weather proof making fiberglass reinforced plastic a viable option for the project.

3.1.10.2.2 – Plexiglas

Poly (methyl methacrylate) or (PMMA) is better known as Plexiglas. Plexiglas is an acrylic plastic that is similar in looks to glass but extremely different in chemical make-up. Plexiglas is a petroleum based plastic that is transparent like glass but doesn't have the same safety risks glass does [38]. There are various types of Plexiglas that have slightly different chemical variations to make them thicker and stronger. Plexiglas is also made in different forms including: transparent, opaque, white/color translucent, solar control colors, infrared transmitting, and ultraviolet light filtering Plexiglas. In each form of Plexiglas light transmittance varies giving different levels of protection for the material the Plexiglas is enclosing. The chemical resistance of Plexiglas is based on several factors, including stresses generated by fabrication operations and end-use stresses caused by changes in the temperature in the environment the Plexiglas is in. Taking these factors into consideration Plexiglas is actually resistant to most chemicals and some acid solutions which makes Plexiglas an extremely useful acrylic plastic [39].

One downfall to Plexiglas is with change in temperature and humidity it will expand and contract. If temperatures differ on the inner and outer surfaces it can cause the Plexiglas to slightly bow in the direction of the higher temperature or higher humidity. After it returns to equilibrium the Plexiglas then returns to its original flat state. Considering this, it is important to attach the Plexiglas sheet in a manner that allows the Plexiglas to expand and contract within its frame so it will not become permanently damaged. The chemical makeup of Plexiglas makes it an excellent electrical insulator. It has a high dielectric constant which causes somewhat of a static charge on the surface but it does not affect how well Plexiglas serves as an insulator. Another positive about Plexiglas is the incredible strength it has. Some variations have even been made thick and strong enough to stop a bullet [38]. It takes an extreme amount of force to even crack most Plexiglas making it a highly desirable material for structure in many different industries.

Since Plexiglas has different thicknesses the range of which solar energy and light transmittance differs. Below is Table 3.1.10.2.2.1 showing the average amount of light transmittance through different variations of white translucent Plexiglas. Starting from the top is the clearest, most translucent Plexiglas material going through ranging to an opaque white Plexiglas material that barely any light can be transmitted through [40].

Total Luminous Transmittance (%) (6500° K Average per day)					
White Translucent Variations	.188'' (3.0 mm) Thickness	.177'' (4.5 mm) Thickness	.236'' (6.0 mm) Thickness	.354'' (9.0 mm) Thickness	.472'' (12.00mm) Thickness
Clear (W2067)	71%	61%	52%	27%	19%
Clear Frosted (W2447)	50%	42%	35%	N/A	N/A
White (W7508)	9%	6%	3%	N/A	N/A

Table 3.1.10.2.2.1 – Luminous Transmittance

The chart above gives a breakdown of the three shades of Plexiglas being considered for the project and there translucence [40]. The ideal material for the top structure is not a completely clear Plexiglas, but translucent enough to gain energy from the sun for the solar panel below directly below the top structure. A clear matte finish or better known as frosted Plexiglas is what will be considered for this project.

Different vendors sell various shades of frosted Plexiglas in different colors and textures. Below is a table showing three different vendors with the shade of frosted Plexiglas that is ideal for this project. The price increases with the thickness of the Plexiglas which is shown below in Table 3.1.10.2.2.2.

Vendor Price Comparison ($)					
8 12'' X 12'' Clear Matte Finish Sheets	.188'' (3.0 mm) Thickness	.177'' (4.5 mm) Thickness	.236'' (6.0 mm) Thickness	.354'' (9.0 mm) Thickness	.472'' (12.00mm) Thickness
TAP Plastics	$59.20	$86.00	$144.80	$146.00	$214.80
eStreetPlastics	$47.92	$63.92	$103.92	$111.92	$127.92
Professional Plastics	$40.40	$88.32	$117.76	$130.00	$172.00

Table 3.1.10.2.2.2 – Vendor Pricing

As shown in the chart above, the price comparisons of eight sheets of twelve inch by twelve inch dimensions with different variations of thicknesses. The cheapest vendor Professional Plastics has the highest shipping costs making it even more expensive than the highest priced vendor TAP plastics. These price comparisons give a better understanding of which vendor to choose when considering the budget for the top of the structure.

3.1.10.3 – Material of Bottom Structure

3.1.10.3.1 – Wood

There are a lot of benefits to going with a wood bottomed structure. Seeing as these stepping stones are going to be a lawn garnishment, it will give these modernly shaped lighting enhancements a woodsier look. Wood is also easy to cut, shape, sand, lacquer and basically turn into whatever is needed of it. Going with this option saves the team from having to produce a 3-D version (although it may still be a good idea for prototyping purposes) in a program like SolidWorks or AutoCAD and needing to send that design to an outside vendor who will then produce the necessary shape and sized piece of material. Wood can be relatively cheap while cutting and shaping ourselves saves the money in labor. Although it is simple to think of the benefits of wood, it is important to keep in mind the limitations as well. Depending on the type of wood, it may be difficult to find something that will not undergo discoloration or corrosion from being exposed to the elements. It is important to find the proper types of wood that do not need to be regularly maintained after being lacquered a few times.

The first type of wood that is highly recommended by woodworkers for outdoor applications is White Cedar. This wood is affordable since it is grown right here in the northern United States. It is straight grained and easy to cut and shape. The wood is naturally resistant to weather and insects. Best of all, is does not fall prey to mold, mildew or decay easily and can last up to 25 years. To maintain it is optional to apply a water-based stain annually. Jarrah is a redder wood found in Australia, South Africa and South America. This wood resists rotting, termites or other insects, and will not decay. Like Teak, Jarrah is capable of lasting up to 50 years. This wood requires a little more maintenance than the other woods. To keep the color, it is requested that it me treated two to three times a year with a special type of finish made specifically for Jarrah. It also should be power washed and scrubbed. Lastly, it is also very expensive because of needing to be imported, and having such a long lifespan. An option that can be found close to home and is relatively affordable is Pine. Untreated pine is not as resistant to rot and is not as durable as treated pine. Treated pine is pressurized and can last twenty years. If the group decides to go with untreated pine, maintenance will have to take place quite frequently since it needs to be resealed yearly. Treated pine does not need as much maintenance but still may not be the best option for year-long outdoor applications. A final option is redwood which is strong and straight-grained. It is ruddy and durable. It can be found on the western coast of the United States. A positive characteristic of redwood is its resistance to termites and rot and it is capable of lasting up to 25 years when maintained properly. It needs to be cleaned yearly and then protected with a special oil-based stain that includes water-sealer and preserver [41].

It is also very important to employ some type of wood preserving technique in addition to selecting a reliable outdoor wood. The chart below helps when trying to decide which type of preservative to use since it shows some options that are widely used in building applications. It also helps identify some of the benefits and drawbacks of differing types of liquid varnishes. Each of these types has its own negative down-sides and could cause problems if the group chose to use any of them [42] [43].

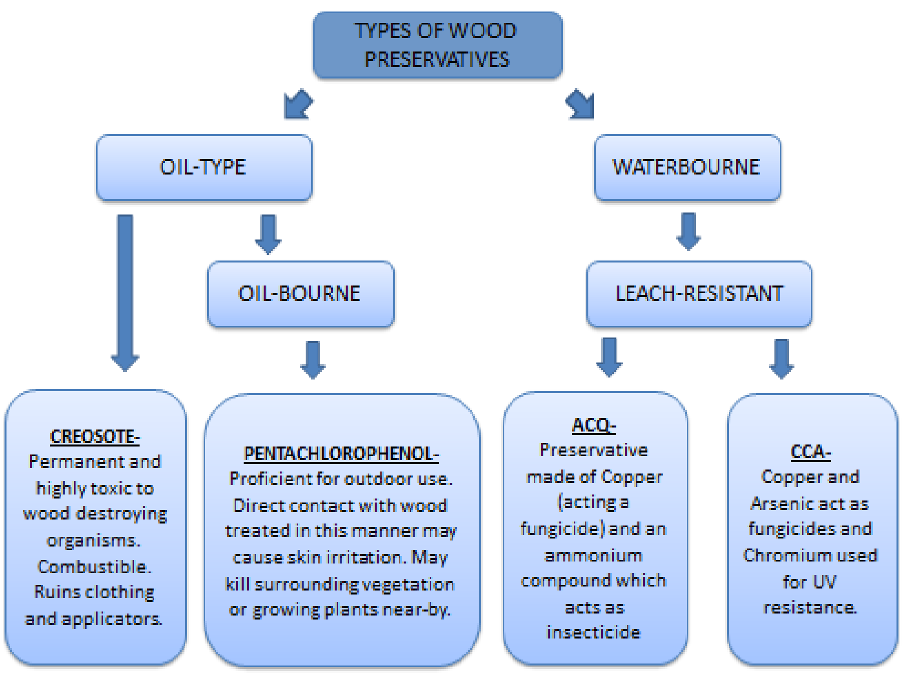


Figure 3.1.10.3.1.1 - Flow chart shows the different types of preservatives used to treat wood.

3.1.10.3.1.1 – Epoxy Resin Sealant for Wood

Another option for sealing the wood aggressively would be to apply a thick coat of epoxy or resin to the outside to protect the inside would. This would basically mean that the lower section of the outer casing would be half made of wood and half made of plastic (dried epoxy/resin). It would then be necessary to select an epoxy that is weatherproof to the point of usually being used for marine grade situations. It would also be important to select an epoxy that is not too toxic and can be easily handled without any special equipment. The following figures outline the benefits and drawbacks of using certain epoxies. It also gives a basic idea of the way these epoxies are regularly used and for what specific applications [44].

	Amine Epoxies	Polyamide Epoxies	Amidoamine Epoxies	Epoxy Phenolics/Novolacs
Description	Form very hard, adherent films with excellent chemical and corrosion resistance. Amine cured epoxies are often used as protective coatings and linings in highly corrosive environments. Amine epoxies require care in handling since the amines can be moderately irritating to the skin, and may cause allergic reactions.	Polyamide epoxies generally offer the widest latitude in coating formulation. They are considered more resilient and flexible, and have better weathering resistance and a longer pot life than amine cured epoxies. Polyamide epoxies generally have less solvent and acid resistance than amine cured epoxies.	Amidoamines are reaction products of a polyamine and a fatty acid. Their properties generally fall between those of amines and polyamides. They have good water and corrosion resistance like amines, and good toughness like polyamides. They have relatively small molecular size giving them low viscosities and making them very good surface wetters.	These coatings allow wide range formulating latitude. Novolac epoxy resin increases chemical resistance and solvent resistance. Increasing the level of phenolic increases the chemical and solvent resistance, but the coating loses flexibility. Some phenolics require heat curing.
Advantages	• Excellent alkali and water resistance • Very good acid resistance • Excellent solvent resistance • Hard, abrasion resistant film • Excellent corrosion resistance • Excellent wetting of substrate • Chemical/moisture barrier	• Very good alkali and water resistance • Good acid resistance • Longer pot life than amines • Easy to apply • Cures more quickly than amines • Good weathering characteristics • Good film flexibility • Excellent adhesion	• Excellent surface wetting • Excellent adhesion • Excellent water resistance • Low viscosity • Longer pot life than amines • Good gloss retention	• High heat resistance • Excellent chemical resistance • Excellent solvent resistance • Excellent corrosion resistance • Hard, abrasion resistant film
Disadvantages/ Limitations	• Amines can be irritating/toxic • Relatively short recoat time • Relatively short pot life • Slower dry than normal polyamides • Chalks/may discolor	• Faster dry than amines • Chalks • High viscosity • Temperature dependent • Slow cure	• Slow cure • Fair color retention • Temperature dependent	• Some may require heat cure • Relatively slow air cure • Chalks/may discolor • Relatively brittle
Primary Uses • Refer to product data sheets for specific use information	• Severe chemical resistant coating • Barrier coating • Offshore structures • Storage tanks, structural steel • Bridges, power plants • Tank linings • Secondary containment	• Water immersion • General industrial • Offshore structures • Storage tanks, structural steel • Water/wastewater plants • Tank linings • Bridges, power plants • Secondary containment	• Barrier coating • Surface tolerant coating • Where chemical and moisture resistance is required • General industrial • Refineries • Bridges, power plants	• Severe chemical resistance • Tank linings • Secondary containment • General industrial • Refineries • Bridges, power plants
S-W Products	**Amines** Shelcote II Epoxy Shelcote II Flake Filled Dura-Plate UHS Tank Clad HS Epoxy Sher-Glass FF **Ketimines** Dura-Plate MT Macropoxy 920 PrePrime **Phenalkamines** Dura-Plate 235 **Water-Based** Water-Based Tile-Clad Zinc Clad VI Fast Clad DTM Waterbased Epoxy	Kem Cati-Coat HS Filler/Sealer Tile-Clad High Solids Recoatable Epoxy Primer Copoxy Shop Primer Zinc Clad IV Zinc Clad III HS Hi-Solids Catalyzed Epoxy Macropoxy 646 Fast Cure Macropoxy 846 Winter Grade Epolon II Primer Epolon II Multi-Mil Macropoxy HS Epoxy Pro Industrial High Performance Epoxy	Epoxy Mastic Aluminum II	Phenicon HS Epoxy Phenicon Flake Filled Epo-Phen Nova-Plate UHS

Table 3.1.10.3.1.1.1 - The figure above is an Epoxy Coating Comparison Chart from the Sherwin Williams Company

	Siloxane Epoxies	Coal Tar Epoxies	Water-Based Epoxies	Epoxy Esters
Description	Siloxane epoxies are relatively fast curing coatings with excellent stain and mar resistance. They have excellent color and gloss stability. Siloxane epoxies are typically used in high performance industrial applications. Also acceptable for architectural applications.	Coal tar epoxies are a combination of a basic epoxy resin and coal tar. The coal tar is in the form of a semi-liquid pitch and blended with the epoxy resin. The curing agents for coal tar epoxies are usually either amines or polyamides. Coal tar epoxies offer excellent resistance to fresh and salt water and are highly resistant to cathodic disbondment.	Generally consist of a non-yellowing acrylic resin disbursed in water mixed with an emulsified epoxy resin. They are relatively hard, durable coatings with moderate chemical resistance. They offer good stain resistance, abrasion resistance and resistance to most commercial cleaning agents and sanitizers. They can be used over previously applied conventional paints to upgrade the surface for better performance without wrinkling, lifting or bleeding.	A combination of epoxy resin and alkyd resin resulting in an air-drying coating. Epoxy esters provide a hard, durable film ideal as a machinery finish. Recommended for general atmospheric use in areas not considered severely corrosive.
Advantages	• Very good weathering resistance • Hard, abrasion resistant film • Very good acid resistance • Excellent color and gloss retention • Relatively fast dry	• High film build with one coat • Excellent salt water resistance • Excellent water resistance • Excellent resistance to cathodic disbondment • Economical	• Good chemical and solvent resistance • Hard, abrasion resistant film • Upgrades conventional systems to high performance • Water clean-up, low-odor • No strong solvents • Good adhesion • Very long pot-life • Good weathering	• Hard, durable film • Easy to apply • One component • Good moisture resistance • Minimal surface preparation • Moderate cost • Low temperature application • Increased alkali resistance over alkyds
Disadvantages/ Limitations	• Solvent resistant • Heat resistant	• Not for potable water • Black color • Critical recoat time/ difficult to recoat • Fair solvent resistance • Chalks/browns	• Flash rusting on ferrous metal unless primed	• Fair solvent resistance • Poor weathering characteristics • Poor exterior gloss retention
Primary Uses • Refer to product data sheets for specific use information	• Bridges • Marine • High performance finish coating • Kennels, • Schools, jails, hospitals • High moisture areas • Stain resistant coating	• Liner for sewage treatment tanks • Not-potable water tanks • Pipe coating • Penstocks, dam gates • Offshore rigs • Paper mills • Chemical Plants • Secondary containment	• Light/moderate industrial areas • Tile-like wall coating • Schools • Hospitals • Food plants • Office areas • Kitchens • Hallways • Nursing homes	• Moisture resistance • Where odor or low temperature limitations prevent solvent-based epoxy use • Abrasion resistance
S-W Products	Polysiloxane XLE-80	Hi-Mil Sher-Tar Epoxy Tar-Guard Coal Tar Epoxy	Water-Based Epoxy Primer Water-Based Epoxy Pro Industrial Hi-Bild Waterbased Epoxy	

Table 3.1.10.3.1.1.2 - The figure above is an Epoxy Coating Comparison Chart from the Sherwin Williams Company

The tables above cover a multitude of differing types of epoxies. This process is necessary for all types of epoxies since epoxies are made up of a two part mixture of resin and hardener. Initially separate, the two types of solution are measured to a certain percentage of the final product and are mixed well. If this process is not completed without error than the epoxy may not undergo the chemical reaction and produce enough internal heat in order to make it harden on the wood.

The first that is mentioned is the ‘Amine epoxy’ which can dry quickly and is weathering resistant but it is said to be a very harmful skin irritant so the person applying the solution would have to be very careful when undergoing the arduous measuring, mixing and application process. The next epoxy type mentioned is the 'Polyamide Epoxy'. This type weathers very well and has a very strong aversion to water intrusion. One of the significant downsides for the needs of this project is its fast curing time. This may lead to it drying too quickly when a flood coat is applied on the wooden base. It is also quite dependent on the temperature of the environment and that mixed with a quick dry time can be a disastrous combination when it comes to curing. The next type shown in the table is the ‘Amidomine Epoxy’ which adheres well to whatever surface it is applied to and retains its sheen well. But like the previously mentioned type, it also is temperature dependent. ‘Novolac Epoxy’ is the next type shown and this type is very heat, corrosion and chemical resistant. This type is used for very industrial application on a regular basis so it may be a little too extreme for an application like the project being outlined in this report. It is a strong epoxy but it is also quite expensive to have those types of results. ‘Coal Tar Epoxy’ is shown on the second chart and this type seems to be water resistant and economical but it is said to have a black tar-like consistency which may not be ideal for this project. The bottom section of the exterior of the stones is preferred to have a glossy wooden appearance so coal tar epoxies may not be ideal. ‘Epoxy Esters’ result in a hard durable coating and are relatively moisture resistance but this type does not stand up very well to weathering characteristics. Since the stone will be sitting out in the middle of the customer’s yard for months on end being subject to UV rays and rain, it would be necessary to use a solution that can withstand the forces of nature.

The solution that seems to suit our needs the best would be the ‘Solixane Epoxy’ type. This is because it weather well, it is resistant to heat and it can retain its color and gloss. The thing that is most significant about this type is how it is primarily used for marine grade sealant applications. If the group decided to go with an epoxy, the Siloxane Epoxy type would be ideal to flood coat the stones with. A flood coat is when you pour the resin/hardener mixture over the surface you are trying to seal and allow it time to level out on the surface and dry. There will be residue that drips from the edges but to maintain a smooth surface on the edges, one can take a sander to them and smooth off the uneven portions. With Siloxane epoxy being used for marine situations, it goes without saying that it can stand up to most types of weather.

3.1.10.3.1.2 – Polyurethane Sealant for Wood

Another option the group could use to seal a wood casing from the elements would be polyurethane. Polyurethane is basically a thermoplastic polymer. This type of method usually does not require a two part measuring and mixing step. It already has all that is needed within the given product and uses contact with outside air to activate the hardening characteristic. Some polyurethane products may also require heating to harden. Polyurethane is used very often to coat and seal wood and is easily applicable.

The benefits of going with polyurethane coating are numerous. It is less expensive than going with the two-part epoxy resin and it also has shorter lead times since it is more widely used and can be found in most home improvement stores. It has excellent resistance to scratching and has a glossy sheen once dried. This type of coating has a wide range of harnesses and is specifically classified when purchased so depending on the necessary application, it is possible to choose a certain polyurethane with varying hardness capacities. It adheres well unto the surface that it is applied (especially in the case of wood). It even can show characteristics like flexibility in some situations since some types of polyurethane are modified with vegetable oils to increase pliability and help with bonding. Toughness is increased due to polyurethane's high resiliency factor which means that it also has very high tear resistance and is characterized with very high tensile properties. It is resistance to oil and grease in addition and will not swell if these factors play into the environment. It dries quickly in most cases as well so for the needs of this group project, it would not be necessary to wait very long in order to start integrating parts together. Polyurethane has a high load bearing capacity and due to its earlier-mentioned resiliency, it can be compressed or tensed and may be initially changed in its originally set shape but it will return to its previous form very quickly without any evidence of this change. Best of all, polyurethane is not impeded by weathering or acids and can perform well in harsh environments. This means that it stands up well to liquids and will help insulate the wood casing from water intrusion which would result in molding, mildewing and fungus incursion. The last reason polyurethane would be a wonderful solution to use is its ability to electrically insulate. If any of the electrical components were ever to be touching the casing on accident, it would not conduct and cause issues with shorting of the printed circuit board. This means that we could avoid future failures by going with this as an outer casing compared to some type of metal casing.

The drawbacks of polyurethane are also significant. If one wants to apply another coat after having already used a first coat of polyurethane, they will need to sand the surface to give the second coat rigidity to adhere to. Over time, polyurethane coatings begin to brittle and separate from the surface to which they have been applied. This brittleness leads to decreased resistance to impact and decreased pliability. It is possible to extend the life of a polyurethane coating by regularly applying oil to this outer coating to keep it from completely drying out [45] [46].

3.1.10.3.2 – Resin Mold

Instead of utilizing the option of wood for the bottom section of the outer casing, it would also be interesting to go with a resin mold casing. To do this, it would be necessary to either 3D print or fashion a hexagonal container (possibly from wood) to be the original cast so that one could pour silicone rubber in to make a negative of the shape like that of the bottom section laid out in figure 2.1.5.1.2. Give the original cast a thin film of sealant. After that, one would use silicone rubber to pour over the original cast. Silicone rubber is made of a two-part mixture which takes six hours to fully harden after being mixed and exposed to air. Once it hardens, it can be used as a mold for the rest of the casts to be made. Silicone rubber is a compatible mold to be used with solutions that are easy release or have high temperature resistance. This type of silicone can be used for casting polyurethane, epoxy resin, polyester resin, waxes, gypsum products as well as low temperature metals. As discussed in the wood section, polyurethane would be easier to manipulate and would dry quicker. The polyester resin would exhibit similar characteristics to the polyurethane cast. Gypsum products and waxes would be too pliable and would not be able to stand up against the weathering the casings will need to endure. In the case of this group project, the ideal casting that would be used is a clear epoxy resin. Although it is expensive and difficult to mix, it stands the best chance against the outdoor odds it will be facing. The silicone rubber mold (once made) could be used to create multiple epoxy resin casts of outer bottom casings for each of the stones [47].

Another option would be to find some type of preexisting rubber mold that would be the correct size or one would need to get one manufactured which could result in high expenses for the project. This negative casting method could end up being a bit arduous. Not only that but the most ideal casting ingredient, resin, is expensive itself and gallons of this resin would need to be purchased in order to make the outer bottom casings of six or so stones. As mentioned before in the epoxy resin solutions of the previous wood section, resin is made up of a two-part solution that needs to be measured out and mixed correctly or else it will never dry. The same goes for a resin mold. If measurements for hardener and resin are off by even a small amount, it could cost the group hundreds of dollars if the molding process would need to be revisited correctly a second time. As interesting as it would be to have a clear base casing where students or consumers could see the inner workings of the stones, it is also a very difficult process to make such a base with what types of financial options the group has at their disposal. It is also a gamble on whether or not the process could be done right the first time around. Overall, when factoring in the need for a silicone rubber mold with an original cast and numerous epoxy resin casts to follow, we see that this process has many steps and has a higher failure rate with proportionally high monetary costs. The resin mold option is a solution that remains on the table for the group but it may not be as easily fashioned as a wood base could be.

3.1.10.3.3 – Plexiglas as Bottom Casing

A valid option would be to make the bottom casing out of Plexiglas. It would be necessary to cut 6 small pieces of Plexiglas to act as the six outer sides of the hexagonal stepping stone shape and one large hexagonal sheet as the bottom side. A few options for bonding these pieces of Plexiglas together would be to use either a Methylene Chloride Plexi Solvent or acrylic cement. In the case of the Methylene Chloride Plexi Solvent, it actually causes a chemical reaction to take place which results in a chemical weld of the two pieces being bonded. One would think that at the bonding point, it would be weakest but when using this solvent, the bonding point becomes stronger and has a much lower probability of cracking or breaking in comparison to adjacent unglued areas. The bond is optically clear and it dries very quickly and cleanly after it has been applied. This bonding agent is a very viscous solution so due to that characteristic, one does not need to use much solvent to accomplish the task. This means that one bottle can last a very long time and can go for numerous uses. When using this type of glue it is important to do so in a well-ventilated area and to use gloves and goggles to make sure it does not touch the skin or the eyes. Although the solvent will not result in stickiness to the skin as glue does, it is still a chemical and should not come in contact with the body.

An additional bonding option would be acrylic cement. Acrylic cement is a water thin liquid that acts very similar to the methylene chloride solvent mentioned before. It is a chemical that softens plastic surfaces so that they merge and the molecules of each piece intertwine creating one single piece of plastic. Then the acrylic cement evaporates leaving a strong glue-free joint. Depending on the type of Plexiglas you are using, it may be better to use a specific bonding agent in order to hold the hexagonal bottom casing together. Either way, each of these methods is better than regular gluing because with gorilla glue or super glue, the bond is only as strong as the additional dried plastic between the two pieces. This leaves a lot of room for future failures. It is important to take into consideration the strength of these bonds seeing as users will be stepping on these pieces on a daily basis so it is important that the unions at the edges are very strong and stable.

There are many benefits to using Plexiglas over other products. Plexiglas is robust, shatter resistant, safe, bendable, sturdy, easy to handle and simple to cut. Plexiglas is the same material that is used on the backboard of a basketball hoop. It is much more durable and crack resistant than a piece of glass that is equivalent in thickness. It is also worth noting that when a piece of Plexiglas is broken, it does not crack into many tiny sharp and dangerous pieces as glass does making it much safe than most options for an outer casing. Plexiglas is also transparent which makes it a really great solution for the needs of this stepping stone project. Since this group's goal is to create a mechanism that proves the concept of programmable LED walkway stepping stones, it would be interesting if the prototype were to have a transparent casing showing all the inner-workings and circuitry of the final product. Plexiglas is easier to cut than glass and it can be cut easily using a saw. Plexiglas is less dense and therefore less heavy than actual glass. It is easy to purchase, transport and manipulate into whatever shape needed. When moving, it is not as probable that it will break since it is made of a very durable polymer. If one were to use a special 2D laser cutting machine, it would also be possible to add customization to the outer casing by drawing thin shallow lines into the outside that help to refract the light coming into as well as escaping from the stones. The last and most prevalent characteristic of Plexiglas that is worth mentioning is the fact that it can be coated with special UV protection treatments. These treatments are clear and do not conflict with the overall transparency of the Plexiglas itself.

3.2 – Software

3.2.1 – Lighting Communication

Of the many communication standards for lighting control DMX, ACN, Streaming ACN/ANSI E1.31, and DALI, were considered as being most effective standards to achieve the design goals. Some of these standards were created by Entertainment Services and Technology Association (ESTA), while others were developed by International Electrotechnical Commission (IEC). Each communication standard is further described below.

3.2.1.1 – DMX 512

DMX 512 was created by ESTA, the DMX part stands for digital multiplexing and 512 means that it has 512 channels of communication. Since 512 channels can sometimes be too restrictive for its intended use DMX can be grouped in universes, with each universe consisting of no more than 512 devices. There is not a standard for what each channel does for every device, so careful programming is required when using the DMX standard. [48]

It's commonly used in professional entertainment lighting events, such as theater, and concerts. DMX can control multiple types of devices from traditional dimmable lights, to moving lights, color changing lights, fog machines, some solenoid devices, etc. There are two types of DMX devices, an output device, and input device. Output devices are typical a lighting control console, where the user inputs commands to send to each light. The input devices are end device themselves. To save space on the output devices, DMX is configured to be a daisy-chain protocol.

With DMX each channel is an associated address, starting at 1 up to 512. So a simple dimmable light uses 1 address number, and a typical RGB LED will use at least 3 DMX address numbers. It is possible to have multiple lights share the same address, however it is important to note that each time that channel is called, all lights with that address will execute their respective DMX commands received. Sharing the same DMX address is only done with like devices so as to avoid having lights do different things when their address channel goes high. The generally accepted practice for building DMX lighting systems is to use address offsets for dissimilar lights.

The signal for DMX repeats all 512 intensities as fast as 44 times per second. DMX is a wired standard that follows the RS-485 standard. That is DMX transmits a differential signal on two separate wires twisted together. There are five pin and three pin configuration for DMX, although three pin is not commonly used in most applications a three pin DMX connection exists because of pins four and five being unused in the current version of the standard.

PIN OUT	FUNCTION
1	Ground
2	Data (-)
3	Data(+)
4	Unused
5	Unused

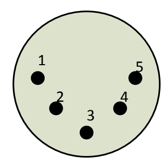


Figure 3.2.1.1.1 – DMX Pin Out Configuration and Connector

DMX signal is a 250 kbps serial signal, eight bits in length with one start bit, two stop bits, and a frame break. Each frame consists of 513 bytes, with the first byte indicating the format of the frame. A break character is used to signal the start of a DMX frame. A break is defined as an asynchronous signal that has any period longer than the duration of a signal. In DMX the break (at sender) is longer than the minimum lasting 92 µs of continuous low signal, then a 12 µs high level Mark After Break (MAB). The next low indicated the control slot or start code. At the receiver the start packet has an 88 µs break or greater, followed by an 8 µs or greater MAB. This break is used to start reception of DMX slots. Mark Time Between Frames (MTBF) can last up to 1 second, and is set high. The maximum frame period is 1240 µs and 1 second.

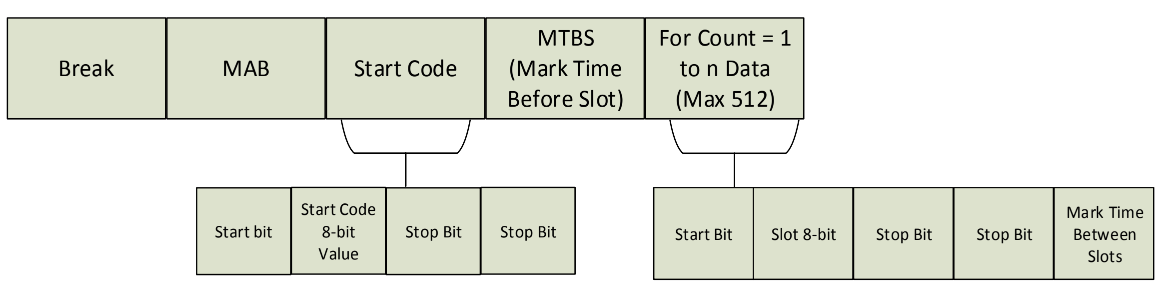


Figure 3.2.1.1.2 – DMX 512 Frame Headers

3.2.1.2 – Architecture Control Networks ANSI E1.17

Architecture Control Networks (ACN) is a suite of protocols and languages which could be combined with other standard protocols to form a flexible networked control system. ACN came from the need for the lighting industry to have a common protocol to take advantage of emerging technologies that offered cheap high speed communications. Some of the features in the design of this protocol was to be able to handle multiple sources and multiple receivers, sources and sinks are not be equated with controllers and controlled devices, ACN is compatible to work with other mainstream protocols, and it is reasonably frugal with bandwidth, sending only changes in output levels rather than a constant refresh.

The control parameters of ACN devices are set in their properties. A device is monitored by getting the property values, while control is done by setting them. This is done by the Device Management Protocol (DMP) with basic messages such as Get_property and Set_property. DMP also handles the addressing of variables with the device. The addressing scheme for DMP uses range addressing, to give very larger numbers of property values to be transferred with minimal overhead. DMP gives a generalized method of getting and setting values. A more specific method could have been used, however it would have made the protocol too complicated to interface with many devices. With this in mind using a generalized approach required a different protocol to handle the specifics. The mapping of properties and a specific function is handled by the Device Description Language (DDL). This protocol defines the format and languages in a way that allows the controller to find the functionality of each property.

Get/Set_property messages are typically short, but protocols such as Ethernet or TCP/IP will transport large blocks of data for efficiency. To correct this, and make ACN work within these protocols, ACN allows large numbers of short message to be condensed into one large packet. This packet is then sent out to all the concerned devices in a single message with each device extracting their respective message. Devices know if the packet is meant for them based of their component identifier (CID) address.

If a device receives an out of order Set_property, or even if that message drops in transmission, the device could end up in an incorrect state, so some kind of error-detection is needed to ensure proper settings of devices. To provide this error-detection with the multicast environment of ACN the Session Data Transport (SDT) protocol is used. This protocols provides a reliable, ordered delivery of multicast messages. ACN uses a common message format for all its protocols in order to recognize and decode messages across of different message types (i.e. SDT and DMP), this common message format is called the Protocol Data Unit (PDU). PDUs are broken down in five fields: Flags, Length, Vector, Header and Data. Only the flags and the length are in one octet, the others are separate octets [49].

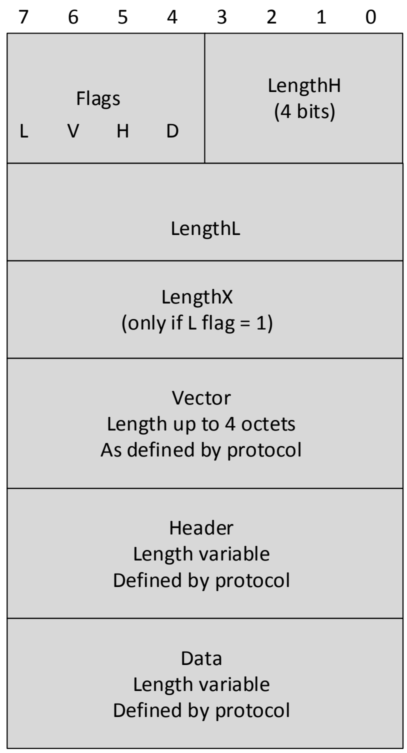


Figure 3.2.1.2.1 – ACN PDU Layout

Flags are a 4-bit field that declares how the PDU is packed, L – length, V – vector, H – header, D - data. Length specifies the octet length of the entire PDU, it is the number of octets from the start of the PDU to start of the next PDU. If the PDU length is 4096 octets or less the L flag is zero, length is 12-bits. The Vector field is a short, fixed length directing the receiver where and how to pass the PDU onto the next level. The Header field provides supplementary information of the PDU, and can vary in length depending on the protocol. A zero value is possible for the Header. Data contains the content of the PDU and its interpretation is defined by the protocol, message type or other handler indicated in the Vector field. Length and Vector fields are always byte order as big endian. Header and Data fields order is dependent on the protocol used, which is defaulted to big endian. For a protocol to use anything other than big endian there would have to be an exceptional reason.

Using this common message format then enables the protocols of ACN to become modular. This then gives a common entry point of the protocol stack, which is given to the Root Layer protocol. The Root Layer defines how PDUs from different ACN protocols are to be combined into packets for transmission over an existing network. If that network is a LAN then ACN is to be configured to use TCP/IP protocols. ACN is not required to use the entire TCP/IP protocol stack, rather just a subset to keep it simple. It is possible to use SDT over TCP/IP's UDP without the need for using the TCP protocol.

There can be different transports on information, which can vary wildly in operation, and services. To make transmission successful over ACN additional information, such as, packet length, error checksum, and packet identification is required. To handle this extra information the Root Layer Protocol consists of a preamble and post amble along with the PDU information being sent. Because of the many variations of protocols and transports the Preamble is dependent on the transport protocol; for instance UDP systems place a marker string in the Preamble to identify ACN packets [49]. The Preamble is not required to contain any information within its field. PDU block contains multiple PDUs within the packet and is compressed as was defined above. The Post amble is treated much the same as the preamble, dependent on the transport protocol, it may be used to hold a checksum for transports not requiring an error check.

On an Ethernet network, ACN controllers send out Get/Set_property messages to devices using DMP. The messages are transmitted via SDT to provide the reliability and status of devices. The DMP and SDT messages are condensed into PDUs, which are then transmitted using UDP over the network. To transport each packet, the transport protocol requires the transport protocol address of the receiver of the ACN packet, the transport protocol of the send of the ACN packet, the length of the ACN packet, and the data that makes up the packet.

3.2.1.3 – Streaming ACN ANSI E1.31

Also established by ESTA, Streaming ACN (sACN or E1.31) was designed to operate DMX over the Ethernet protocol. It is used to transfer DMX packets of all start codes via ANSI E1.17 (ACN) supported networks. A packet wrapper is used encapsulating DMX data following an ACN packet. When on a TCP/IP network ACN is sent using UDP packets. The standard uses multicast addressing to partition traffic for each distinct universe, and direct unicast is also supported.
Figure 3.2.1.3.1 shows the frame configuration for E1.31 protocol as a subset of the TCP/IP protocol.

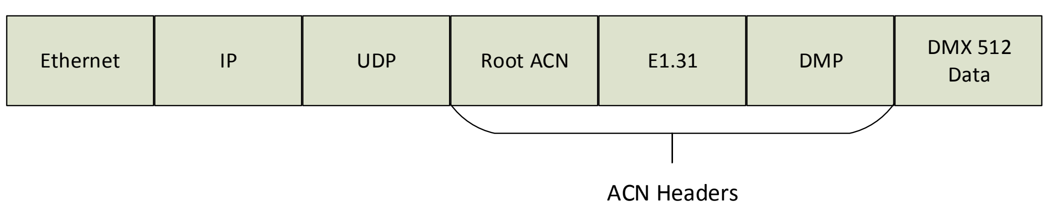


Figure 3.2.1.3.1 – Frame Configuration for sACN Protocol

E1.31 is a protocol within the suite of protocols defined by ACN standard. The ACN standard provides a method for layering protocols. The lowest layer of ACN is called the Root Layer Protocol (RLP). E1.31 defines an outer layer Protocol

Data Unit (PDU) wrapper that gives the specific number of a packet and carries a block of data. This block contains a nest PDU with a single message of Device Management Protocol (DMP) of ACN to carry the DMX data. Further explanation of the E1.31 framing protocol can be found in Table 3.2.1.3.1 – Table 3.2.1.3.3. [50].

Octet	Field Size	Field Name	Field Description	Field Contents
Root Layer				
0-1	2	Preamble Size	Define RLP, Preamble Size	0x0010
2-3	2	Post-amble Size	RLP Post-amble Size	0x0000
4-15	12	ACN Packet Identifier	IDs this packet as E1.17	0x41 0x53 0x43 0x2D 0x45 0x31 0x37 0x00 0x00 0x00
16-17	2	Flags and Length	Protocol flags and length	Low 12 bits = PDU Length High 4 bits = 0x7
18-21	4	Vector	Identifies RLP data as 1.31 Protocol PDU	0x00000004
22-37	16	CID	Sender's CID	Sender's unique ID

Table 3.2.1.3.1 – Root Layer Breakdown for sACN

Octet	Field Size	Field Name	Field Description	Field Contents
E1.31 Framing Layer				
38-39	2	Flags and Length	Protocol flags and length	Low 12 bits = PDU Length High 4 bits = 0x7
40-43	4	Vector	Identifies 1.31 data as DMP Protocol PDU	0x00000002
44-107	64	Source Name	User Assigned Name of Source	UTF-8 encoded string, null-terminated
108	1	Priority	Data priority if multiple sources	0-200 default 100
109-110	2	Reserved	Reserved	Transmitter Shall Send 0 Receivers Shall ignore
111	1	Sequence Number	Sequence Number	To detect duplicate or out of order packets
112	1	Options	Option Flags	Bit 7 = Preview Data Bit 6 = Stream Terminated
113-114	2	Universe	Universe Number	Identifier for a distinct stream of DMX data

Table 3.2.1.3.2 – sACN Framing Layer Breakdown

Octet	Field Size	Field Name	Field Description	Field Contents
DMP Layer				
115-116	2	Flags and Length	Protocol flags and length	Low 12 bits = PDU Length High 4 bits = 0x7
117	1	Vector	Identifies DMP Set Property Message PDU	0x02
118	1	Address Type and Data Type	Identifies format of address and data	0xA1
119-120	2	First Property Address	Indicated DMX Start Code is ad DMP address 0	0x0000
121-122	2	Address Increment	Indicates each property is 1 octet	0x0001
123-124	2	Property value count	Indicates 1+ the number of slots in the packet	0x0001-0x0201
125-637	1-513	Property values	DMX start code + data	Start Code + Data

Table 3.2.1.3.3 – DMP Layer Breakdown for sACN

Since E1.31 operates within ACN all PDUs in the same manner as previously described for ACN, that is they consist of a Preamble, PDU block and Post amble. For E1.31 the Preamble size is set to 0x0010. If using UDP and Preamble, size not equal to this will be discarded. The Preamble size consists of preamble size field, the post amble size field, and the ACN packet identifier with length of 0x10 octets [50].

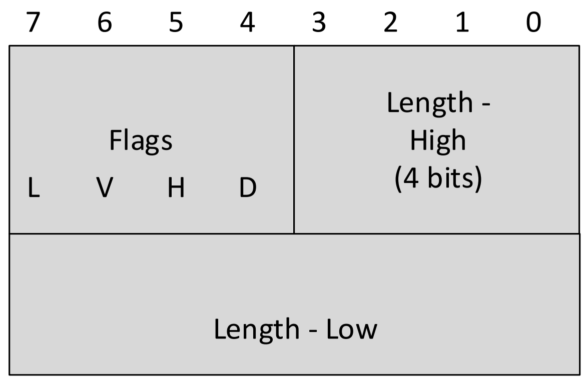


Figure 3.2.1.3.2 – RLP Flags and Length

The Root Layer's Flags are similar to ACN, a 16-bit field with PDU length encoded to the lower 12 bits. PDU length is computed at the 16th octet (big endian) through the last property value in the DMP layer. Rather than using a DMX address IP addresses are associated with devices and streamed over a network. sACN is capable of supporting up to 63999 universes. There are a few reserved universes, those being 0 and 6400 – 65535 [50]. It is a unidirectional protocol, where data is sent from the controller to the receiver. This protocol allows for multi-source prioritization and merging. Sources are assigned a priority bit 0 being the least important to 200 is the most important. When ties occur, a merging algorithm is used.

3.2.1.4 – Digital Addressable Lighting Interface (DALI)

Defined by the IEC 60929 standard, and updated in IEC 62386 to include LED devices. DALI is a half-duplex digital communication protocol, consisting of forward and backward frames (response after reception of query or a memory command from the forward frame). Forward frames have one start bit, one address byte, one data byte, and two stop bits. The backward frame has one start bit, one data byte and two stop bits. It makes use of Manchester encoding which done by the CPU, and requires an interface voltage range between 11.5 V to 22.5 V [51].

DALI defines the variable Actual Level as one byte in RAM for the current output level of the control gear. It also represents the logarithmic relationship between the different levels from 1 to 254, 0.1% to 100% illumination respectively. Figure – 3.2.1.4.1 shows graphically this aspect of the standard. Each successive level has a constant difference of 2.8%, with an update rate of 1.6 kHz. There are 15 different fade times and rates that control how long it takes to change to the target power level. The shortest fade time is 25 milli-seconds, with the fastest fade rate of 358 steps/second.

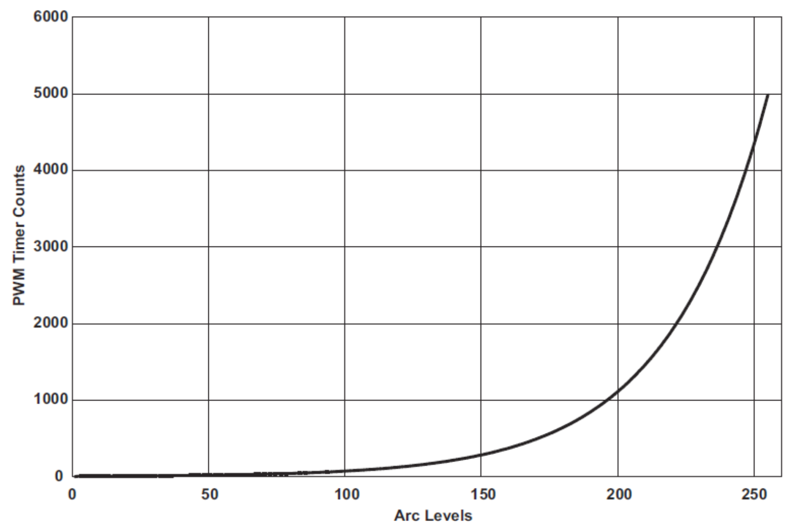


Figure 3.2.1.4.1 – Logarithmic Nature of Increasing Intensity

DALI has a number of software functions when programming it for a system. The initialization function has four tasks: configure the GPIO to support DALI, maintain variables in flash memory, initialize the RAM variables from the values stored in flash, and configure the timer. Transaction Loop, initiates monitoring for the DALI bus, does not return to the main application. The Update Callback is used by the main application to determine if a DALI command has requested in a change in arc power level or the fade routine has requested a change. Flash Update copies the required variables from RAM into the flash memory. It is a one-time operation, Table 3.2.1.4.1 shows the offset values for this operation [51].

Name	Offset
Power On Level	0
System Failure Level	1
Minimum Level	2
Maximum Level	3
Fade Rate	4
Fade Time	5
Short Address	6
Group 0 - 7	7
Group 8 - 15	8
Scene 0 - 15	9 - 24
Random Address	25 -27
Fast Fade Time	28
Failure Status	29
Operating Mode	30
Dimming Curve	31

Table 3.2.1.4.2 – Flash Variables and Offset

3.2.2 – Application Coding

The stones in the project will be completely self-contained in order to be more environmentally sealed. This is so the elements, specifically moisture, will stay out of the casing. As a result of this there will be no wired communication. So wireless communication is needed in order to give commands. For our wireless device we decided to use something everyone always has on their person, the smart phone. In order to use the smart phone an application will be needed. There are many options when it comes to making an application. The two options that were considered are jQuery Mobile using PhoneGap and Android Software Development Kit also known as the Android SDK. Research was done in order to compare using the jQuery framework with PhoneGap or developing from the Android SDK.

3.2.2.1 – jQuery Mobile Using PhoneGap

So what is jQuery mobile exactly? According to the jQuery mobile website "jQuery Mobile is a HTML5-based user interface system designed to make responsive web sites and apps that are accessible on all smartphone, tablet and desktop devices." [52] In other words jQuery Mobile, which from here on out will be referred to as simply jQuery, is a system used to develop the user interface for the mobile web. This interface can then be combined with the PhoneGap service to make native offline applications. As shown below in Figure 3.2.2.1 is an example of what a jQuery app can look like.

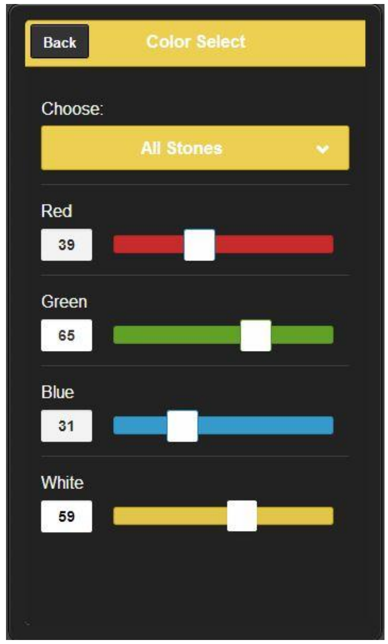


Figure 3.2.2.1 – Example of jQuery Application

This UI framework is the mobile version of the very popular jQuery. As you can see from Table 2.2.2.1 the amount of popular websites that use the jQuery framework is astounding. This means there is a large knowledge base and library of features using the jQuery framework. Also this means there are lots of people who are experts in using this system which is a large factor in determining which application creation method we are going to use. That is because none of the team has experience in the creation of applications. Table 3.2.2.1 shows the popularity of jQuery mobile and how it will be of great use to the project.

Coverage Totals of jQuery 2014

Category	Percentage
Top 10,000 Sites	69.6%
Top 100,000 Sites	61.9%
Top 1,000,000 Sites	54.6%
Most of the Internet	30.7%

Table 3.2.2.1 – jQuery Coverage

Another huge advantage of using jQuery is that it can run on any mobile platform. With one set of code the application would be able to run on Android, iOS, Windows Phone, Blackberry OS, Symbian, webOS, Bada, Meego, Kindle, etc [53]. It can be run on any age and any size mobile device that is web capable. This is an obvious huge advantage for the project for several reasons. One factor being that this will make the project very accessible to the end user, as the application will be able to work on any smart phone they have whether it is Android, iOS, or anything else. Also, this is an advantage when it comes to developing the software. If we wanted to get that same kind of user accessibility but with the native SDK’s it would mean writing separate applications for each environment. This would take exponentially more time than using jQuery which is already limited for this project.

The jQuery mobile framework uses HTML-5, CSS3, and JavaScript to create the mobile web app. The main uses of HTML-5 is creating the menus and buttons for the user interface. This works by a page system, where each page is a separate HTML-5 file that the user can then program in headings, footers, text, menus, links, etc. This is beneficial since HTML-5 is fairly straight forward and simple to use. That means the inexperience our team has when it comes to creating apps will be mitigated by the shallow learning curve of HTML. The CSS3 code is primarily used for “animations, gradients, effects, and UI rendering” [53]. JavaScript is what the whole jQuery mobile framework is built upon. This is beneficial since this is a programming language that the team has experience with.

Theming the app with jQuery Themeroller is made very simple. Developing the theme for the app is important so it is presentable and user friendly. Using the Themeroller program is very intuitive and straightforward. This is again very useful for the project since time is a factor is creating this application. Once the theme is created the file is simply downloaded from Themeroller and inserted into the jQuery code. This makes it very simple to edit a theme on the fly and test in in the working code. An example of using Themeroller is shown below in Figure 3.2.2.2.

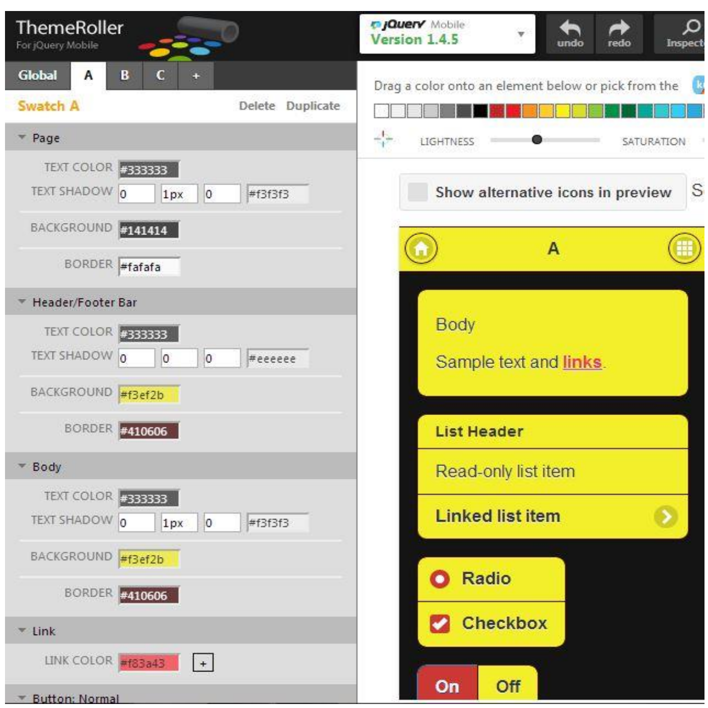


Figure 3.2.2.2 – Themeroller Example

Once the web-app is built using the jQuery foundation it still does not function like a typical application. It will function more like a website. In order to get the jQuery app exported to be installed like a native application a service called PhoneGap will need to be used. This service takes the JavaScript, CSS, and HTML-5 files that were used to build the application and then converts them to be displayed on mobile devices like a normal native app. It will produce an IPA file for iOS, an APK file for Android, or an XAP file for Windows phone [54]. These files can then be used to put the application in any of the popular app stores such as the iTunes store or Google Play. This greatly increases the usability of the P.R.E.S.S. app by packaging it in a way that the user will be familiar and comfortable with.

In summary jQuery is a very user friendly and lightweight framework for making a smart phone application. With the addition of the PhoneGap service an app that functions similar to a native app can be created with fairly simple programming in HTML-5. The ease of use, extensive knowledge base/library, and ability to be packaged for use on any mobile device is the reason jQuery is being considered as the way to program our application.

3.2.2.2 – Android Software Development Kit

The second method that is under consideration for developing the application for the project is the Android Software Development Kit, also known as Android SDK. The Android SDK is a robust set of tools used to create from the ground up an Android application for mobile devices. Once the SDK is downloaded it can be used in any IDE the programmer wishes, though the program Eclipse is recommended by the developer. Benefits of using the Android SDK include access to behind the scenes aspects of the Android operating system, packages for more advanced effects such as Physics, 3D rendering, and 3D models [55]. An example of developing with the Android SDK using the included Android emulator is down below in Figure 3.2.2.2.1.

Figure 3.2.2.2.1 – Software Development in Android

One advantage for using the Android SDK is the access to the hardware of the phone in an easier more straight forward way than any other application development software. This allows the programmer to access features such as the accelerometer, camera, and the interface that is specific to Android. This interface can be imitated by other development software but never truly duplicated. This give Android SDK native apps a specific look and feel that people are used to and expect. Features such as location information gathered from the phones GPS system, being able to add notifications to the notification bar, being able to set alarms, and being able to run various background processes are all things that the Android SDK has available to it [56].

Another benefit of using the Android SDK is that the development of the application is done eclipse using JavaScript as opposed to HTML-5. This is a benefit because the group has more experience coding in JavaScript which can cut down on development time. Also included in the Android SDK is a visual layout editor. This is useful as you can see in real time the layout of the application you are creating in real time. This way you can immediately see if the result is what you desired or if it needs to be edited in some way in the hard code. Another useful component of the Android SDK is the Android emulator. This allows you to immediately test your application in the actual android system that the user will be using. By using this emulator you can detect bugs and undesirable looks and/or functions that were not immediately apparent in the code.

3.2.2.3 – Android SDK vs jQuery Using PhoneGap

After the research done about each respective application development method, a decision must be made on which will be the way that the application for the project will be created. Taking into account the pros and cons of each solution the decision has been made to move forward using jQuery as the framework to develop the application. This takes into account several considerations.

First, the ability of jQuery apps to be used on any mobile platform with one set of code is extremely important. This will allow not only many options for the end user, but will allow ease of testing no matter the smart phone that is currently available. Also this will save time in the development process. Because only one set of code needs to be created for the multiple platforms. Each other platform would have different coding methods; Objective-C for iOS and JavaScript for Android for example. This would add even more development time to the project. In order to avoid this extra time there are two options: either restrict the platform the user can use the application on or use the jQuery framework. This is a main reason the jQuery framework was chosen.

Second, jQuery has much less of a learning curve than the Android SDK. Though the group has experience with JavaScript more so than HTML-5, the HTML-5 syntax is very simple and should prove simple to master. Also because jQuery is used so extensively throughout the internet as well as the mobile web, there are lots of resources for help when developing the application. This also applies to the PhoneGap service. This has a very good support system as it is the main way jQuery Mobile code is transformed into native applications. Since this is the method we are using to distribute the application the extra support is a positive.

Finally, as was mentioned in the Android section that the application can be live previewed as the coding done. There are web applications can do this same feat with the jQuery framework. This is a huge positive considering the other pros listed above. Combined with the Themeroller service provided by the jQuery team, making an attractive and functional layout for the application is both simple and easy to troubleshoot. For these reasons the jQuery Mobile framework is the method we are just to create our application.

3.2.3 – Software Communication

Since the stones for the project will be completely contained in their case, a way to wirelessly communicate between them is needed. A mobile phone application will be the device used to communicate to the stones in order to give the eight stones of the P.R.E.S.S system commands. These commands will include color settings, manually powering the stones on/off, etc. There are two methods considered for communication between the stones. One being a Wi-Fi network and one being Bluetooth. In this section research is discussed in implementing each system using the jQuery Mobile framework in an attempt to determine the more effective solution.

3.2.3.1 – Bluetooth Connectivity with jQuery Framework

Bluetooth is one method considered for communications between the smart phone application and the stones. Though the bulk of the application interface is written in jQuery using HTML-5, the actual method for communicating with Bluetooth is introduced when the HTML-5, CSS3, and JavaScript files are imported to the PhoneGap service. PhoneGap is the service that will take the three files written using the jQuery Framework and will package them in order to run them as a native application on the mobile device. This is also the point of the applications development that the Bluetooth functionality will be added to the program.

This plugin is introduced into the configuration file of the jQuery Framework produced pages. This addition will allow communication using the Bluetooth signal [57]. It is compatible with both Android and iOS. Though it states that “it was written for communicating between Android or iOS and an Arduino” [57] I believe with edits to the code it will be able to connect to our TI MCU, which is most likely going to be an MSP430. This particular plugin cannot be used to connect mobile device to mobile device, be it Android or iOS. Which is fine for the project being designed as the application will only need to communicate between the mobile device and the Bluetooth transceiver inside the stones. Also the mobile device must the one to start the communication via Bluetooth. Again this is fine for our uses, because the user will determine when communication to the stone is needed. Therefore the mobile device will always begin transmission to the stones initially.

This Bluetooth plugin features several functions that will be of great use to the project. There is of course a bluetoothSerial.connect function that connects to the desired Bluetooth device using either the macAddress of the stone in the case of an Android mobile device or the UUID of the stone in the case of an iOS mobile device. This is of obvious use for the project as an initial connection must be made in order to being communication. Inversely there is also a bluetoothSerial.disconnect to disconnect the two systems. This will most likely be done when the application is closed and no more commands are needed to be sent to the stones.

Other functions include: write, available, read, readUtil, subscribe, unsubscribe, clear, list, isEnable, isConnected, readRSSI. These will be very useful to the project as well. The write function in particular has several methods of writing over a Bluetooth signal. Data can be written using an array buffer, integer array, and unit8 array. When using this write function the data must be in the form of a string. It is then converted into with an array buffer. The string conversation assumes 8 bit characters when doing the conversion. There are three parameters in this write function, the data, success, and failure parameters. The success and failure options are optional and are not required when called the write function.

A benefit of using this plugin is that it will work with both iOS and Android environments. This was a pivotal reason when picking the jQuery mobile framework for our coding structure. In regards to the Android software it was developed on Android software version 4.4, using Cordova. Cordova is a slightly different version of Phonegap. They each have similar capabilities when it comes to packing the HTML, CSS, and JavaScript components of the jQuery mobile framework. They can almost be used interchangeably.

Though the system was developed on the Android 4.4 software version it should work on newer Android software versions as well as newer versions of the Phonegap. This plugin is limited however when it comes to Apple's iOS. According to the documentation the plugin "currently iOS only works with ReadBear Labs Hardware and Adafruit Bluefruit LE" [57]. This limits the hardware choices for the project, which could an issue in the later stages of the development and construction of the P.R.E.S.S system. However the development will be primarily done on an Android device, so it should not present a large problem to the project's development.

This plugin also supports Bluetooth LE, where the LE stands for Low Energy. Bluetooth LE using considerably less energy than classic Bluetooth technology. Considering the obvious power concerns for the project given that each stone will be powered solely by solar power, this is a huge benefit for using this plugin. Considering this is a technology that can be used in any Bluetooth plugin, this is a huge reason to use Bluetooth over Wi-Fi. As Wi-Fi uses much more energy than Bluetooth, and as stated before power is a large concern when considering systems for the project.

3.2.3.2 – Wi-Fi Connectivity with jQuery Framework

The second option considered for communication between the application and the stones was to communicate over a Wi-Fi network. This network would be hosted internal to the stones via C3200 chips made by Texas Instruments or by using a chip with similar features. The initial benefits of using Wi-Fi that were considered was it was initially thought that Wi-Fi would have a lower power cost in comparison to Bluetooth. Also it was considered that the range of Wi-Fi is much more than that of Bluetooth.

Another considered benefit to using Wi-Fi over Bluetooth is that using Wi-Fi all of the stones can be connected on the same network that would be generated by the Wi-Fi chip inside of a main stone. This way transferring data between the stones would be more straightforward considering they will all already be connected to the same network. The data that would be transferred from the phone jQuery Mobile application would then need to be directed to the correct MAC address of the stone desired. That way the information will be sent directly to the stone whose status will need to be change. That status either being an on/off setting, color setting, or luminosity setting.

Using the JavaScript portion of the application code you can create a connection check to check if the application has access to a wireless network. This would be very useful when checking if communication can be transmitted. This is done using the connectionStatus function. This returns with ‘offline’ or ‘online’. The function by default checks cellular 2G, 3G, 4G, Wi-Fi and Ethernet connections. However this can be edited to only check for Wi-Fi connection. This would be very useful in trouble shooting the system.

3.2.3.3 – Wi-Fi vs. Bluetooth Software Decision

Based on the research conducted in previous sections a decision will need to be made on which communication scheme to use based on software. Factors considered include: Reference designs, connectivity, power usage, and communication distance. These considerations are broken down in Table 3.2.3.3.1.

	Bluetooth	Wi-Fi
Reference Designs	Designing a software scheme using Bluetooth technology will be easier given plugins that are well documented and already in use.	Hard to find protocols and solutions for transmitting data over Wi-Fi. Will be generally more difficult to implement and test communication.
Connectivity	Using functions from various plug-ins connectivity can be determined quickly and check periodically. Once connected, very stable.	Can use JavaScript to determine if the application is currently connected to the Wi-Fi network.
Power Consumption	Using Bluetooth LE technology can use very little power. Does not require a software change to use.	Much greater power usage than Bluetooth.
Communication Distance	Shorter Range	Longer Range

Table 3.2.3.3.1 – Wi-Fi vs. Bluetooth Software Decision

Considering these facts listed in Table 2.2.1.3, the decision made for software design is that the project should use Bluetooth communication. This is because of the robust plugins that exist that are proven to work. Also this is because of the Bluetooth LE technology that uses significantly less power than Wi-Fi. Since our project will be running off solar panels and power usage will be a big concern. Finally the communication range is not of a concern as the typical use for the project the user will be well within the range of Bluetooth. Therefore based on software considerations Bluetooth should be used for the projects communication scheme.

3.2.3.4 – Classic Bluetooth vs. Bluetooth LE

Though it has been determined that Bluetooth should be used for the project the next logical question is, what type of Bluetooth technology should be used. Two main forms of Bluetooth to be considered is Classic Bluetooth and Bluetooth low energy (LE). Bluetooth Low Energy is a much newer than Classic Bluetooth, given that it was introduced in 2011 [58]. Though the names are only slightly different the technology and the uses that they are best for are quite different. These must be considered in order to determine what is best for the P.R.E.S.S system. An overview of the differences can be seen in Table 3.2.3.4.1.

	Classic Bluetooth Technology	Bluetooth Low Energy Technology
Data payload throughput (net)	2 Mbps	~100 kbps
Robustness	Strong	Strong
Local System Density	Strong	Strong
Large Scale Network	Weak	Good
Low Latency	Strong	Strong
Connection Set-Up Speed	Weak	Strong
Power Consumption	Good	Very Strong
Cost	Good	Strong
Range	Up to 1000m	Up to 250m

Table 3.2.3.4.1 – Classic Bluetooth vs. Bluetooth Low Energy

As can be assumed given the name Bluetooth Low Energy that this new Bluetooth technology has a much improved power consumption rating than Classic Bluetooth. The way the power consumption is kept to a minimum is that the technology is in sleep mode most of the time. It is only woken up when a connection is initiated. Given that connections are “only a few milliseconds” [58] this is what gives the device its extreme low power capabilities. It has the ability to be powered “with a tiny coin cell battery for 5-10 years” [58], this is an amazing feat. Given power is an extreme concern for this project given that it will be powered via solar panels this is a hugely beneficial capability.

It can be seen from Table 3.2.3.4.1 that the range of Classic Bluetooth is much higher than Bluetooth Low Energy. The lack of range is one of the major issues when it comes to using Bluetooth Low Energy over Classic Bluetooth. This is not considered a problem in terms of its use for the project. Primarily because the user is intended to be fairly close when setting stone preferences via the mobile application. It is not believed giving the user an extra 750 meters will significantly add any usability or convenience to the project compared to the power savings that will be inherited by using this technology. A sacrifice of range is okay to bear given the power benefits of the Bluetooth Low Energy system.

Another trade off when it comes to using Bluetooth Low Energy is amount of data that can be transmitted. Classic Bluetooth has faster data transmission speeds by several orders of magnitude. This makes Classic Bluetooth ideal for live streaming data and complex data that needs to be updated very quickly. However the P.R.E.S.S system will not feature anything like this. This data that would need to be transmitted between the mobile application and the stones will be fairly simple and compact. The data transmission of Classic Bluetooth would most likely be overkill considering the needs of the project.

Another benefit of using Bluetooth Low Energy is that the connection speed is much greater when compared to Classic Bluetooth. This is important because it means the mobile application will be able to connect to the stones very quickly, giving the ability of the system to be very responsive and fast when it comes to taking in new parameters from the user. Furthermore because the transmission speed of Bluetooth Low Energy is enough for the project, this combined with the increased speed of connection will greatly increase the overall speed of the communication. Compared to the speed that would be see by Classic Bluetooth which would seem slower than Bluetooth Low Energy even though the transmission speeds are must faster.

In conclusion the obvious choice for the Bluetooth technology that should be used in the project is Bluetooth Low Energy. The fact that the power consumption is so much lower is almost reason enough to select this method. This fact combined with the cheaper cost and faster connection speed makes this a clear winner. Though there are limitations when it comes to range and transmission speed these negatives are well worth the added benefits when it comes to using this Bluetooth Low Energy technology. This technology will greatly and positively impact the project by giving fast and responsive communication between the user via the mobile application and the stones themselves.

4 – Design

4.1 – Hardware Design

4.1.1 – Power Design

4.1.1.1 – Solar Design

For the solar power portion of the project much time needed to be spent searching for the best solar panel. There are many different types of panels available on today's markets so the first decision that needed to be made was the type of solar panel that would be most cost effective and efficient for each individual stone in P.R.E.S.S. Since P.R.E.S.S. will be composed of a total of six stones each needing to contain a solar panel, charge controller, and battery there needed something that was affordable and small enough to fit inside the stones small structure.

The first decision was between mono-crystalline silicon panels and poly-crystalline panels. Both of these types of photovoltaic panels are most commonly used in solar charging and the easiest to find on the market. Thin film solar technology has not developed enough and is too expensive for it to be considered for the project. Mono-crystalline silicon photovoltaic panels are slightly more efficient then poly-crystalline panels due to the more pure chemical make-up inside the cells. This is in turn makes mono-crystalline silicon panels a bit more expensive than poly-crystalline panels, but the fact that they are more efficient made them the right choice for the project. The small savings in cost of the poly-crystalline initial panel cost does not reflect the savings in energy cost over the lifetime of the photovoltaic panel.

The next decision that needed to be made was how much power all of the components of the project would consume. The size of the panel was a big contributing factor since it needed to be small enough to fit inside the stone while leaving room for the PCB boards containing the LED arrays to show through the top of the structure. The desired solar panels were found at sparkfun.com. It was narrowed down to two options, one was to stack three small mono-crystalline panels to get an open voltage of 13.5 V, 300 mA short circuit current, and about 1.5 Watts of power. This would cost $47.85 per stone making the total solar cost $287.10. The three solar panels stacked would be 11.1 X 7.2 inches area which still leaves enough room for the surrounding LEDs. The other option was to use one large mono-crystalline photovoltaic panel to get an open circuit voltage of 8 V, 310 mA short circuit current, and 2.5 Watts of power. This single panel costs $34.95 per panel and size would be needed to fill each stone costing a total of $209.70. The size of this larger photovoltaic panel is 7 X 4.5 inches making it the most ideal design choice for this project. Below is Table 4.1.1.1.1 comparing the two specifications of the mono-crystalline solar panels.

SparkFun Specifications	3 Small Solar Cells Stacked Part- 07845	1 Large Solar Cell Part- 07840
Open Circuit Voltage	13.5 V	8 Volts
Short Circuit Current	$300*10^{-3}$ Amps	$310*10^{-3}$ Amps
Power Supplied	1.5 Watts	2.5 Watts
Dimensions	11.1 X 7.2 Inches	7 X 4.5 Inches
Weight	30 Grams	100 Grams
Efficiency	15-15.2 %	15-15.2 %
Cost for 6 Stones	$287.10	$209.70

Table 4.1.1.1.1 - Comparison of SparkFun Solar Panels

After taking into consideration size restraints, power consumption, cost, and weight of the 2 solar panel choices a choice was made. P.R.E.S.S. will use a 07840 Large Solar Cell mono-crystalline solar panel from sparkfun.com. It was decided that using one larger cell is more cost efficient and the size is smaller than the three small solar cells stacked together.

4.1.1.2 – Battery Design

After choosing the solar panel, the battery needed to be chosen to accurately meet all the needs P.R.E.S.S. Energy storage must be optimized to ensure the most effective results for the project. When choosing the type of battery some key things needed to be considered. One of the main concerns was the battery needs to be rechargeable and compatible for solar charging. The choice was then between a deep cycle lead acid battery and a rechargeable lithium-ion battery. Lead acid batteries are predominately quite large but are most common in solar charging systems. Lithium-ion batteries tend to be more expensive but are compact and light weight batteries. Lead acid batteries were the first choice for P.R.E.S.S. but due to size constraints other options needed to be considered. Below is Table 4.1.1.2.1 comparing the advantages and disadvantages of deep-cycle lead acid batteries and lithium ion batteries.

Specifications of Batteries	Deep-Cycle Lead Acid Batteries	Lithium-ion Batteries
Depth of discharge	75%	80%
Cost	Low	High
Lifespan in cycles	1000	3000
Efficiency	72-78%	100%
Self-discharge	Average	Negligible
Energy Density	30-50 (Wh/kg)	100-200 (Wh/kg)
Charge Time	12-16	1-4
Dimensions	Large	Small

Table 4.1.1.2.1 - Deep-Cycle Lead Acid and Lithium-ion Batteries Comparison

The decision is to go with lithium-ion batteries. Lithium-ion batteries have a longer lifespan which is an advantage for P.R.E.S.S. It is ideal for the battery to last as long as possible so the user does not need to replace batteries frequently. Lithium-ion batteries are also compact in size and have a high energy density.

While searching in various places and online for the best lithium-ion battery for P.R.E.S.S. we got it narrowed down to SparkFun Polymer Lithium-Ion battery. After taking into consideration the amount of energy storage that P.R.E.S.S. needed from the mono-crystalline solar panel chosen in the above design section, a 6 amp hour triple polymer lithium-ion battery was chosen. The batteries are three single polymer lithium-ion batteries attached in parallel to increase the amount of storage. Each cell has a nominal voltage of 3.7 V and while connected in parallel creating a total of about 12 V. Since they are connected in parallel the three batteries fully charge and discharge in parallel. This battery has excellent long term self-discharging rates less than 8%. It can also function under extreme weather conditions ranging from -13 degrees F to 140 degrees F. This is a great advantage since P.R.E.S.S. will be consistently out in the sun charging from energy produced from the sun making the inside of the structure very warm. In the Table 4.1.1.2.2 describes the specifications of this lithium-ion battery.

Specifications	SparkFun Polymer Lithium-Ion Battery Part- 08484
Nominal Capacity	6 Ah
Nominal Voltage	3.7 V
Charge Voltage	4.2 V
Charge Current	1 A Standard Charging 2 A Rapid Charging
Maximum Charge Current	6 A for continuous charging mode 6 A for continuous discharging mode
Dimensions	54 X 60 mm
Weight	110 grams
Price for 6 Stones	$179.70

Table 4.1.1.2.2 - SparkFun Polymer Lithium-ion Battery Specifications

4.1.1.3 – Charge Controller Design

For the charge controller section of the power design portion some specifications needed to be met. The mono-crystalline panel that was chosen gives out 2.5 Watts of power and 9 V. Taking this into consideration a charge controller that could support that much watts and power was important. There are many different types of charge controllers ranging from pulse width modulation controllers to maximum power point tracking controllers. Each type of charge controller has advantages and disadvantages so it is important to choose one that will benefit this project and being the most efficient for P.R.E.S.S.

After much research it was concluded that a Maximum Power Point Tracking charge controller would be the best fit for the project. The most inexpensive vendor found that was compatible with lithium-ion batteries and with a 2.5 Watt 9 Volt solar panel was the SparkFun Sunny Buddy – Maximum Power Point tracking solar charger. The SparkFun Sunny Buddy is a solar charger specially made to charge single cell lithium-ion batteries. The point of this maximum power point tracking solar charger is regulate the amount of voltage and current that gets delivered to the lithium-ion battery from the mono-crystalline photovoltaic solar panel. The Sunny Buddy should be connected in parallel with the battery to charge correctly. The default values for the Sunny Buddy maximum power point tracking solar charger is set at a maximum of 450 mA with a maximum 20 V input voltage and a minimum 6 V input voltage.

This charge controller comes with equipped with a built in LT3652 power tracking 2 A battery charging circuit which is a great advantage to this charge controller.

The LT3652 acts as a step down battery charger that operates between 4.95 V and 32 V input voltage range. The charger employs a 3.3 V float voltage feedback reference so any desired battery float voltage up to 14.4 V can be programmed into the LT3652 using a resistor divider. LT3652 employs an input voltage regulation loop which takes action to reduce charge current if the input voltage falls below the desired program level. This component on the SparkFun MPPT charge controller tracks the maximum power up to 98% as shown in Figure 4.1.1.3.1.

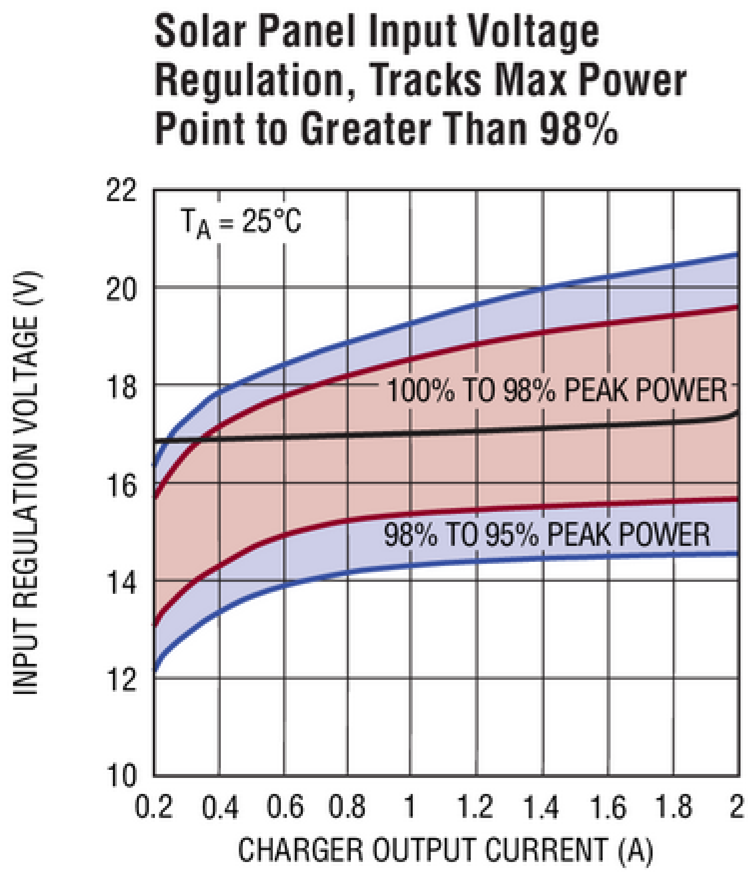


Figure 4.1.1.3.1 - Showing the MMPT accuracy Linear Technology Permission Requested from Sparkfun.com

This charge controller is optimal for P.R.E.S.S. since it is compatible with both the mono-crystalline solar photovoltaic panel and the 6 A polymer lithium ion battery. The entire power system for press with absorb the energy from the sun, the voltage and currents will run through the charge controller, and then be modified to accurately charge the battery without over charging.

4.1.1.4 - Actual Power Management Design

P.R.E.S.S. utilizes solar energy to power the MSP430, Bluetooth module, force sensitive resistor, and LEDs inside the stone. Each of the stones power systems are comprised of a solar panel, a battery, a charge controller circuit, and a voltage regulation circuit.

The components for the power system needed to be small, efficient, and cost effective. There are many options for types of solar panels on the market today including Mono-crystalline panels, poly-crystalline panels, and thin film technology. Mono-crystalline silicon photovoltaic panels are slightly more efficient then poly-crystalline panels due to the more pure chemical make-up inside the cells. Thin film solar technology has not developed enough and was too expensive to be considered for this project. Each stone in P.R.E.S.S. contains an 8 volt Mono-crystalline panel with dimensions measuring 7 X 4.5 inches and an efficiency rating of 15%. The power supplied from this panel is 2.5 watts which meets the power needs for each stone in P.R.E.S.S.

The battery portion of the power system needed to have a great amount of energy storage in a compact size. Once the battery is hooked into the power system it is ideal for the user to not have to replace, or make adjustments considering they will be sealed inside each P.R.E.S.S. stone. Polymer Lithium-ion batteries were chosen to meet these requirements. Polymer Lithium-ion batteries have a long lifespan, charge quickly, have high efficiency ratings, are compact in size, and are rechargeable. The specific polymer Lithium-ion battery chosen has a nominal capacity of 6 Ah from three 2 Ah batteries connected in parallel. The batteries in parallel have matching internal impedances and are capable to being fully charged and discharged in parallel. It is also equip with a protection circuit internally to prevent over-charging and over-discharging. The battery has a charge current of 1 Amp, nominal voltage of 3.7 V, and a charging voltage of 4.2 V.

To allow the Mono-crystalline solar panel to charge the Poly-Lithium-ion battery a solar charge controller circuit is needed. This circuit takes the output from the solar panel and regulates the amount of power the battery will receive. The linear technology LT3652 chip was chosen to create the solar charger. This charger uses Maximum Power Point Tracking (MPPT). There are a variety of MPPT algorithms, most commonly for larger panels they have the ability to sweep the entire operating range of the solar panel to find where maximum power is produced. The advantage of a full MPPT algorithm is that it can differentiate a local power peak from a global power maximum peak power. Typically, a full MPPT algorithm is required to find the maximum power operating point. It does so by intermittently sweeping the output range of the solar panel and remembering the operating conditions where maximum power was achieved. When the sweep is complete, the internal circuitry forces the panel to return to its maximum power point. In between these periodic sweeps, the MPPT algorithm will continuously waver the operating point to ensure that it operates at the peak. For a simpler panel configuration like the one used in P.R.E.S.S. a simple circuit can force the panel to operate at a fixed voltage and approximate maximum power operation. A voltage divider is used to measure the panel voltage and if the input voltage falls below the programmed level, the load on the panel is reduced until it can maintain the programmed voltage level.

The LT3652 acts as a complete monolithic step-down battery charger and has an operational input voltage between 5 V and 32 V which corresponds with the panel chosen which is rated at 8 V. The LT3652 is a constant current/voltage output design that has a programmable output current maximized at 2 amps to the battery [2]. LT3652 employs an input voltage regulation loop that extracts the maximum energy available from the solar panel while maintaining a steady output for peak output power. This regulation loop reduces the charge current if the monitored input voltage from the solar panel falls below the battery float voltage from the battery. For P.R.E.S.S. the input regulation loop is being set with a 10 kΩ potentiometer making it easily adjustable if a larger solar panel were to be used.

The VFB pin on the LT3652 senses charger output voltage through a resistor divider to determine the battery float voltage. The resistor divider in P.R.E.S.S. coming off of the VFB pin rates the battery float voltage at 4 V. The variance between the float voltage on this pin and an internal 3.3V voltage reference is integrated by the voltage error amplifier. This amplifier generates an error voltage on its output, which corresponds to the average current sensed across the inductor current sense resistor at the RSENSE pin. The output of this assessment controls the charger's switch pin. This current is adjusted in the charge controller circuit in P.R.E.S.S with a current of is 0.9 amps. Once the battery reaches its maximized charge cycle, the SENSE pin is then reduced to 0.1 µA to minimize battery discharge while the charger remains connected. For this project the battery will be minimally disconnected from the charge controller making the components of the SENSE pin important.

Testing the solar charge controller in various environments led to the successful charging of the Polymer Lithium-ion battery from the mono-crystalline solar panel used in each stone of P.R.E.S.S. With various inputs ranging from 7-10 V outputting from the solar panel into the input of the charge controller to the output to the battery was regulated at 4 V. In the Figure 4.1.1.4.1 below, it shows testing of the solar charge controller.

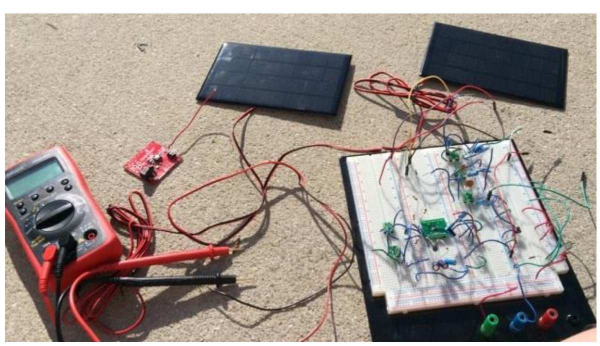


Figure 4.1.1.4.1 - Solar Charger Test.

The output of the battery leads to the voltage regulation system PCB. The battery output goes to the input of the first voltage regulator in the system that will regulate power for the LEDs in each P.R.E.S.S. stone. Ten WS2812 LEDs are lined in series in the stone with a requirement of 5 V and a minimum current of at least 0.6 amps. The TI TPS61252 Step-up Boost converter is used to take in a range of 3.7 V - 4.2 V from the battery and then boost up the voltage to output 5 V to the LEDs. This boost converter has an adjustable input current and output voltage that can be adjusted by adding resistors at the VOUT and ILIM pins. This can be accomplished using the equations 1 and 2 below.

$$Vout = VFB * \left(1 + \frac{R1}{R2}\right)$$

Equation 1

With a 5 volt output required the values for R1 = 768 kΩ and R2 = 243 kΩ using the equation above.

$$Rlim = \frac{1.0\ V}{Ilim} * 10{,}000$$

Equation 2

With a 0.6 A minimum current requirement Rlim = 6.65 kΩ.

The second voltage regulator on the voltage regulation PCB takes the 5 volt output from the TPS61252 boost converter into the input on the integrated circuit and outputs 3.3 V to power the MSP430, the Bluetooth module, and the force sensitive resistor. The TI TPS71701 low drop-out linear regulator with an adjustable output voltage is used to fulfil the requirements. The voltage divider between VOUT and FB pins determine the output voltage to be 3.3 V. The output current from the TPS71701 is 0.4 A which meets the requirements of the MCU, Bluetooth, and force sensitive resistor.

4.1.2 – Communication Design

To achieve wireless communication the TI CC2500 2.4 GHz RF Transceiver was selected to connect each stone with a remote device as well as each other. Main operating parameters of the CC2500 and the 64-byte transmit/receive FIFOs are controlled using a SPI interface. Table 4.1.2.1 gives the range ratings for the CC2500.

Parameter	Min	Max	Unit	Note
Supply Voltage	-0.3	3.9	V	All supply pins same voltage
Digital Pin Voltage	-0.3	VDD +0.3	V	Max 3.9 V
Voltage for:				
RF_P	-0.3	2	V	
RF_N	-0.3	2	V	
DCOUPL	-0.3	2	V	
Voltage ramp-up rate		120	Kv/µs	
Input RF level		10	dBm	
Storage Temp		150	C	
Solder temp		260	C	
ESD		<500	V	

Table 4.1.2.1 – Minimum and Maximum Ratings for CC2500

Figure 4.1.2.1 shows a schematic layout of how to connect the CC2500 to the MCU. Table 4.1.2.2 shows the pin out connections between both the MCU and the CC2500. The MSP430 chosen for this design comes with four SPI connections to choose from, for the wireless communication USCI_A1 was used USCI_B1 is used for the LED driver controls.

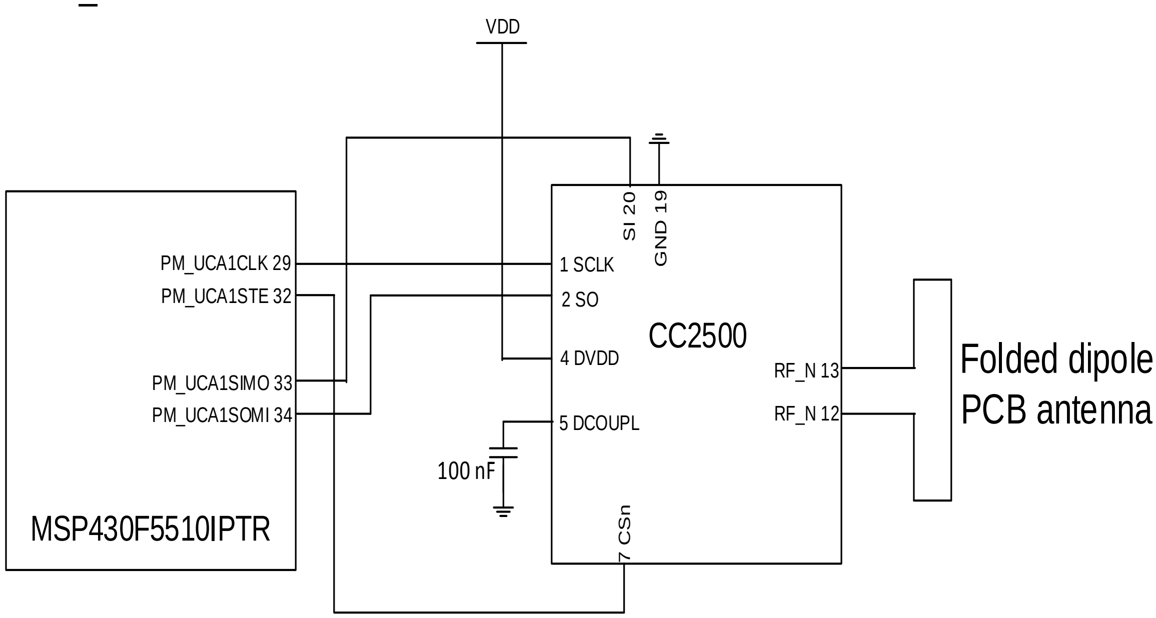


Figure 4.1.2.1 – Wireless Communication Schematic

MCU PIN	MCU PIN NAME	CC2500 PIN	CC2500 PIN NAME
29	P4.0/PM_UCA1CLK	1	SCLK
33	P4.4/PM_UCA1SIMO	20	SI
34	P4.5/PM_UCA1SOMI	2	SO
32	P4.3/PM_UCA1STE	7	CSn

Table 4.1.2.2 – MCU to CC2500 Pin Connection

The antenna for the CC2500 is embedded into the PCB so as to save space within the stone. VDD will come from the power supply within each stone. The DCOUPL pin was suggested to have a capacitor that is then grounded in the CC2500 datasheet. Table 4.1.2.3 shows a description of what each pin on the MCU does in controlling the CC2500.

PIN NAME	FUNCTION
PM_UCA1CLK	Master clock output
PM_UCA1SIMO	Slave input Master Output
PM_UCA1SOMI	Slave output Master Input
PM_UCA1STE	Slave transmit enable, used to each new stone command over adjacent as person walks across

Table 4.1.2.3 – Pin Description from MCU

4.1.2.1 Actual Communication Design

P.R.E.S.S. operates with a MSP430G2553 as its MCU. The decision was made to go with this series of MCU because it meets the low power requirement, it offers both SPI and UART communication, available analog-to-digital conversion, its clock is configurable up to 16 MHz, and the familiarity with the MSP430 family. The MCU will be used to send out lighting commands to the WS2812 LEDs, process Bluetooth instructions, and sense if the stone is stepped on via a force sensitive resistor. The MSP is constantly looking for input either from the ADC input or the UART input, Figure 4.1.2.1.1 shows the general flowchart as to how the MSP430 is programed.

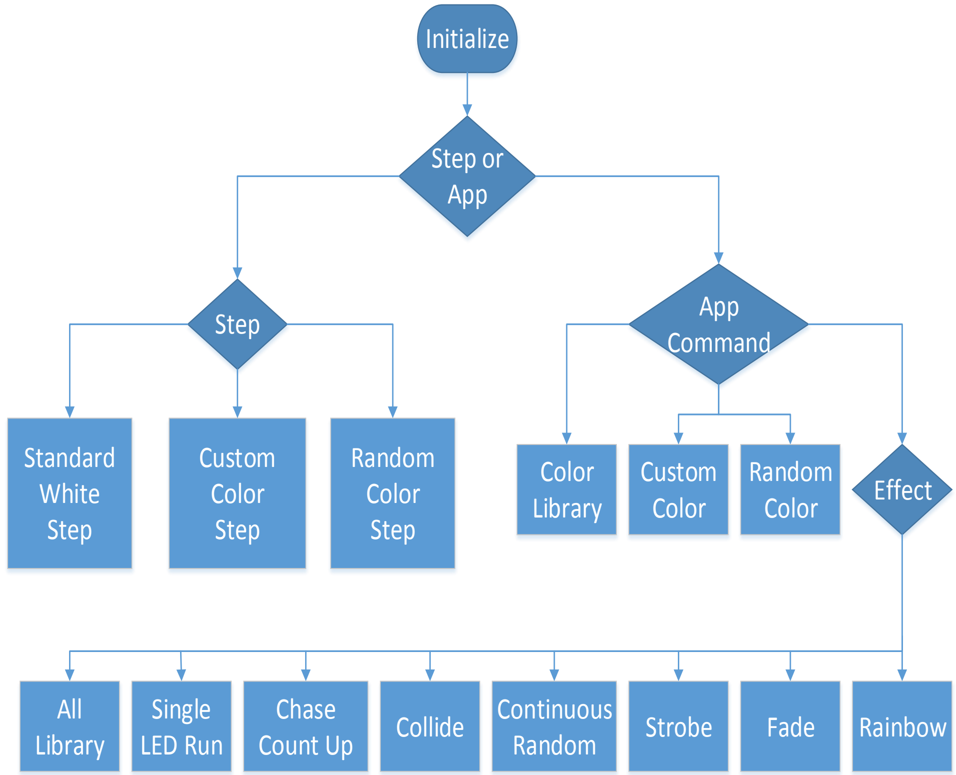


Figure 4.1.2.1.1 – MCU Software Flowchart.

Control of the LEDs is based on the SPI communication functions built in, however traditional SPI configuration is not fully utilized. Typically a clock line is connected between two SPI devices along with a data line, this configuration only requires a data line connection. The LED drivers will recognize a change based on the high and low codes it receives. A high code consists of a long period of 1's sent followed by a short period of 0's, whereas the low code is the inverse. The amount of time it takes to process a high or low code takes approximately 1.25 µs, so it is recommended to have a processor send commands for the LEDs at 800 kHz. Although in testing it was found that control of the LEDs can be achieved at less than this frequency, Figure 4.1.2.1.2 shows control sending 10 LEDs to light in red at 583 kHz.

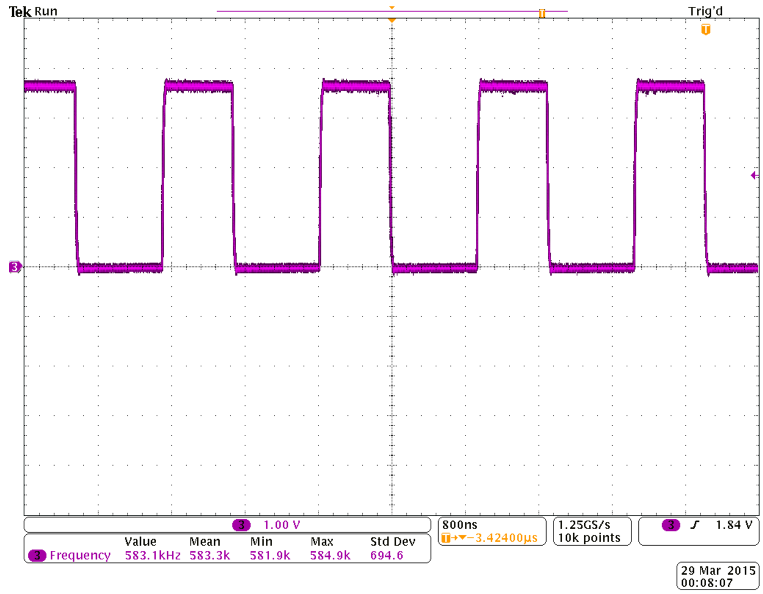


Figure 4.1.2.1.2 – Red LED Output Frequency 583 kHz.

For the application to communicate with the MCU a Bluetooth module that operated using UART was configured to operate at 9600 baud rate, no parity, error detection, and it functions based off an interrupt service routine. Received data is stored into a received variable which is then used to switch through the various features of the stepping stone functioning with a pre-defined color library, user defined colors, and effects. The MCU does not transmit back any information as it operates solely as a slave device. Information sent from the application to the MCU is sent as ASCII codes and used to determine where in a switch statement to go. The custom color feature also uses ASCII codes to determine intensity values for all three RGB colors. The intensity values are based on 1% increments of 256 steps, and go through a comparison based on input received.

The user has the capability to choose a completely random color, based on a random number generator (RNG) that fills in each color. The RNG is generated by using the very low oscillator (VLO) set to the auxiliary clock (ACLK) and the digitally controlled oscillator (DCO), configured with the sub-main clock (SMCLK) set to be the input for the Timer_A of the MCU. Timer_A counts the number of clock pulses from the DCO before the VLO transitions from low-to-high. This number is stored in the Capture/Compare Register and left shifted 16 times to create a 16 bit random number. The project further refines this number to fall between 0x00 and 0xFF for each color. This random color generator was expanded to do a continuous loop of random colors effect; both the continuous random color and custom color can be configured to be the color that lights when a person steps on the stone. Both of these choices are automatically configured to be the step function when activated.

Analog-to-digital conversion is needed to sense if the user standing or applying pressure on the stone. The ADC onboard the MSP is a 10 bit value. The circuit configuration is equivalent to a two resistor voltage divider with R1 being a variable resistor, and R2 being a fixed value. Lights will trigger once the output from this circuit reaches the threshold of 0.2 V. The variable resistor used in this project is a force sensitive resistor (FSR) made of a robust polymer thick film that is normally in a high a resistance greater than 10 MΩ and will decrease in resistance as force is applied. These FSRs have a force range of 0.1-100 N so they are sensitive enough to sense a human footstep. Fig 4.1.2.1.3 and Fig 4.1.2.1.4 show oscilloscope readings of the Vout for the FSR circuit before pressure is applied and after respectively.

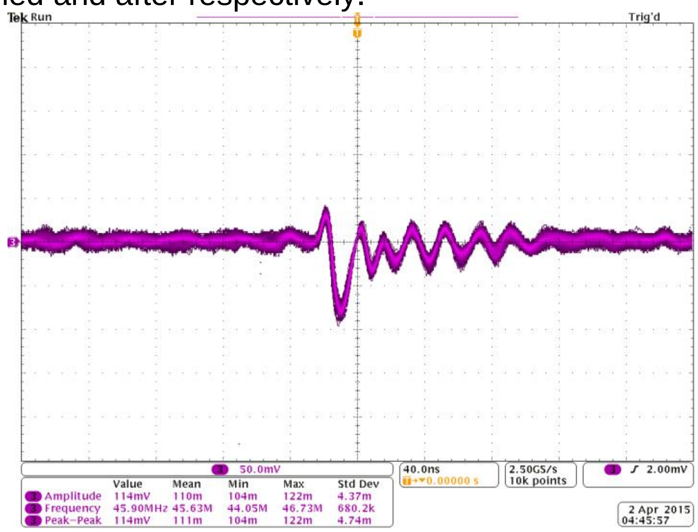


Figure 4.1.2.1.3 – ADC No Step: Peak-to-Peak Voltage 114 mV, Frequency 45.9 MHz.

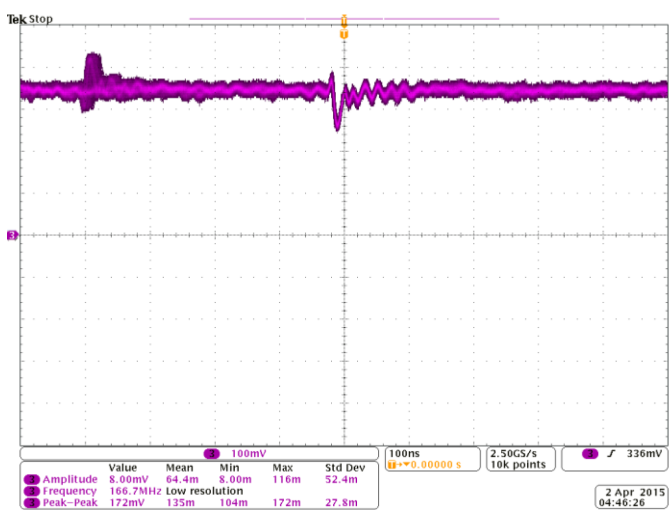


Figure 4.1.2.1.4 – ADC Stepped: Peak-to-Peak Voltage 172 mV, Frequency 166.7 MHz.

4.1.3 – LED Circuit Design

To achieve the desired lighting parameters set forth in the design two LED chips were chosen, one for RGB output another for white light output. The RGB LED is from Osram part number LTRBGFSF-ABCB-QKYOZ, and the white LED is an Osram LWQ38E-Q152-3K6L-1. Table 4.1.3.1 and Table 4.1.3.2 give the specifications of RGB and white LEDs respectively [59].

Parameter	**Red**	**Green**	**Blue**	**Unit**
Wavelength	632	523	465	nm
Dominant Wavelength (If = 20 mA)				
min	619	519	457	nm
typ	625	530	460	nm
max	631	540	470	nm
Viewing Angle	120	120	120	degrees
Luminous Intensity Iv	700	1350	160	mcd
Luminous Flux	2.1991	4.24115	0.50165	lumens
Forward Voltage (If = 20 mA)				
min	2	3	3	V
typ	2	3	3	V
max	2	4	4	V
Forward Current If				
min	-	5	5	mA
max	40	50	50	mA

Table 4.1.3.1 – Osram LTRBFSF RGB LED Parameters

Parameter	**Value**	**Unit**
Color Temperature	8200	K
Viewing Angle	150	degrees
Luminous Intensity Iv		
min	71	mcd
max	280	mcd
Luminous Flux		
min	0.33065	lumens
max	1.30395	lumens
Forward Voltage		
min	2.6	V
typ	2.85	V
max	3.1	V
Forward Current If	15	mA

Table 4.1.3.2 – Osram LWQ38E White LED Specifications

A general schematic of the lighting subsystem is pictured in Figure 4.1.3.1 [60]. The MSP430 controls the TLC 5971 LED drivers by Texas Instruments which in turn controls the intensity for the LEDs. One TLC 5971 controls RGB output while the other controls the white LEDs. The TLC5971 has four output controls for RGB output and can have multiple LEDs wired to each output pin. The MSP430 has a GPIO output and clock output to control the LED driver. The TLC 5971 comes in two packages the PWP package was chosen for this design. Table 4.1.3.1 describes the pin connection between the two LED drivers and the MSP430.

MCU Pin Num	MCU Pin Name	Driver Pin Num	Driver Pin Name
14	P1.0/TA0CLK/ACLK	10	SCLK
15	P1.1/TA0.0	9	SDTI
16	P1.2/TA0.1	9	SDTI

Table 4.1.3.1 – Pin Connection Between MSP430 and TLC 5971

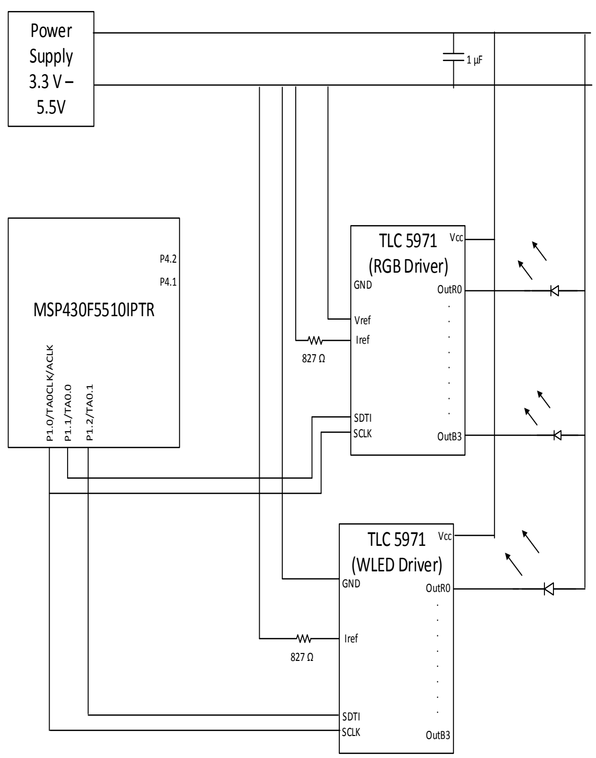


Figure 4.1.3.1 – General Schematic Circuit of LED Subsystem

4.1.3.1 – Actual LED Design

The WS2812B LEDs were actually used in the build of this project. They come on a flex-board pcb with weatherproof casing. These are RGB LEDs with an individual LED driver allowing each LED to have individual control. The LEDs take 24 bits of information 8 bits each for each color, and gives the possibility of 16777216 possible colors. Each stone contains two strips of five LEDs arranged on opposing ends of the stone and angled at a 30 degree incline. Specifications for the WS2812B are shown in Table 4.1.3.1.1

Parameter	Rating
Power Supply Voltage VDD	+3.5 - +5V
Input Voltage	-0.5-0.5 V
Viewing Angle	120 degrees
RGB IC Characteristic	Intensity + Voltage
Red	390-420 mcd 2-2.2 V
Green	660-720 mcd 3-3.4 V
Blue	180-200 mcd 3-3.4 V

Table 4.1.3.1.1 – Specifications for WS2812B LEDs

The LEDs are connected to Pin P1.7 SPI SOMI with a 100 Ω resistor, and biased with +5 V. Figure 4.1.3.1.1 shows the schematic part of the WS2812B used.

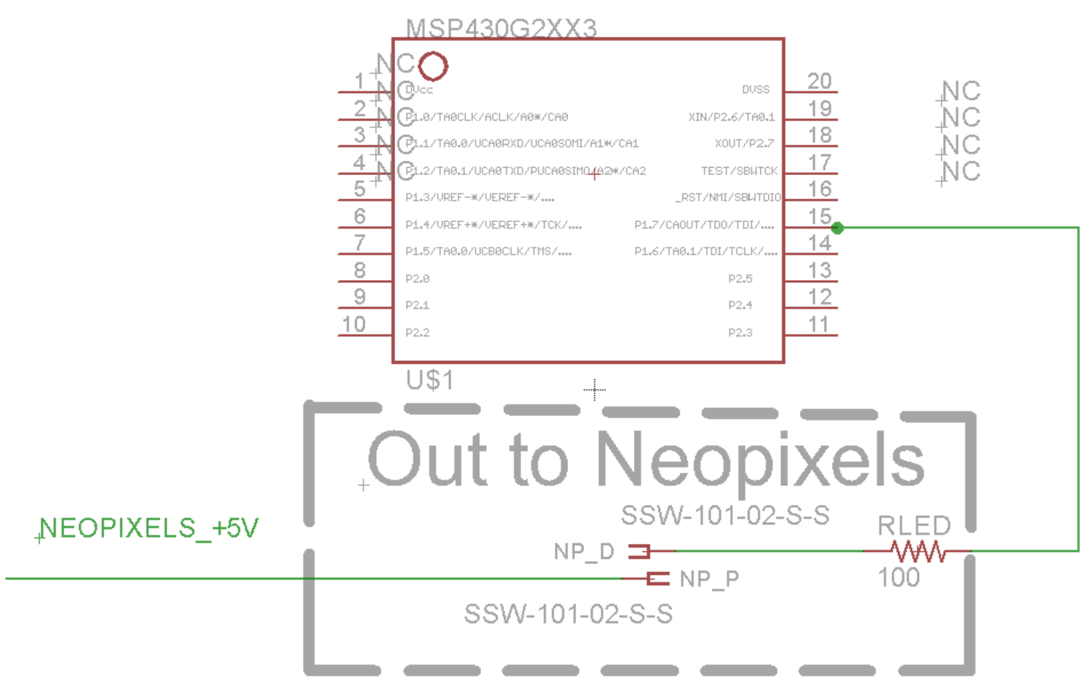


Figure 4.1.3.1.1 – Schematic of LEDs

4.1.4 – Sensor Design

The Freescale MMA2241KEG accelerometer was chosen to act as a switch to sense footsteps to turn stones on. It is a 16 pin and comes in a SOIC package. The design of this subsystem is to act as a switch that when the accelerometer senses a force sends a signal to the MCU which in turns sends a command to the LED driver to turn white lights on. If the accelerometer is activated after a certain time, the MCU also sends out an alert to a connected phone telling the homeowner there is someone outside. The subsystem schematic can is shown in Figure 4.1.4.1

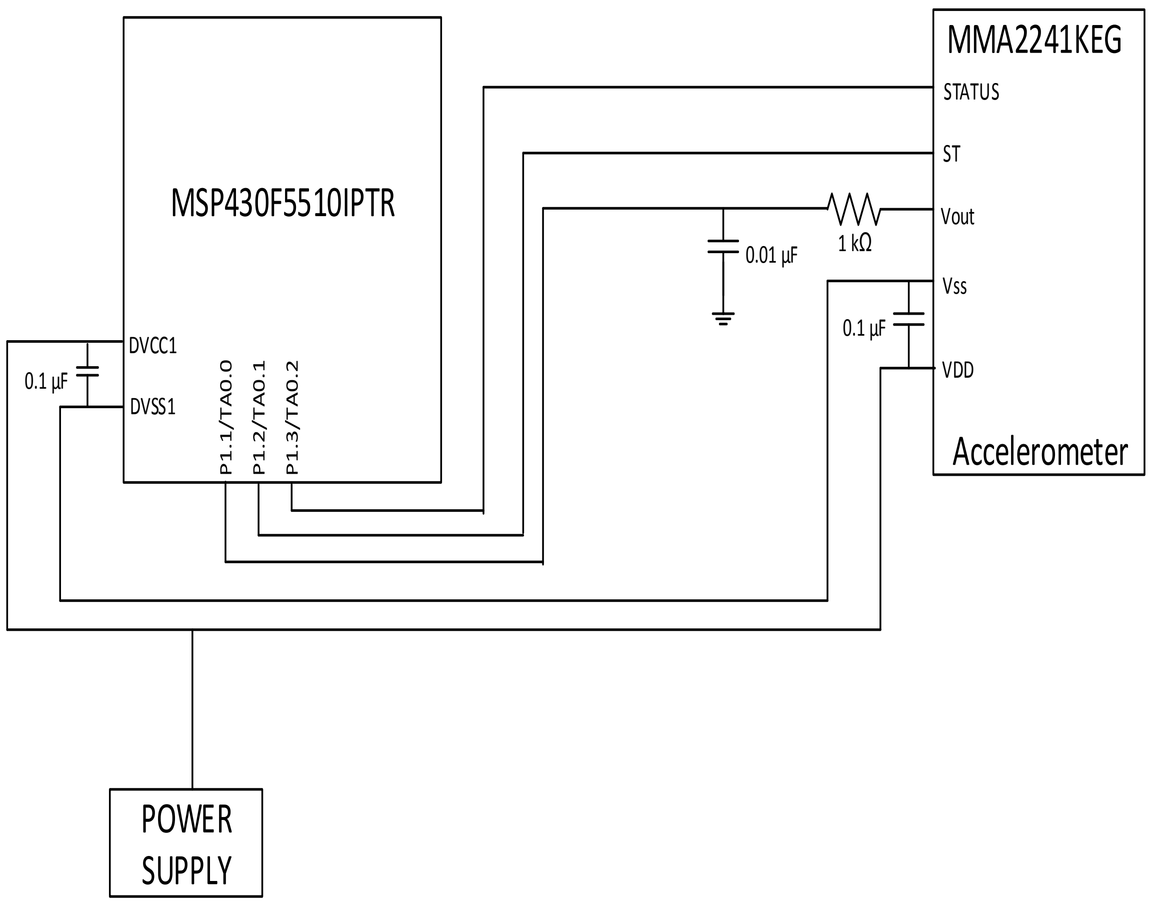


Figure 4.1.4.1 – Sensor Schematic

Pin out connections for the accelerometer are listed in Table 4.1.4.1.

Pin Num	Pin Name	Description
1-3		No internal connection
4	ST	Logic input use to initiate self-test
5	Vout	Output voltage of accelerometer
6	Status	Login output to indicate fault
7	Vss	Power supply ground
8	VDD	Power supply input
9-13	Trim Pins	Used in factory do not connect
14-16		No internal connection

Table 4.1.4.1 – Pin Out for Accelerometer

Table 4.1.4.2 shows the pin number and names for both the MCU and accelerometer and how they are connected.

MCU Pin	MCU Pin Name	Accel Pin	Accel Pin Name	Purpose
15	P1.1	5	Vout	Signal MCU to activate white LEDs
16	P1.2	4	ST	Initiate accelerometer self test
17	P1.3	6	STATUS	Tell MCU there is a fault in the accelerometer
11	DVCC	8	VDD	Power supply
12	DVSS	7	Vss	Power supply ground

Table 4.1.4.2 – MCU to Accelerometer Connection

4.1.4.1 – Actual Sensor

Use of the accelerometer was too much for this particular project, and so a redesign was taken to make a pressure sensor circuit easier. A force sensitive resistor (FSR) with a fixed value resistor of 470 Ω was used as a voltage divider circuit that leads into the ADC pin P1.3. The FSR acts as an open when no pressure is applied, and as force is applied resistance drops allowing voltage to pass through the FSR to the ADC pin. Biased to 3.3 V on the top end of the FSR, the MCU is programmed to light when the voltage exceeds 0.2 V. Table 4.1.4.1.1 shows the specifications for the FSR. Figure 4.1.4.1.1 shows the schematic of the sensor circuit.

SPECIFICATION	VALUE
Force Sensitivity Range	0.1 – 10,000 N
Force Resolution	Continuous
Non-Actuated Resistance	>10 MΩ
Device Rise Time	<3 µs
Number of Actuations	10 million
Sensor Size	4 mm

Table 4.1.4.1.1 – Specifications for FSR

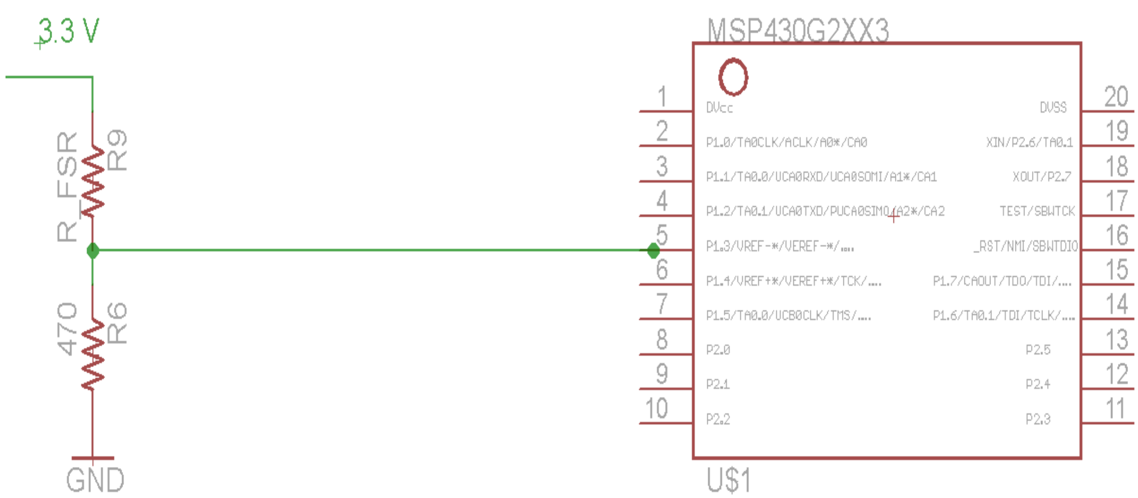


Figure 4.1.4.1.1 – Schematic of Sensor

4.1.5 – Printed Circuit Board

The printed circuit board or PCB is a very pivotal part of the project that will need to be designed properly in order for the project to function as desired. It is where all of the internal components of the stone will be mounted and where they will all interface with each other. There are many things to consider when designing a PCB including parts, size, number of layers, size of the traces, etc. Also there are needs for the project that will need to be considered including external USB connections and test boards.

One of the main things that need to be done when designing a printed circuit board is the placement of components on the board. According to the express PCB website it is always “best to place parts only on the top side of the board’ [61]. This follows common sense to want to have all components on one side for mounting and testing needs. Other recommendations are when placing the components make sure a snap-to-grid feature is turned on with a grid of .05’’ [61]. Furthermore it is important to try and minimize the size of traces on the printed circuit board. For this reason is it recommended to put components that will connect close to each other on the board. Another thing to consider when placing components on the board design is to always place integrated circuits either vertical or horizontal for a clean design.

After the components are placed it is important to route the power and ground traces on the printed circuit board. These are obviously very important as they distribute power and ensure all the components are properly grounded. It is important to use “wide traces that connect to common rails for each supply” [61]. The next step in making the printed circuit board will be drawing the signal traces between the various components. It is considered best practice to make these traces a short as one can make them to save space on the board. The width of signal traces can vary depending on the amount of current passing through them. A rough guide via the expressPCB website is shown in Table 4.1.5.1 [61].

Width of Traces (inches)	Current (Amps)
0.010	0.3
0.015	0.4
0.020	0.7
0.025	1.0
0.050	2.0
0.100	4.0
0.150	6.0

Table 4.1.5.1 – Signal Trace Width

Furthermore when it comes to signal traces it is very important to make sure to leave enough space between each trace. Via the PCB manufacture expressPCB it is recommended that a minimum gap between traces of 0.007’’ but 0.010’’ is better.

The final part of the printed circuit board design procedure is deciding if silk screen and/or solder mask is needed for the design. For this project I would recommend both of these options. Silkscreen will allow the mounting of the parts to be much easier and we can see exactly where each part goes on the board without having to refer to the original design. Solder mask will further protect the project too, which is very important considering the environment that the boards will be in during their use.

Other considerations that are needed when designing our printed circuit board is the need for various USB connections on the board itself. These connections will be used to access the various integrated circuits that may need to be reprogrammed during testing and implementation. Another extra consideration that will need to be made for the project is the ordering of test printed circuit boards. These will be used to mount components for testing purposes since they are impossible to connect to traditional breadboards. These should not be very expensive and will be very valuable during the development of the project.

4.1.5.1 – Actual PCB Design

The final PCB is made up of two parts. There is a main board which holds most of the components of the circuit and a voltage controller board which is separate. The main board houses the solar panel input, charge controller, MCU, force sensitive resistor, Bluetooth module, and WS2812 LEDs all connect to the main board. This board mounts to the inside of one of the hexagonal sides and is 3.94” x 2.8” and is two layers. An image of the footprint in Eagle is shown below in Figure 4.1.5.1.1.

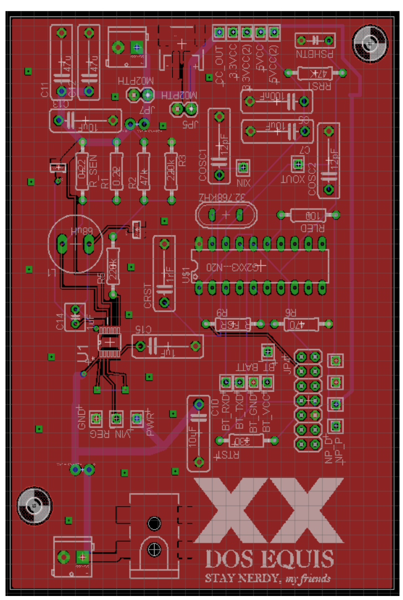


Figure 4.1.5.1.1 –Main board drawn in Eagle 6.6.0 ©.

The second PCB that was designed for the needs of this project is the voltage regulation board which is 1.86” x 1.33” in dimension. This circuit is made up of a boost converter for the 5V output and a low-dropout linear regulator for the 3.3V supply to the rest of the components on the main board. The Eagle footprint layout for this board is shown below in Figure 4.1.5.1.2.

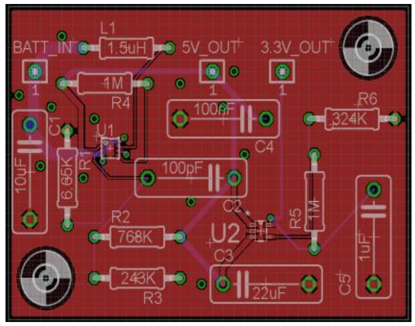


Figure 4.1.5.1.2 –Voltage regulator drawn in Eagle 6.6.0 ©.

These PCBs have standard 10 mil wide traces for most signals excluding the trace for the voltage coming in from the solar panel which was sized to be 50 mils wide for a higher input current. Another 50 mil trace width was used for the output node from this board going into the voltage regulation board. 24 mil wide traces were used between the voltage regulator ICs as well as for the power output rail to the WS2812 LEDs on the main board. Equations 1 and 2 below were used for trace width calculation using current in amps, area in square mils, thickness in ounces and with a ΔT = 10° C.

$$Area = \left(\frac{Current}{0.024 * \Delta T^{0.44}}\right)^{0.725}$$

Equation 1 – Trace Cross-sectional Area

$$Trace\ Width = \left(\frac{Area}{Thickness * 1.378}\right)$$

Equation 2 – Trace Width Calculation.

The equations and constants for trace width calculation are defined by the IPC-2221 Generic Standard for Printed Circuit Boards which is a standard that helps to improve reliability and versatility of output products.

4.1.6 – Structure Design

The outer structure of this project is comprised of two parts: an upper Plexiglas section and a bottom casing made of wood. The bottom casing is to be hexagonal in shape with a .5 inch thick base and .75 inch thick sides. The

Plexiglas top piece is .236 inches thick and sits flush with the upper surface and rests on a lip provided by the bottom casing. The dimensions are as shown below Figure 4.1.6.1 – 4.1.6.3:

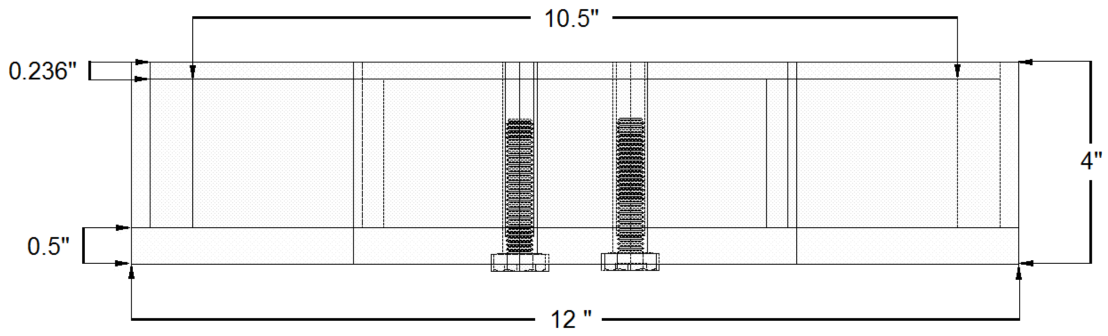


Figure 4.1.6.1 - Side x-ray view of structure design in AutoCAD 2012©.

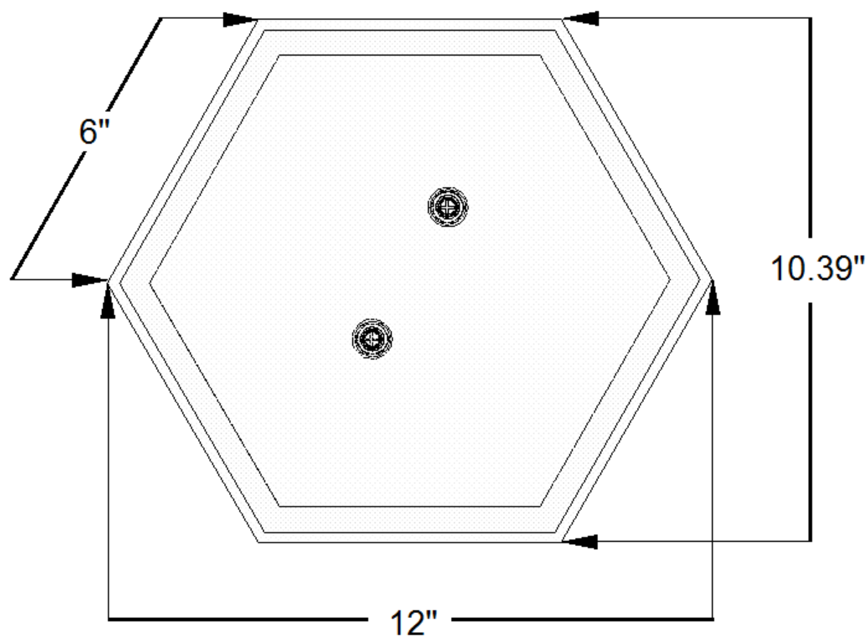


Figure 4.1.6.2 - Top x-ray view of structure design in AutoCAD 2012©.

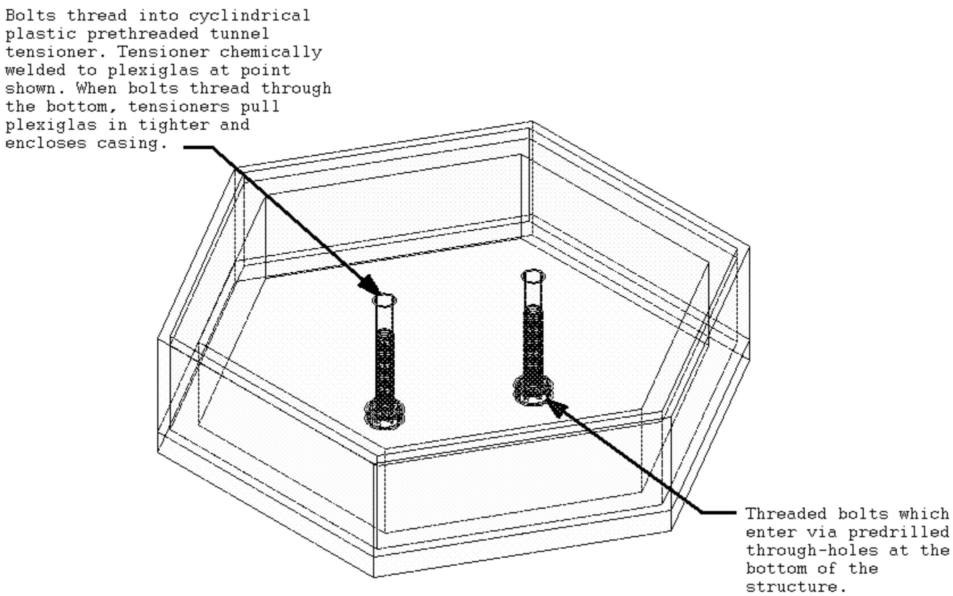


Figure 4.1.6.3 - Diagonal x-ray view of structure design in AutoCAD 2012©.

Figure 4.1.6.4 shown depicts the structure in a realistic viewing format. The models below help to outline the specific materials chosen for the upper and bottom casing pieces. As mentioned before, the top will be a hexagonal pane of .236” thick Plexiglas. The bottom will be made of Cedar wood with a thick polyurethane coating to keep wood from weathering. The bolts used will be galvanized steel so that they do not rust and the pre-threaded cylindrical tensioner will be made of some form of strong and thick acrylic/plastic. The chemical weld of tensioner to Plexiglas pane will be done using acrylic cement. There will also be weatherproof washers on the underside of the casing so as to prevent water intrusion where the bolts thread in. This is shown in the images below.

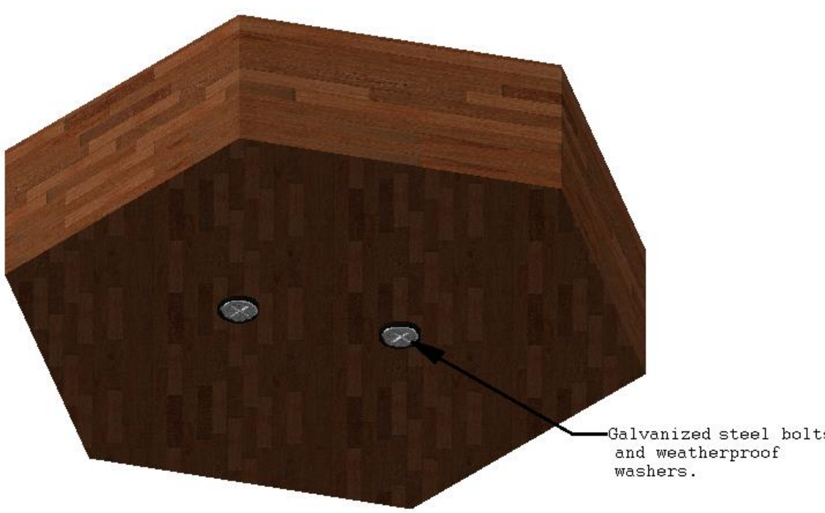


Figure 4.1.6.4 - Bottom realistic view of structure design in AutoCAD 2012©.

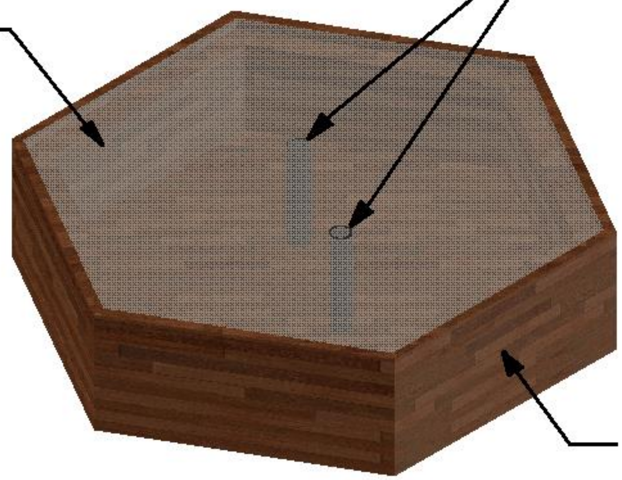


Figure 4.1.6.5 - Top realistic view of structure design in AutoCAD 2012©.

The final model shown in Figure 4.1.6.5 is a simulated rendering of what the final product will be for the stones. All of the circuitry, PCB, microcontroller, and LED arrays will be within each of the stones under the Plexiglas. The final design of the structure meets all the necessary requirements of stability, wreathing capability, quick turnaround time and inexpensive production all while giving off a rustic yet modern feel acting as a stylish addition to any yard space.

4.1.6.1 – Actual Structure Design

A very pivotal aspect of this design is the outside structure. It was decided that the sides and bottom of the structure would be made of pine wood. The sides are around two inches in thickness and four inches in height. They come together to form a hexagonal shape which sits atop a hexagonal cut of yellow pine plywood which is approximately a half inch thick. Outdoor-rated screws were used to bring the wooden pieces together. A .236" deep lip was carved into the top of the structure in order to facilitate a single hexagonal sheet of opaque-translucent Plexiglas sitting flush with the surface and therefore acts as a barrier between the electrical components and the elements while still allowing light into and out of the stone. This makes it possible for the LEDs to be seen through the sheet at night and for the solar panel to receive light for charging during the day. To help with stability, acrylic rods are chemically bonded to the inside of each hexagonal piece of Plexiglas. This was designed and modeled in AutoCAD prior to development of a prototype. Below in Figure 4.1.6.1.1 is a side view is shown emphasizing the height and width dimensions.

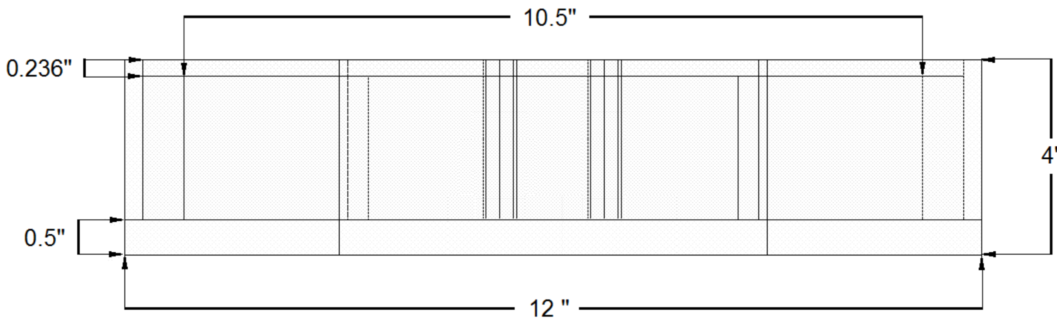


Figure 4.1.6.1.1 - Side x-ray view in AutoCAD 2012©.

Figure 4.1.6.1.2 is a rendering of the top/side view which demonstrates the shape of the structure as well as the dimensions and placement of the supporting rods.

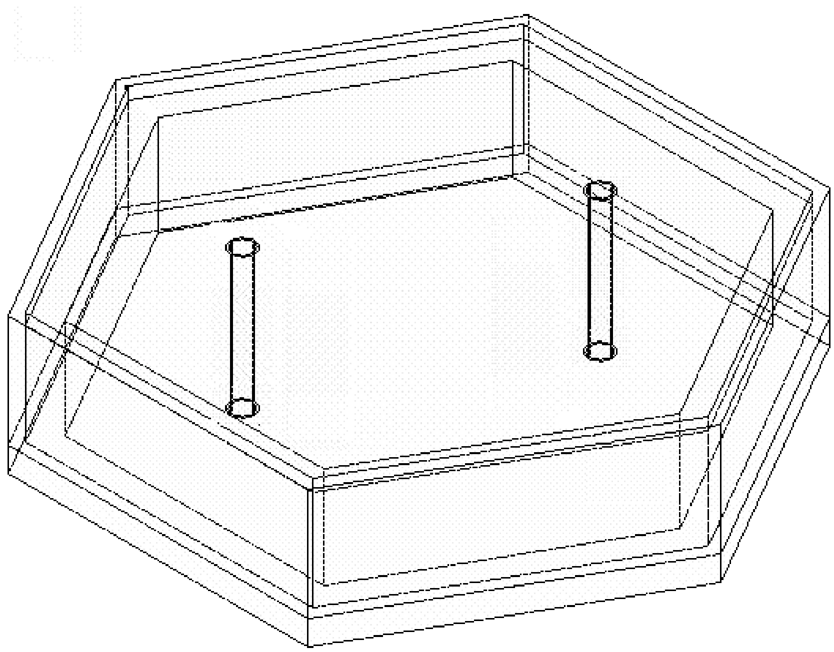


Figure 4.1.6.1.2 - Diagonal x-ray view in AutoCAD 2012©.

Once built, the structure was coated with Thompson's water sealant which protects the wood from pests, mold, mildew and rot. The edges were lined with DAP clear rubber sealant to avoid water intrusion.

Figure 4.1.6.1.3 – Diagonal view of final structure build.

Above is Figure 4.1.6.1.3 the final structure built with all finishing touches added to ensure that the outer structure has a long lifespan and that the internal components are protected from the elements. The width from the widest corners measure 12 inches in length, each side on the structure 6 inches long, and the height of each side 4 inches tall.

4.2 – Software Design

4.2.1 – Application

The phone application for the project will be used to communicate between the stones and the user input via a smart phone. After research was done on what development scheme to use it was decided that jQuery mobile with the addition of Phonegap will be used to produce the application. This was for reasons of device flexibility and simplicity of coding and troubleshooting. This section will be dedicated to laying out design procedures and a more detailed look on how the application will be developed using the jQuery mobile framework with Phonegap.

4.2.1.1 – Interface Coding

The jQuery mobile framework creates a user interface primarily via the programming language HTML-5. This gives the programmer the ability to both easily and effectively create an interface that is both functional and stylish to the end user. Creating a user friendly interface is key to the usability of the project as a whole. As the mobile application will be the singular way the user interacts with the P.R.E.S.S system.

The first step in the design of the application interface is hosting the files necessary to use the jQuery mobile framework. There are two options when it comes to hosting these files. The first option is to download the files onto the programmer's computer for the code to access. This must include the jQuery mobile files, and the jQuery files. This is because the jQuery mobile files use the foundation that is set-up by the jQuery files. The benefit of this method is that the files will be hosted directly within the application and will not require access to an outside server for these files.

The second option when it comes to hosting these files is to use what is called a CDN, or a Content Delivery Network [53]. A CDN is an online server used to host the files that jQuery mobile requires. This way the application will access the files via an internet connection and there is no need to download any files to the application itself. The benefit of this method is that there is no need to download any files, which makes this a great way to get started when first making the application. Using these files is as easy as putting in two lines on code to the beginning of the interface HTML-5 code. A negative of using this method is the application must have an internet connection to access the files. Also if the CDN is not functioning properly the application will not work. For these reasons for the project the option of hosting the files within the application will be used.

Once the proper files are hosted for the jQuery mobile framework the creation of the mobile application can begin. A main thing to understand about coding with the jQuery mobile framework is the different roles that exist and that can be used when creating the application. The roles include the page, which is the main role used in jQuery mobile. This is the main base for each display that the user will see. There can be multiple pages that link to one another via various buttons and menus. These various pages can either be contained within one HTML-5 or have multiple HTML-5 files for each page. For this project the second option will be used to keep the code clean and easy to troubleshoot. Other roles used in the application are listed in Table 4.2.1.1.1 [53].

Role	Function
Header	Header of a given page
Content	Content of a given page
Footer	Footer of a given page
Navbar	Defines a navigation bar, normally this will be inside a header
Button	Renders a visual button
Controlgroup	Renders a component
Collapsible	Collapsible panel of content inside a page
Collapsible-set	Group of collapsible panels (collapses like an accordion)
Fieldcontain	Container for form fields
Listview	Content of multiple items as a list

Dialog	Dialog page
Slider	Visual slider for Boolean values
Nojs	Element that will be hidden on jQuery Mobiles compatible browsers

Table 4.2.1.1.1 – jQuery Mobile Roles

As shown in Table 4.2.1.1.1, the typical page for a jQuery mobile application will contain a heater, content, and finally a footer. Various forms of informational and navigational content can be displayed in all of these sections. The header of a given page as one would imagine is located at the top of the page while the footer is located at the bottom of the page. Typically the header will contain the title of the current page that the user is on, as well some form of navigation. Most commonly this navigation characteristic is a back button used to take the user back to the previous page accessed. This is a convention that is used in many applications that are currently available so including this in the application for the project will add a sense of familiarity to the user when using the application. A common use for the footer is to display information that is not immediate useful to the user. An example of this is copyright information of the application. The content section is where the majority of the information will be in the application. This can be in the form of menus, buttons, text boxes, links, videos, images, etc.

The application for this project will contain at a minimum three separate pages. Each page will be contained within its own HTML-5 files. These pages include a Home page, a page when the user will be able to manually turn on stones, and finally a page where the color for each stone will be able to be selected. In order to transition between pages the button will need to be linked with the desired page. Each page will be given its own ID, this ID will be used to link between the pages. When the pages transition various transition animations can be displayed to create a more visually pleasing style to the application. Transitions can include slides, pops, fades and flips. Other than contributing to the visual style of the app transition also help the user navigate by creating a path for the user to follow. For instance in the application for the project navigating to a page outside of the Home page will create a slide left animation. While moving back to the home page creates a slide right animation. This visually lets the user know that they are back where they started. The navigation diagram for the application is shown below in Figure 4.2.1.1.1.

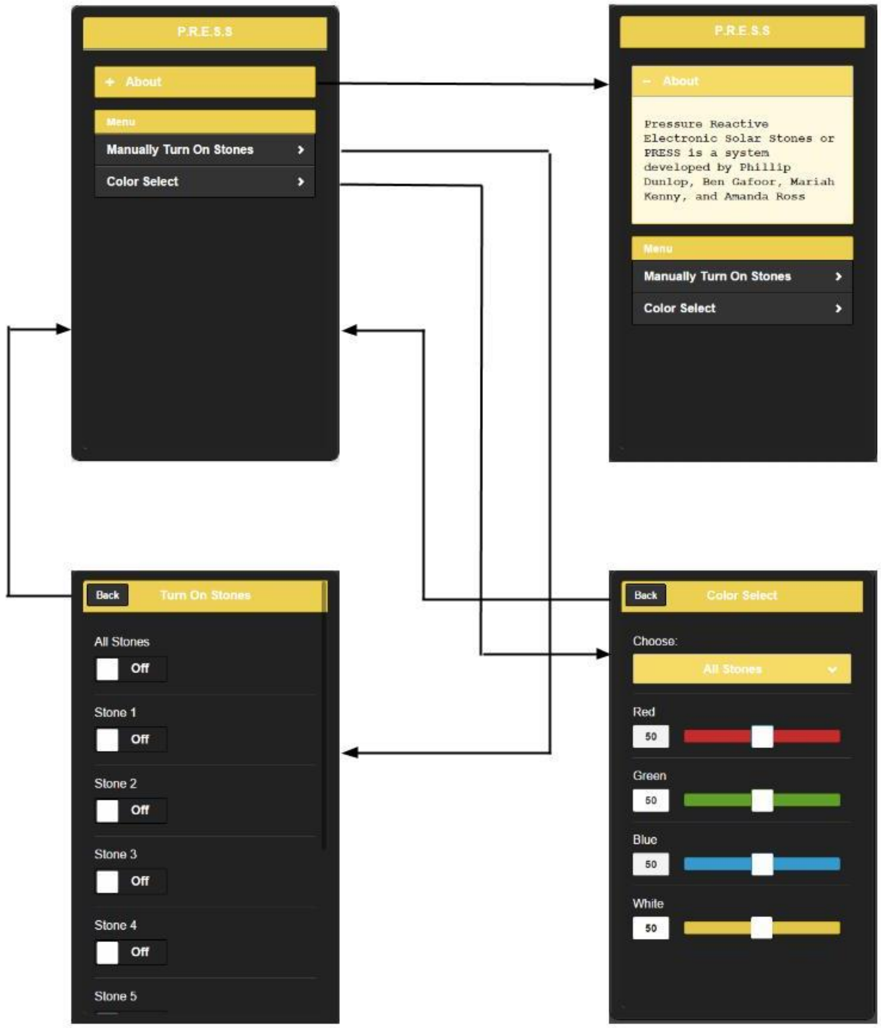


Figure 4.2.1.1.1 – Navigation Flow Diagram

As you can see in Figure 4.2.1.1.1 the page that features the option to manually select which stone is turned on utilizes toggle switches. The values of these switches are saved as long as the application is turned on. These settings will also be saved on the MCU on the stone side of the project and will only be altered if further edited within the application. Also it can be seen in the color select page sliders will be utilized in order to give a dynamic range for the color options. These sliders will allow the user to indicate exactly what color they would like the stone to emit by adjusting combinations of red, green, and blue.

Now that it is understood the general layout of a page and how the application will navigate between pages, it is also useful to understand how the code of each page is organized. Instead of simply showing the code which is not immediacy intuitive diagrams will be used. In Figure 4.2.1.1.2 how the HTML-5 code is organized is shown. Each different color box is another sub layer of the code. Also each box then lists the data role and the content of each section of the code. The links to the different pages of the application are shown in the 'Href' portions of the sub layers. You can see that the list view style menu is made up of a separate title portion as well as the links to the pages. Each link to the other pages has its own designated transition style.

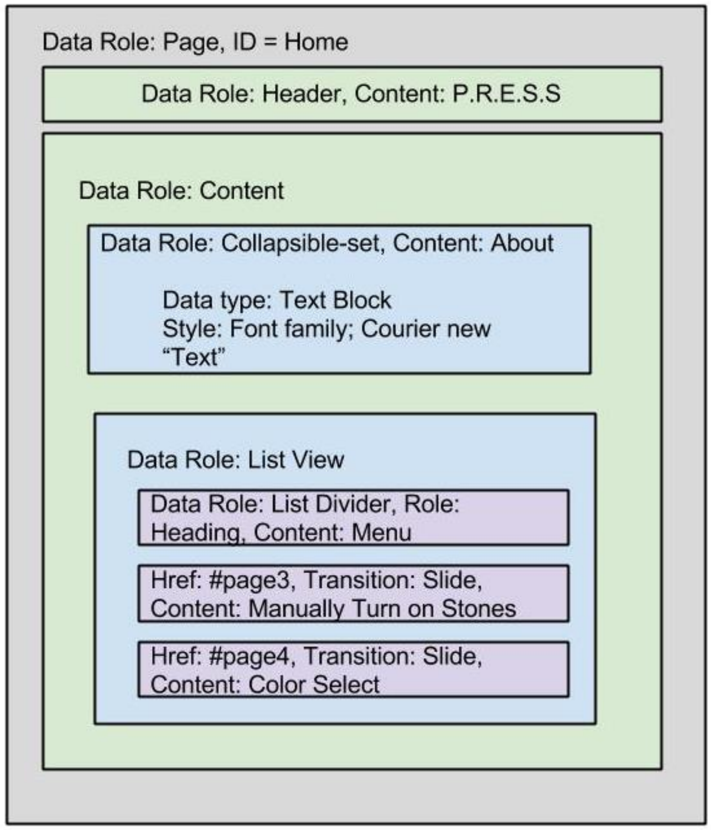


Figure 4.2.1.1.2 – Home Page Block Diagram

This same approach to displaying the code for the home page can be applied to display how the code functions for the other two pages. The next page shown in Figure 4.2.1.1.3 is the “Manually Turn on Stones” page broken into boxes to display the roles used and how the code is organized. This page utilizes many toggles switches to select which stones should be turned on despite what the pressure sensor is reading internal to the stone.

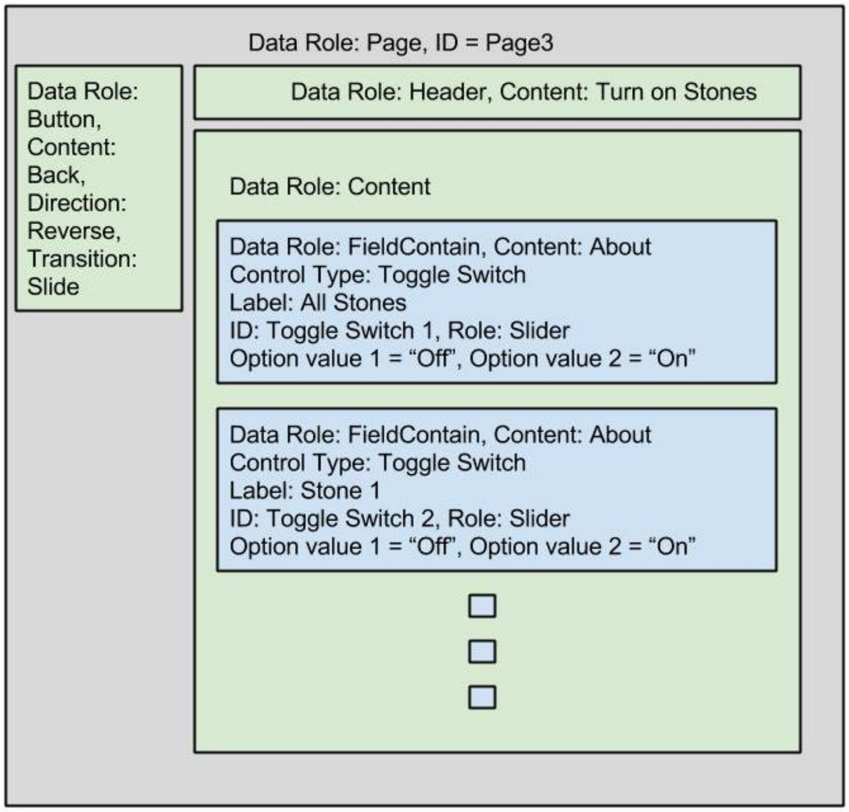


Figure 4.2.1.1.3 – Manually Turn On Stones Block Diagram

As you can see in Figure 4.2.1.1.3 this page of the application utilizes the back button that is located next to the header. It is used to link backward to the homepage and it given the reverse of the transition that was used to navigate to the current page. Also it can be seen that this page utilizes the same code for each toggle switch, it is merely repeated and given a separate label and ID corresponding to the stone that is being selected. For this reason only two boxes representing two toggle switches were shown.

The final page of the application is the page that does the color selecting for each stone. The user will be able to go into this page and select which stone, or all stones, and choose the exact color of their liking. The Block Diagram showing how this page is laid out using HTML-5 code is shown in Figure 4.2.1.1.4. This page is the most complex of the three pages of the application. It includes both a drop down menu as well as four sliders. Each slider represents a color (red, green, blue) and the fourth slider represents the color white. This is because the project will be using RGBW LED's so this range of color is the range that is able to be selected.

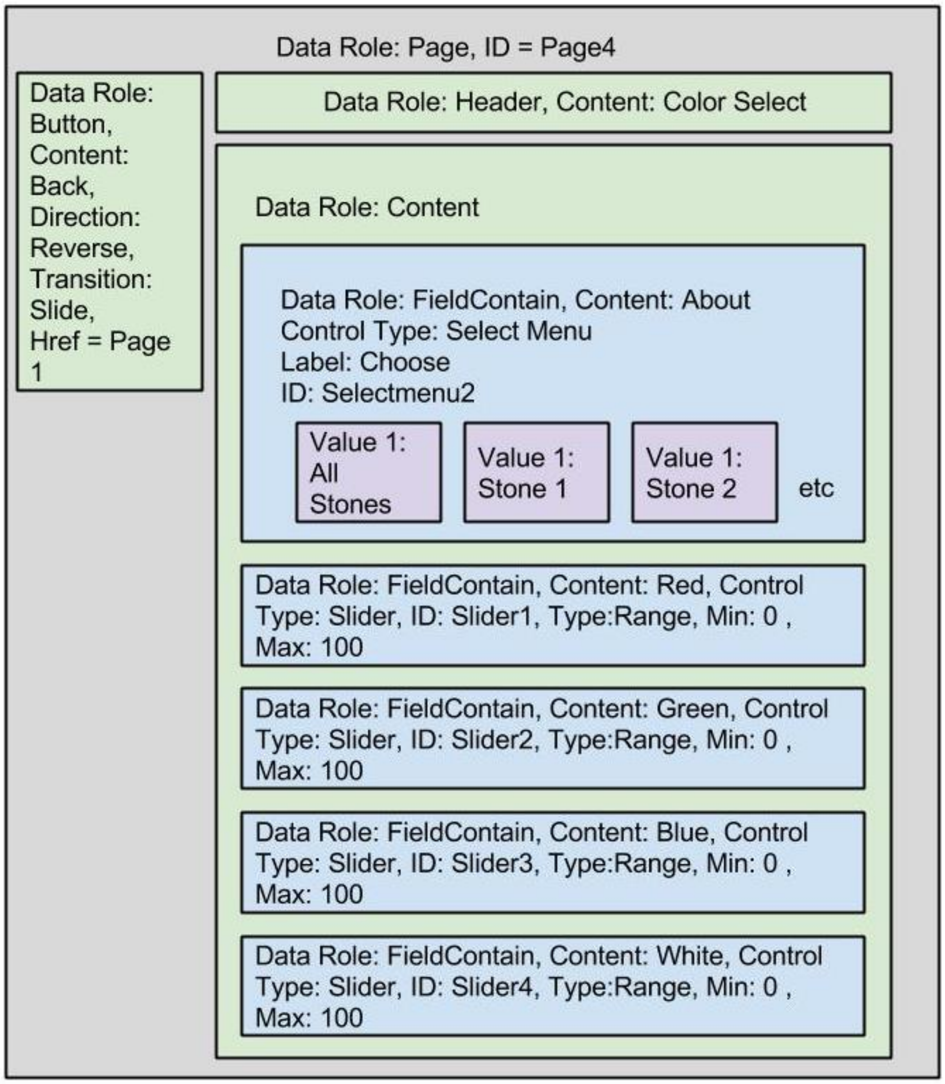


Figure 4.2.1.1.4 – Color Select Block Diagram

Each slider as can be seen in Figure 4.2.1.1.4 has its own ID and content section different from the other three. However the range is the same for each slider. This range may need to be edited in future versions once development is further along to accurately represent the capabilities of the LEDs. Another possible position that could be updated in future versions is the selection of which stone the user wishes to edit the color of. For instance gives the user an option to edit multiple stones at once instead of one at a time or all of them at once. This will make it similar to give alternating patterns between stones for an interesting and appealing appearance. Given how easy HTML-5 code is to work with this addition should not be too involved and will be complete by the time the working prototype is fully developed. Furthermore the entirety of the interface will continue to be developed as the process moves forward in order to create a user friendly, appealing, and responsive application.

4.2.1.2 – PhoneGap Framework Implementation

The PhoneGap framework will be used to both package and add features to the webapp created using the jQuery Mobile framework. The application developed using jQuery Mobile is primarily a website or more specifically a webapp. In order to morph this into a native app similar to the ones downloaded from the Google Play store or iTunes store that is developed using the native development software a system such as PhoneGap will need to be used. This framework takes the HTML-5, CSS, and JavaScript code and packages it to behave and make it able to be packaged as a native application. This is extremely useful as it allows us to use the robust and simple jQuery mobile framework to develop the interface but still be used as a native application.

The main way this is done is using the cordova command-line interface (CLI). This interface is where all the work will be done to build the application and add any useful plugins that the application will need. This CLI supports almost all forms of mobile environments, this is a great advantage to the project since one of the main reasons for selecting this method for our application coding is the cross platform capabilities of jQuery Mobile. The fact that this also extends to PhoneGap using the cordova CLI is very advantageous. The majority of the compiling and installing of the application will be done within the command line of the computer being used to develop the application.

In order to install the Cordova CLI the Node.js file that is available on the PhoneGap site will need to be downloaded and installed to the system. Also a git client must also be installed in order for the CLI to operate properly. From here creating the application is as simple as running a few lines on the systems command line. This is also the method used for adding new platforms that the application can run on as well as adding useful plugins. These plugins can be additions such a barcode readers or plugins that can access the camera of the phone, something normally available to only the applications developed in the native development environment. For this project the plugin used will be the addition of Bluetooth communication for the application. This will be used to communicate with the stones. The details of this plugin will be discussed in detail in the communication section of this document.

This design of this application is paramount to the project as a whole. Without this application the user would have no means to communicate with the stones and customize their experience and use of the P.R.E.S.S system. The development of the interface via the jQuery Mobile framework is very easy given it is done using the HTML-5 coding language. It allows the application to be tailored to the projects need very effectively. Also the addition of the PhoneGap framework creates the ability of the application to be installed on mobile devices in the fashion of a native application as well as adding useful additions to the applications functionality.

4.2.1.3 – Actual Application and Communication Design

An important feature of the P.R.E.S.S system is the user interaction via the mobile android application, which can be seen in Figure 5.1. Through this application all the lighting and extra effects can be communicated to the processers inside each stone. Connectivity between the application and the system is done with a serial Bluetooth module connecting to the UART ports of the MSP430G2553. Each one of the stones has its own Bluetooth module with an individual 48-bit Bluetooth address used for establishing a connection. Since these Bluetooth modules will only be receiving instructions and not transmitting any information back to the user, each module is operating in a slave configuration. These Bluetooth modules are both easy to implement and require very little power, making them ideal for integration into the system.

Figure 4.2.1.3.1 – Mobile Application

There are two ways in the application that the user can choose to communicate with the stones. Either by establishing a direct connection with one stone with a drop down menu, or by sending settings with the 'All Stones' button. The direct communication method simply uses the application Bluetooth client to connect to the unique 48-bit address of the selected stone. From here a constant connection is maintained where the user can set a color from the library, create their own custom color, as well as set any of the various other features offered.

The All Stones option simply communicates a single command to all the stones. This is done with a global variable that store the most recent command issued by the user. Once the All Stone button is selected this variable, and therefore the command, is send one-by-one to each of the stones. Clocks are used as a delay in order to make sure the connection and disconnection are given enough time to fully execute on the Bluetooth modules. Once each stone has received the data the user can then choose to send another command to all of the devices or make a direct connection to alter an individual stone. The flow of the 'All Stones' option is shown in Figure 4.2.1.3.2.

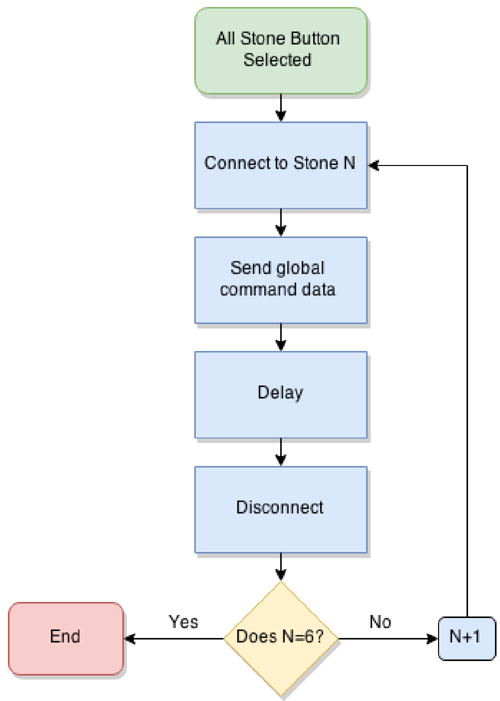


Figure 4.2.1.3.2 – All Stones Flow Chart.

In the application comes a set of 64 preprogrammed colors. These colors were based off Apollo Design Technologies' lighting gel colors. An eight by eight grid is used to display these colors in the application that can be seen in Figure 4.2.1.3.3. Each color has its own unique ASCII code associated with it. When a color is selected this code is transmitted through the Bluetooth serial connection into the MCU where the hexadecimal values for the red, green, and blue LEDs are set. Also shown in Figure 4.2.1.3.3 are the various features included in the P.R.E.S.S system. These include random colors, strobe, fading, and more. Each one of these features as its own unique ASCII code associated with it as well which will let the MCU know which feature to implement.

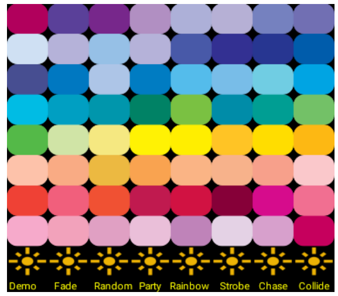


Figure 4.2.1.3.3 – Color Library and Features.

The final option for the user in the application is the ability to create a custom color. This is done by controlling the intensity of the red, green, and blue LEDs independently. First the user presses the custom color button which sends the ASCII code to let the processer know to expect color information. Next values between 0-85, which represent the full color range of the LEDs in 1% steps, are entered in the text boxes and sent. When red is set the stone will light up all red, similarly when green is set the stone will light up in all green. Finally after blue is set the custom color will be displayed. This custom color will automatically be the color that is displayed when the stone is stepped on. This gives the user full control and customizability of the system. A flow chart of the how the user will typically interact with the application can be seen in Figure 4.2.1.3.4.

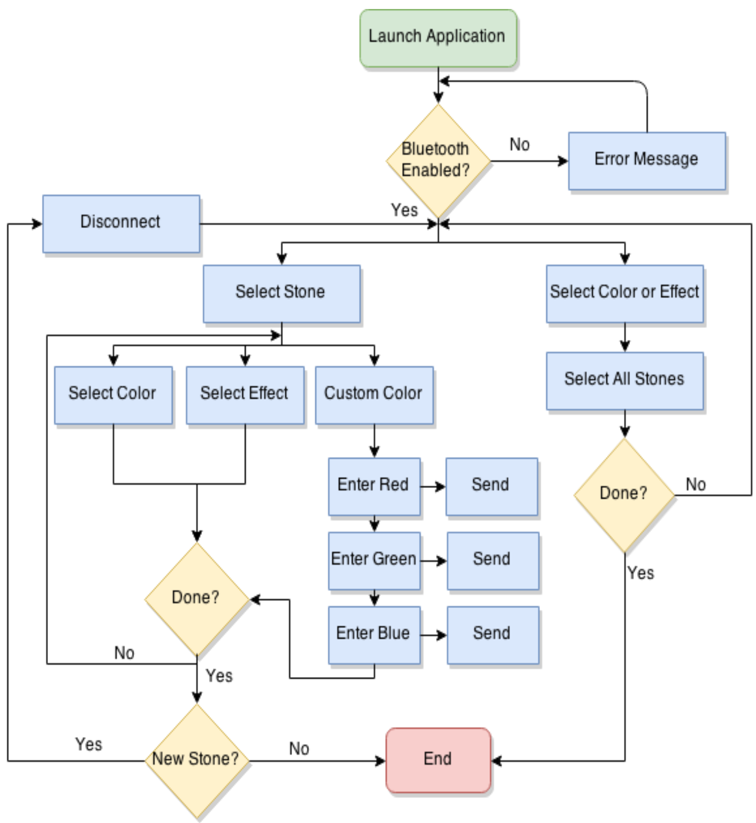


Figure 4.2.1.3.4 – Application Flow Chart.

4.2.2 – Communication

Since the stones will be self-contained with no wires going to or from the system, a method for wireless communication was needed. After much research was done the system that will be used to fulfil this need is Bluetooth technology. These reasons include the low power consumption, the relative simplicity of the technology, and existing methods for implementing this method via a mobile phone application. There exist plugins that have been developed for use by implementing the PhoneGap framework, these are the plugins that will be used for this project. However there are several plugins that can be used and the correct one will need to be chosen carefully.

One of these plugins works specifically with Bluetooth Low Energy technology, also known by the name BLE. Bluetooth Low Energy main has several differences between itself and classic Bluetooth technology that were explained in detail in the research section of this document. Quickly the benefits of this Bluetooth Low Energy technology are faster connection speeds, cheaper cost, and of course lower energy consumption. The last point is of particular concern to the project given the power constraints that come along with relying on solar power to run the entirety of the project.

The plugin mentioned above is a very viable option to be used for the project. It has all the abilities to scan for devices, connect, read, and write. Also a possibly useful aspect is the ability to be notified when a value changes. This could be used perhaps for showing a live representation of which stones are active and which are not. Perhaps a feature could be added showing a live update of which stones are being step-on straight to the phone. The information given by this system could then be used in a security situation. If this was enabled the user could be made aware when someone was walking up their walkway

This plugin works with both iOS and Android 4.3 or newer, this is very useful for the project as a benefit of using the jQuery Mobile and PhoneGap frameworks was the ability to create a multi-platform application. There are several limitations that were disclosed in the plugin documentation. These include:

- All services are discovered, this can be slow, especially on iOS
- Implementation doesn’t stop you from scanning during a scan
- Indicate is not implemented [62]

The issue of being able to scan during a scan could cause problems in the implementation of the design. The user will have to be notified that they will not be able to do that at risk of crashing the application. Also the fact that indicate is not implemented could create a problem when trying to create the security feature mentioned before. However this will not be of great impact to the project as a whole.

The final thing that will need to be done in order for the plugin to work is to install the plugin using the Cordova Command Line Interface. This is a very simple process that involves only two lines of code in the Cordova Command Line Interface. These are: $ cd path/to/the/project followed by $ cordova plugin add com.megster.cordova.ble [62]. Once this is done the plugin is installed and ready to use to design the Bluetooth Low Energy capability for the application for the P.R.E.S.S system.

This plugin is broken into ten different methods that have various functions that can be used for the Bluetooth Low Energy communication. These include a scan feature, connect, disconnect, read, write, notify, indicate isConnected etc. The details of these methods are shown in Table 4.2.2.1 and Table 4.2.2.2. These methods should be all that is needed in order for the communication between the mobile application and the blue controller inside of the P.R.E.S.S system.

Method	Description	Parameters
Scan	Scans for BLE devices. The success callback is called each time a peripheral is discovered.	Services: [] to find all devices Seconds: number of seconds to run Success: Callback Function Failure: Callback Function
Connect	Connect to a Peripheral. Call back is long running. Service and characteristic info will be passed to the success callback in the peripheral object.	Device ID: UUID or MAC Address Connect Success: Callback Function Connect Failure: Callback Function
Disconnect	Disconnects from the selected device.	Device ID: UUID or MAC Address Success: Callback Function Failure: Callback Function
Read	Reads the value of a characteristic. Raw data is passed from native code to the callback as an Array Buffer.	Device ID: UUID or MAC Address Service UUID: UUID of the BLE service Characteristic UUID: UUID of the BLE characteristic. Success: Callback Function Failure: Callback Function
Write	Writes data to a characteristic.	Device ID: UUID or MAC Address Service UUID: UUID of the BLE service Characteristic UUID: UUID of the BLUE characteristic. Data: Binary Data, use an Array Buffer. Success: Callback Function Failure: Callback Function

Table 4.2.2.1 – Plugin Methods [62]

These methods are the most important methods included in the API for this plugin. They involve the basic and crucial actions that will scan for open Bluetooth Low Energy devices, connected to the device, read from the device, write to it, and after that is done disconnect from the device. The role of the different parameters of each method is very important to the design to understand so the code will work without many troubleshooting issues. These will be the most used methods in the code for the software communication. Other methods are shown in Table 4.2.2.2 [62].

Method	Description	Parameters
With Without Response	Writes data to a characteristic without confirmation from the peripheral. There is no notification if the write fails in the BLE stack. Success is called when the characteristic is written.	Device ID: UUID or MAC Address Service UUID: UUID of the BLE service Characteristic UUID: UUID of the BLUE characteristic. Data: Binary Data, use an Array Buffer. Success: Callback Function Failure: Callback Function
Notify	Register to be notified when the value of a characteristic changes.	Device ID: UUID or MAC Address Service UUID: UUID of the BLE service Characteristic UUID: UUID of the BLUE characteristic. Success: Callback Function Failure: Callback Function
Indicate	Register for an indication when the value of a characteristic changes. Similar to notify except indicate sends a confirmation back to the peripheral when the value is read.	Device ID: UUID or MAC Address Service UUID: UUID of the BLE service Characteristic UUID: UUID of the BLUE characteristic. Success: Callback Function Failure: Callback Function
Is Enabled	Reports if Bluetooth is enabled. Success or failure callback is possible depending on the state of Bluetooth.	Success: Callback Function Failure: Callback Function
Is Connected	Reports the connection status. Success when the peripheral is connected, failure when is not connected.	Device ID: UUID or MAC Address Success: Callback Function Failure: Callback Function

Table 4.2.2.2 – Plugin Methods Continued

These methods shown in Table 4.2.2.2 are also very important to the design of the software communication for the project. Particularly IsEnabled and IsConnected. These will be of great use to the user to be able to know if the mobile application is both able to connect to the stones and has actually successfully connected to the stones. This is also very important when developing and testing the system, in order to determine if the P.R.E.S.S system is functioning as intended.

The code for the software communication will need to be laid out in a very particular way in order to function properly. This involves correctly using methods Scan, isConnected, write, read, disconnect, etc. Error messages will also need to be displayed in order to correctly display the situation to the user. Proper loops will need to be implemented so the code does not time out before the communication is concluded. This flow of the code can be seen in Figure 4.2.2.1.

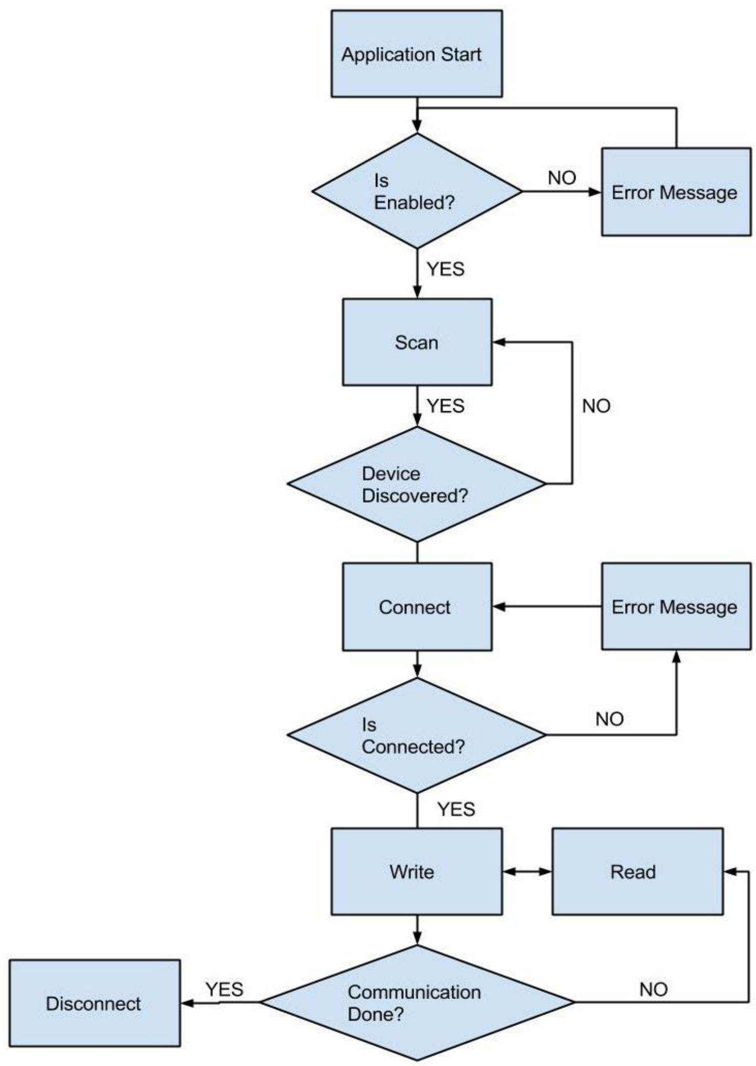


Figure 4.2.2.1 – Communication Flow Chart

4.2.3 – MCU Software Design

Programming the MCU unit is accomplished in Texas Instruments Code Composer Studio version 6.0.1 using the C programming language. A flow chart of a three stone system with just the accelerometer can be seen in Figure 4.2.3.1. Every stone starts in an idle state, when stepped on the accelerometer sends a signal to the MSP430 to turn on the white LEDs in that stone, as well as to turn on the white LEDS in two stones a head, one behind that stone and turn off the rest.

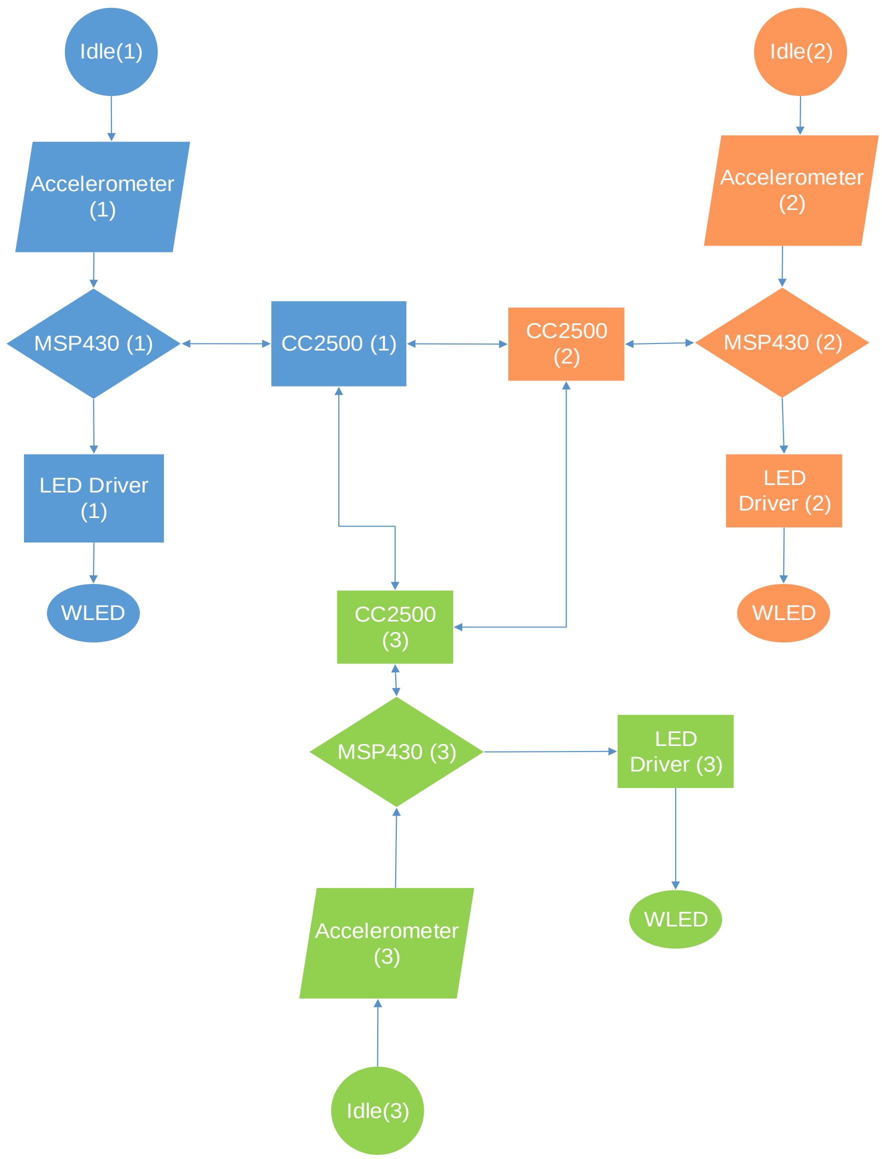


Figure 4.2.3.1 – Accelerometer control for MCU Flow Chart

The application will allow for more control over the stone's light system. Specifically color changing will be allowed as well as programming chase scenes where the stones alternate color looks, and time on. Figure 4.2.3. depicts the flow of the application control on the MSP430 to turn on light and off lights.

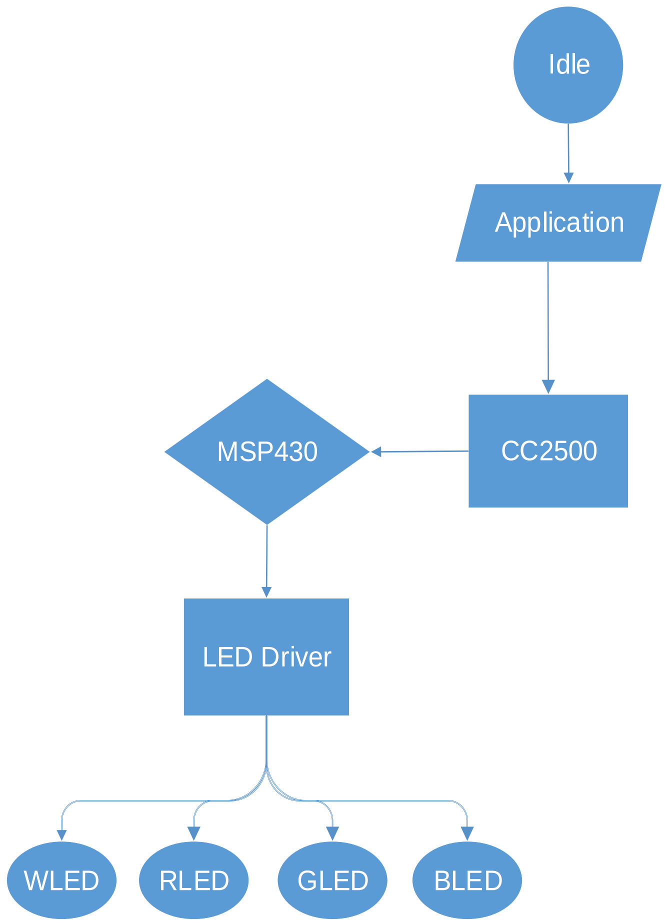


Figure 4.2.3.2 – Application Control System on MCU

4.3 – Design Summary

In the over-all system design for P.R.E.S.S. it consists of both hardware and software design function for each of the six stones. Each stone will include a solar panel, maximum power point solar charge controller, a lithium-ion battery, an LED array, and a printed circuit board. On each PCB it will comprise of the microcontroller, LED drivers, the accelerometer, and the wireless interface components. The main purpose of P.R.E.S.S. is to integrate renewable energy into stones that can be controlled by the user wirelessly via Bluetooth technology. The accelerometer is also used to sense the pressure change on the stones to also produce lights when Bluetooth isn't an option. This is the part of the project that the team will design the various subsystems and integrate all them to create each stone in the P.R.E.S.S. system.

The actual structure each stone in P.R.E.S.S will be composed of three separate elements. Those components include: the top structure, the bottom encasing, and the plastic rods and screws to hold the top and bottom together. The shape of each stone in P.R.E.S.S. will be in the shape of a hexagon. The top of the structure will be made out of a frosted Plexiglas at a quarter of an inch thick. Plexiglas is compatible for the top of the stone because of its stronger than glass, cost efficient and practically weather proof which is necessary to protect all the electrical components inside the stones structure. The bottom encasing will be made up of wood and sealed with polyurethane wood sealant. Each side of the hexagon will measure six inches in length and be three quarters of an inch thick of total thickness. At the top of the bottom encasing there will be a half inch thick lip cut out of the sides of the hexagon structure. That edge on the inner lining of the bottom casing on the top of the structure will let the Plexiglas sit flesh with the top edge of the bottom encasing creating a flat surface. On the bottom of each stone will be two screws that are filtered through plastic piping connecting the top structure and the bottom encasing.

Sunlight will generate energy and the solar panel will then absorb that energy. The solar panel will generate electricity by the photoelectric effect. The solar panel that will be used in this design is an 8 V open voltage and a 310 mA short circuited mono-crystalline photovoltaic solar panel. The power will then be sent through the charge controller where the current and voltages will be measured. The charge controller is set to only allow enough current and voltage to the charge the battery attached without overcharging it. The charge controller used in this design is a Sunny Buddy MPPT solar charge controller. The charge controller will then regulate the charge of the battery in the power system design. The battery chosen for this design is a 6 Ah Polymer Lithium-ion Battery. This entire power system will generate enough energy to power every other subsystem in the P.R.E.S.S. design.

Texas Instrument’s components were used to fill the need for most of the electrical components needed in P.R.E.S.S. The microcontroller chosen for the project is the Texas Instruments MSP430F5510IPTR. Programming the MCU unit is accomplished using Texas Instruments Code Composer Studio in the C language. The stones will light up in accordance to the accelerometer sensing or via wireless Bluetooth interface. The accelerometer acts as a pressure sensor to the MCU and is activated when weight is applied to the stone. The accelerometer being used in P.R.E.S.S. is the Freescale NMA2241KEG and will act as a switch to turn on each individual stone. So as the user steps on stone number one, the accelerometer will activate leading to communication to the MCU then resulting in stone number two and three to light up accordingly.

Another scenario in which the stones in P.R.E.S.S. will light up is with a wireless interface device. Essentially the user can use the P.R.E.S.S. application to communicate with the stones. The user can chose the light scheme across each stone having the capability to use a dimmer function as well. The communication between the application and the MCU is all programmed using a wireless interface component. The wireless interface component that was chosen for the project was the Texas Instruments CC2500 2.4 GHz RF transceiver. The CC2500 operates using an SPI interface that controls the operating parameters and the 64 byte transmits/receive FIFOs. The SPI connections chosen on the MSP430 for the wireless communication is the USCI_A1.

In P.R.E.S.S each stone will have lighting schemes that will stem from lighting protocols including: Red, Green, Blue, and White LEDs. The LEDs are driven by the MCU using LED drivers from Texas Instruments. The LEDs chosen for P.R.E.S.S. are two separate light arrays from Osram parts. The RGB LED array is the LTRBGFSF and the white LED array is the LWQ38E. These LEDs will be mounted on floating mini PCBs placed around the solar panel so the LED light is visible through the Plexiglas top structure. Two Texas Instrument's TLC5971 LED drivers will be used to communicate with the MCU. One of the drivers will drive the RGB LEDs and the other one to drive the white LEDs in each stone. The TLC5971 was chosen to function in the PWP package which is best suited for our design for integrating it with the MSP430. The TLC5971 will be connected to the MSP 430 via GPIO output, clock output, and SPI USCI_B1.

For the software design portion there are multiple key components including: Application programming, MCU programming, and communication from the application to the MCU. The phone application will let the user communicate with the stones via a smart phone, tablet, or PC. The development scheme used for the application coding design was jQuery mobile. jQuery mobile uses the programming language HTML-5 to give the user an easy and user friendly interface. The application will give the user the option to navigate through menus in which stones have the ability to turn on and off by using a sliding function. The user will also be able to use dropdown menus to choose an array of colors and patterns for each individual stone. The user will be able to use a sliding function to determine how bright or dim they want each stones color to be. All of these functions are programmed in jQuery mobile and saved as individual HTML-5 files that can either be stored on an online Content Delivery Network, or actually downloaded onto the user's device. The biggest challenge within the application coding design was how to make the application appear as an actual application on the user's phone since jQuery is primarily used to make web-apps. PhoneGap Framework was chosen to overcome this challenge in the application coding design. PhoneGap uses a combination of HTML-5, code composer studio, and JavaScript code to make it possible for the jQuery mobile framework to be packaged as a native application. The overall interface design uses jQuery mobile with the addition of PhoneGap to meet all the application needs of P.R.E.S.S.

For the communication design portion of P.R.E.S.S the decision needed to make on how to make the MCU communicate with the user via the application. After much research it was concluded that Bluetooth Low Energy technology would be the best suitable option. Bluetooth Low Energy has relatively low power consumption and has existing methods for implementing this action via mobile phone application. This method of communication is a good fit for the project especially because P.R.E.S.S will be run predominately on solar energy so low power consumption is extremely important. This plugin also works with both iOS and Android 4.3 or newer operating systems making it possible for the application to be available on multiple platforms. The communication plugin will complete the crucial actions of being able to scan for open Bluetooth Low Energy devices, when it is connected to a device, the ability to read data from the device, the ability to write to the device, and after completion of tasks be able to disconnect itself from the device. Using Bluetooth Low Energy as the design for the communication portion is capable of completing all the above tasks making it a great choice.

The MCU programming design portion of P.R.E.S.S. is in charge of telling the stones when to turn on by integrating all of the software design subsystems. When an accelerometer is activated the MCU will then take that data and relay the communication onto the appropriate stones via the RF transmitter. When Bluetooth Low Energy is activated from the jQuery mobile application the information is then communicated to the MCU. The MCU then sends the actions necessary to the appropriate stone in the P.R.E.S.S system. Then if either the accelerometer or the Bluetooth Low Energy activates the MCU, the MCU sends the appropriate actions to the LED drivers to turn on the LEDs in the users preferred pattern and color scheme. The MCU is programed using the C programming language in Code Composer Studio and is the most important programming design section of P.R.E.S.S. since it integrates all of the software technologies.

4.3.1 – Design Constraints and Standards

It is always important to keep in mind the overall impact of your design on multiple platforms from various viewpoints. This means that realistic constraints need to be taken into account before producing a final design. Without doing so, the consequences for the industry, society or even the economy can end up being very severe. The table below outlines multiple different design constraints, their standards as defined by a search engine for ANSI Standards and how each of them relate directly to our Pressure Reactive Electronic Solar Stones.

Standard Type	Standard as defined by ANSI	How Standard is met by P.R.E.S.S.
Economic	IES of North America in 'IESNA RP-31-96'defines two techniques for designing and purchasing lighting systems: First level methods of initial cost and aesthetic value versus second level methods of cost/benefit analysis. Both are acceptable to be used in the industry when designing.	P.R.E.S.S. utilizes first level methods for economic design and purchasing of components involved in this exterior landscape lighting system. Due to the nature of this project, it is not yet necessary to perform a cost benefit analysis of the final product.
Environmental	American Society for Quality's document number 'BSR ASQ ISO 14001:2015' specifies the necessities of an environmental management method for establishments seeking to implement, sustain and continually progress a framework with the goal to manage its environmental responsibilities in a way that upholds the 'environmental pillar' of sustainability.	P.R.E.S.S. accomplishes these necessities by utilizing renewable energy to power the device in its entirety. An on-board solar panel and charge controller make it possible for each device to be completely wireless and self-sustaining. No energy is wasted since the stones do not hook into one's home panel. The battery stores the needed energy during the day until it is needed at night.
Social	The association of Records Managers and Administrators in document 'ARMA TR 21-2012' outlines suggestions of collective technologies in records administration. Topics include authority, infrastructure/technology, processes and controls, change management, training, and audit/evaluation.	P.R.E.S.S. is not being marketed at the time therefore there are no social implications of this technology being output to the population. If it were to be made into a product, the topics of infrastructure, controls, revision changes, training for those making the products and auditing evaluations would be very applicable to this technology.
Political	Seeing as there were no US standards available on the website, the Chinese standards will be referenced for the needs of this section. Chinese Standards document 'GB/T 2261.6-2003' Classifies codes to basic personal information as outlines by the National People's Congress.	P.R.E.S.S. does not have a political implications that relate to our design since this device requires no personal information from the user in order to properly operate. It does require the user to use their mobile device to pair with each stone but that pairing information from the phone does not get output to a network where it would not be secure.
Ethical	CSA America, Inc. in document 'CSA PLUS 9018-2004' is designed to be applicable to organizations of all sizes and to be integrated with other management systems, such as quality, environmental, financial, and occupational health and safety management.	Ethical practices apply directly to financial, legal and health and safety implications. The production of P.R.E.S.S. utilized completely ethical practices in each of these arenas. No corners were cut when it came to making a safe, reliable, and quality piece of technology.
Health and Safety	National Electric Code specifies a foot candle luminance level of 3 foot candles for all commercial walk-ways.	P.R.E.S.S. plays an important role in helping to maintain this standard for safety regulation reasons so that walkway users are capable of having an illuminated pathway to walk on therefore avoiding any safety hazards.
Manufacturability and Sustainability	International Electrotechnical Commision's document 'IEC 61943 Ed. 1.0 b:1999' is applicable to those manufacturers of integrated circuits (ICs) who apply for manufacturing line approval. Each manufacturer can use their own approaches for satisfying the necessities of this standard, as long as the required level of control in the industrial line is reached.	For the needs of P.R.E.S.S. all of the integrated circuit pieces were bought from outside organizations such as Texas Instruments or Sparkfun which are held liable for the manufacturability of their own products. These products have been tested and used in the industry for a significant amount of time therefore ensuring their reliability. The stones are also self-contained and need no maintenance over the course of their lifespan. This makes the final product easily sustainable.

Figure 4.3.1.1 – Design Constraints and Standards Table

5 – Prototyping and Testing

5.1 – Power Testing

5.1.1 – Solar Testing

Solar testing will be conducted outside on the University of Central Florida campus outside the Harris Engineering Corporation (HEC) building. Solar testing is important to understand how the environmental changes from day to day effect the amount of power the will be generate and used for the project. It is important to test the panel itself when ordered from the manufacturer since solar panels are fragile and can be damaged when shipped. The tests that will be performed on the solar panel include an open circuit voltage test (Voc), a short circuit current test (Isc), and a test to measure operating current (I). All measurements collected can then be compared to the data sheet from the panel purchased.

To measure open circuit voltage (Voc) the solar panel needs to be completely disconnected from the battery and the charge controller. The solar panel is constantly generating energy when there is sun present so this needs to be connected when there is minimal sunlight hitting the solar panel so no damage to the tester is done. Then by connecting the probes to the positive and negative terminals of the solar panel direct current (DC) voltage can be measure. After connecting the probes it is appropriate to face the panel towards the sun to get accurate measurements.

Next the short circuit current (Isc) can be measured by changing the multimeter setting to DC amps and the probes moved to the positive and negative input terminals. The panel should be facing away from the sun as the probes are attached and then slowly turned towards the sun and tilted to the optimal angle for collecting the sunlight. The multimeter should slowly show the current increasing as the panel turns towards the sun and eventually reach the current provided on the data sheet provided from the manufacturer. Be sure to record results for comparison.

The final test to run on the solar panel is the operating current (I). This can be measured by the connecting the panel to the charge controller and battery. The multimeter should be set to measure DC amps and the positive cable between the battery and the charge controller disconnected. The operating current can then be measured by placing the positive probe from the multimeter onto the positive end of the charge controller, and then by connecting the negative probe from the multimeter to the positive battery terminal. This puts the probe in series with the circuit and measures the current that is passed from the panel and charge controller to the battery itself. This will only work if the battery is not fully charged. In Table 5.1.1.1 below it shows the comparison between the specifications provided in the data sheet with the measured values that will be tested for the solar panel.

	Datasheet	How to Measure	Measured
Open Circuit Voltage (VOC)	8 V	Connect multimeter in parallel with solar panel	To Be Measured
Short Circuit Current (Isc)	310 mA	Connect multimeter in series with solar panel	To Be Measured

Table 5.1.1.1 - Solar Panel Testing

5.1.2 – Battery Testing

There are two key elements to testing the battery used in this project. One of them being the amount of time it takes to fully charge the battery to its full potential. The other important factor to test is the amount of time it takes the battery to discharge to a safe amount. Table 5.1.2.1 below shows the procedures needed to be performed to accurately measure the amount of time it takes to charge the battery being used in the project.

Battery Charging Time Procedures		
Procedure	Expected Result	Actual Result
Test the battery with no load	Charging should initiate	To Be Measured
Measure battery with multimeter (DC voltage)	Voltage should match data sheet value while in charging state	To Be Measured
Measure battery with multimeter (DC current)	Current should match data sheet value while in charging state	To Be Measured
Measure the time it takes to reach the batteries floating charge state	The time it takes should match the ratings calculated from the battery and charge controller.	To Be Measured

Table 5.1.2.1 - Charging Time

Table 5.1.2.2 below shows the procedures that need to be completed to accurately measure the amount of time it takes the battery to discharge.

Battery Discharging Time Procedures		
Procedure	Expected Result	Actual Result
Connect the battery to the charge controller with a predetermined load	Discharging should initiate on the battery	To Be Measured
Measure battery with multimeter (DC voltage)	Voltage should be at fully charged and slowly decreasing	To Be Measured
Measure battery with multimeter (DC current)	Current should read a decreasing value	To Be Measured
Measure the time it takes to reach the batteries floating charge state	The time it takes should match the ratings calculated from the battery and charge controller.	To Be Measured

Table 5.1.2.2 - Discharging Time

5.1.3 – Charge Controller Testing

To test the charge controller some key factors need to be considered. The controller will not produce an output voltage to measure unless it is connected to the load, which is the battery. To get accurate measurements the charge controller should be mounted near the battery to make sure they are rated at the same temperature. Accurate results will not be measured if the charge controller is not connected to the batter. While the battery is fully charged a multimeter should be used to read DC output voltage measurements. The value should be equivalent to the value described on the data sheet of the battery at a fully charged rate.

While the battery is in absorption mode the charge controller switch will be off. When the charge controller is off it should be letting all the current and voltage being produced from the solar panel through to the battery for charging. When the battery reaches the set point value for the battery the charge controller switch will turn on and will cut almost all current and voltage to the battery. The charge controller will function while only allowing a certain amount of voltage and current through causing a trickling charge to the battery. This trickling charge maintains the battery at full charge while not over charging it. Testing this by using a multimeter and reading the voltage as the battery was fully charged. As the battery charge decreases the charge controller will continue to be in the on position, at this point measuring the short circuit current will give show the charge controllers functioning.

5.2 – Lighting Test

Prototyping of the lighting subsystem is done using prototyped designed PCBs for all SMD style chips so as to accommodate use on a breadboard for testing purposes. This test will only be to test the MSP430's control of the TLC5971 and the LEDs connected to the driver. For sake of simplicity all LEDs will be mounted to small PCBs that will also be used in final assembly of the project. This will allow for a modularity of components to be tested individually and collectively. A general test procedure as is follows:

1. Assemble all SMD chips to their respective PCB prototyping boards with appropriate components also mounted to each board.
2. Using jumper wires connect the MSP430 to the TL5971 LED driver, and the LEDs to their respective driver pins.
3. Connect USB cable to the MSP430 board, and launch Code Composer Studio to download the control program.
4. Run the control program sending different current values for each color LED.
    a. Test light intensity of white, red, green, then blue LEDs.
    b. Test light intensity of two color combinations: red and green, red and blue, then green and blue.
    c. Test light intensity of all three colors combined, varying intensities each color at different levels.

Testing this way validates that MSP430 is working properly in its control of the LEDs, and that the LEDs produce the desired colors. At this point any other color combinations made during testing should also be noted for further color preset commands in the application if a preset command is to be made in the future.

5.3 – Application

5.3.1 – Interface

The mobile application is very important to the P.R.E.S.S project as a whole. It is the main way that the user will interact with the stones in order to turn on the stones manually as well as select the color of the stones. For this reason it is important that this application function properly. Without this system the project will lose major capabilities and would not meet the required specifications set. In order to make sure the application is working up to the proper specifications a testing procedure will be needed in order to test that all the capabilities are functioning to their full extent.

Each page of the mobile application will need to be tested. For each page the individual buttons and menus need to be tested as well as all the links to the other pages of the application. The testing procedure will be done in a list form, with lower units of the testing being done within other steps of the process. If something passes the test it might skip other steps of the process. This process helps determine the root cause of the issue in order to better fix the problem.

1. Open Home Page of application.
    a. Click on the About section.
    b. Make sure the text is displaying correctly.
        i. If YES, go to step c.
        ii. If NO, go into the HTML-5 code. Make sure it is a collapsible set and there is data in the textblock section.
    c. Click on the About section again.
    d. Make sure the text is disappearing correctly.
        i. If YES, go to step e.
        ii. If NO, go into the HTML-5 code. Make sure it is a collapsible set.
    e. Under the Menu section, click on the Manually Turn On Stones option.
    f. Check if the page properly links to the Turn On Stones page.
        i. If YES, go to step g.
        ii. If NO, go into the HTML-5 code. Make sure the href is linking to the correct page.
    g. Make sure when clicking the Manually Turn On Stones option the page slides to the left.
        i. If YES, go to step h.
        ii. If NO, go into HTML-5 code. Make sure data transition is set to slide.
    h. Under the Menu section, click on the Color Select option.
    i. Check if the page properly links to the Color Select page.
        i. If YES, go to step j.
        ii. If NO, go into HTML-5 Code. Make sure the href is linking to the correct page.
    j. Check when clicking on the Color Select option the page slides to the left.
        i. If YES, go to step 2.
        ii. If NO, go into HTML-5 code. Make sure the data transition is set to slide.
2. Open Turn On Stones page.
    a. Make sure when clicking the back button it links back to the home page.
        i. If YES, go to step b.
        ii. If NO, go into HTML-5 code. Make sure the href is linking to the correct page.
    b. Check when clicking the back button the page slides to the right.
        i. If YES, got to step c.
        ii. If NO, go into HTML-5 code. Make sure the data direction is set to reverse and the data transition is set to slide.

   c. Check when clicking each of the toggle switches that the switches goes from off to on, and then the reverse.
      i. If YES, go to step 3.
      ii. If NO, go into the HTML-5 code for the particular switch. Make sure the data control type is a toggleswitch and the option values are set to the correct value.
3. Open Color Select page.
   a. Make sure when clicking the back button it links back to the home page.
      i. If YES, go to step b.
      ii. If NO, go into HTML-5 code. Make sure the href is linking to the correct page.
   b. Check when clicking the back button the page slides to the right.
      i. If YES, go to step c.
      ii. If NO, go into the HTML-5 code. Make sure the data direction is set to reverse and the data transition is set to slide.
   c. Make sure when clicking the drop down menu all the options are displayed and are able to be selected.
      i. If YES, go to step d.
      ii. If NO, go into the HTML-5 code. Make sure the data control type is set to select menu. Also make sure all the options are listed under the select section of the data role.
   d. Check the four color sliders. Make sure the value changes accordingly when adjusting the slider.
      i. If YES, testing finished.
      ii. If NO, go into HTML-5 code. Make sure the data control type is a slider. Also check the minimum and maximum values in the range. This applies to all four color sliders.

Using this procedure the interface of the application can be checked to make sure all sections are operating as excepted. Once that is confirmed to be the case the testing of the stones and the communication between the application and stones can take place with full confidence. For this reason this is a very important test procedure for the project as a whole.

5.3.2 – Multiplatform Application Test

The choice of writing an application using jQuery was so that it would function across multiple platform operating systems. Testing of this capability will be done using an iPhone 5s and an android device. Testing each device platform one at a time, launch the application and go through every command available to send to the stones to ensure full cross-over functionality. Note any and all problems that arise on each device, and address each one when testing is done on all platforms. This testing phase should be similar to the testing done in [5.5.1 Interface Testing] and [5.5.3 Communication Testing]. Each platform should be able to control individual colors and their intensities, control individual stones, all the stones or groups of stones at the same time.

5.3.3 – Communications and Connectivity Testing

In order to ensure that the smartphone device is connecting correctly to the stones, there are a few measures that need to be taken. Since Bluetooth is the communication method being used, one must make sure that their smartphone devices have Bluetooth switched in the ON mode. Once this has occurred, the smartphone will then list all of the Bluetooth enabled devices within a certain displacement of that phone's location. The following bulleted steps list what the user must do from this point on:

1. First, make sure the application called "PRESS Stepping Stone Programmer" has been downloaded from the web onto the specific smartphone device that is being used and keep it in the applications library of the phone.
2. Use smartphone device to find Bluetooth enabled device called "PRESS-Master". There will be multiple other Bluetooth devices labeled "PRESS-Slave1", "PRESS- Slave2" and so on depending on how many stones are present. Be sure that your phone connects solely with the Master Stone.
3. Once the Master stone has paired with the smartphone, the smartphones will indicate that a connection has been made.
4. Now, go back to the "PRESS Stepping Stone Programmer" application that was downloaded and begin to interact with the stones.
5. Use the command that tells the stones to only use the pressure sensors for lighting called "Pressure1". Make sure that once this command has been enabled from the smartphone, that the stones only light up when being stepped on. The stones should light up as white.
6. Now select the command called "Pressure2" on the smartphone device. Now make sure that when a stone is stepped on, the stone in front of it and the stone behind it light up in white.
7. Now select the "Manual Customization" command and select stone number one to be lighting up as red. Select stone number two to light up as blue. Select stone number three to light as green. Set the rest of the stones as OFF.
8. Make sure that the stones are lighting up in the pattern specified. And then switch stones one, two and three to be OFF and stones four, five and six to be red, blue and green.
9. Make sure that the stones have lit up in the pattern specified.
10. Next set all of the stones to be on in white mode and make sure that they light up as they have been programmed by the smartphone device.
11. Lastly, set all the stones to be off and watch to see that all of the stones disable once this command is selected.

If all of these steps are taken and all of the commands take place as specified, it can be concluded that the stones are properly communicating commands with the Master Stone and that the master is properly communicating with the user's smartphone via Bluetooth

.

5.4 – Sensor Testing

There are a few very significant sensors that reside on each of the stones. The most prominent include the accelerometer which is used to evaluate pressure sensitivity and a photo-diode which is used in the solar section of the stones. There will need to be two separate tests for each of these sensors.

5.4.1 – Accelerometer Sensor Testing

This test evaluates the effectiveness and connectivity of the accelerometer to the system. It is important to make sure that the microcontroller unit is properly deciphering the output from the accelerometer and that the master stone deciphers the commands from the smartphone and can communicate well with the other sensors through their microcontroller units. The following steps outline a process to make sure that the accelerometers within each stone are working well.

1. Once the smartphone device is paired to the proper "PRESS- Master" device after Bluetooth is enabled, go to the "PRESS Stepping Stones Programmer" application and select the "Pressure1" selection from the menu.
2. Step on each individual stone to ensure that each one lights up when pressure is exerted.
3. Step on two stones at once and make sure that both light up as they are being stepped on.
4. If the stones light up in white when they are pressed regardless of the pattern in which they are pressed, then the accelerometers are working and communicating correctly with their respective microcontrollers.

5.4.2 – Photo-Diode Sensor Testing

This testing ensures that the photo-diode is in a state where it can sense whether or not light is present in the environment. When the photo-diode is active, it acts as a switch that tells the stones there is light present and tells the solar cells to send power to the battery to charge. When the photo-resistor does not sense any light, it cuts off current flow to the battery. The method to use to test this sensing component is listed below:

1. The stone needs to be open for this testing to take place so remove the surface plate from the stone and place the photocell upwards in a lighted environment.
2. Use an ammeter/voltmeter and take the positive lead and place it at the input of the battery. And connect the negative lead to ground.
3. Make sure that the screen on the ammeter/voltmeter reads a positive current value as well as a positive voltage. This means that the battery is charging.
4. Now obstruct the light from the photocell and place the leads of the ammeter/voltmeter on the positive end of the battery. There should be no voltage change. Now make sure that current is running into the microcontroller by putting the ammeter/voltmeter on the input lead of VCC on the MSP microcontroller.
5. If there is current running into the controller then we know that power has successfully been redirected to the proper portion of the stone and that the photo-diode sensor is working correctly in accordance with the system.

5.5 – Overall System Checklist

Overall System Checklist broken down by subsystem. Power system checklist is first and is found in Table 5.5.1.

	Checklist
	Power:
	Apply a voltmeter to the Master stone's internal battery while stone is in range of natural light and check for a charge.
	Repeat for Slave Stone 1.
	Repeat for Slave Stone 2.
	Repeat for Slave Stone 3.
	Repeat for Slave Stone 4.
	Repeat for Slave Stone 5.

Table 5.5.1 – Power System Checklist

If everything is working accordingly move to Table 5.5.1 – Power System Checklist to test both the application control and lighting systems are working as designed.

	Application and Lighting:
	Download application onto smartphone device.
	Make sure the user is capable of opening application.
	Make sure the user is capable of altering settings on the application.
	Once Bluetooth checked as ON within the smartphone, make sure the "PRESS- Master" Bluetooth enabled device is available.
	Make sure the "PRESS- Slave" Bluetooth enabled device is an available option but do not select these.
	Ensure that it possible to pair with the "PRESS- Master" Bluetooth enabled device.
	Set all stones to be ON in white via the application, and make sure all stones light in this manner.
	Set Master stone to light upon sensing pressure via application and make sure that it lights as necessary.
	Repeat for Slave Stone 1.
	Repeat for Slave Stone 2.
	Repeat for Slave Stone 3.
	Repeat for Slave Stone 4.
	Repeat for Slave Stone 5.
	See to it that LED arrays in each of the stones light properly.
	Set all LEDs to red and see to it that LED arrays in each of the stones light properly.
	Set all LEDs to blue and see to it that LED arrays in each of the stones light properly.
	Set all LEDs to green and see to it that LED arrays in each of the stones light properly.

Table 5.5.2 – Application and Lighting System Checklist

If this system checklist passes move to Table 5.5.3 – Structure Stress Checklist to test if stones operates under designed weather proof conditions. This checklist checks if all designed aspects work after being subjected to different weather conditions.

	Structure:
	Pour water onto stone and check for dampness or water intrusion.
	Set stone into refrigerator and give stones commands via the application and check to make sure they light as needed.
	Set stones in outdoor warm environment and give stones commands via the application and check to make sure they light as needed.
	Rest a maximum of 300 pounds of weight upon stones and make sure no cracking occurs.
	Set under 30 pounds of weight upon stones and check to make sure that they do not light up upon pressure sensing when that option is engaged.
	Give commands to the stones and check to see that they respond quickly.
	Turn stones on and set them to be lit at full intensity for duration of four hours and ensure they remain on for that full period.
	Reexamine the Requirements and Specifications section of this report and make sure that all requirements specifically listed in that section are met.

Table 5.5.3 – Structure Stress Checklist

6 – Administrative Content

6.1 – Milestones

A tabular breakdown of the project design project research, design, build and testing is listed below in Table 6.1.1 - Table 6.1.4. This table is start and end date for each step in the design and build process as well as the person responsible for it. Each table is broken down by research, design, prototype/test, and build.

Task Name	Start	Finish	Duration	Resource Names
P.R.E.S.S.	Wed 9/24/14	Wed 4/22/15	157 days	
Research	**Wed 9/24/14**	**Tue 10/14/14**	**15 days**	
LEDs	Wed 9/24/14	Fri 10/31/14	28 days	Ben
DMX Protocol	Wed 9/24/14	Fri 10/31/14	28 days	Ben
Microcontroller	Wed 9/24/14	Fri 10/31/14	28 days	Phill
Weight Sensor	Wed 9/24/14	Fri 10/31/14	28 days	Amanda
Light Sensor	Wed 9/24/14	Fri 10/31/14	28 days	Ben
Heat Coils	Wed 9/24/14	Fri 10/31/14	28 days	Phill
RF Communicators	Wed 9/24/14	Fri 10/31/14	28 days	Amanda
Solar Pannels/Batteries	Wed 9/24/14	Fri 10/24/14	23 days	Mariah

Table 6.1.1 – Timeline of Project Research

Task Name	Start	Finish	Duration	Resource Names
Design	**Fri 10/31/14**	**Fri 1/2/15**	**47 days**	
Light System	Sat 11/1/14	Thu 12/4/14	25 days	Ben
Communication	Mon 11/3/14	Fri 12/5/14	25 days	Amanda
Weather-Proof Case	Sat 11/1/14	Fri 12/5/14	25.71 days	Amanda,Mariah
Power Control	Sat 11/1/14	Thu 12/4/14	25 days	Mariah
Final Design	Thu 12/4/14	Thu 12/4/14	1 day	Amanda,Ben, Mariah,Phill

Table 6.1.2 – Design Timeline for Project

Task Name	Start	Finish	Duration	Resource Names
Prototype	**Fri 12/5/14**	**Thu 1/29/15**	**40 days**	
Lighting	Fri 12/5/14	Thu 1/29/15	40 days	Ben
Wireless Communication	Fri 12/5/14	Thu 1/29/15	40 days	Amanda
Weather-Proof Case	Fri 12/5/14	Fri 1/30/15	40 days	Amanda,Mariah
Power System	Fri 12/5/14	Thu 1/29/15	40 days	Mariah
Parts Ordered	Thu 12/4/14	Thu 1/29/15	41 days	

Table 6.1.3 – Prototyping Timeline for Project

Task Name	Start	Finish	Duration	Resource Names
Build	**Sun 2/1/15**	**Wed 4/22/15**	**63 days**	
Lights	Sun 2/1/15	Thu 2/12/15	10 days	Ben
Wireless Communication	Mon 2/2/15	Fri 2/13/15	10 days	Amanda
Weather-Proof Case	Sun 2/1/15	Wed 2/11/15	9 days?	Amanda, Mariah
Power System	Sun 2/1/15	Thu 2/12/15	10 days	Mariah
Final Document Submitted	Thu 12/4/14	Thu 12/4/14	0 days	Amanda, Ben, Mariah, Phill
Segmented Build Complete	Sat 2/28/15	Sat 2/28/15	0 days	Amanda, Ben, Mariah, Phill
Complete Build	Sun 3/1/15	Tue 3/3/15	3 days	Amanda, Ben, Mariah, Phill

Table 6.1.4 – Build Timeline for Project

6.2 – Budget

QTY	PART NUMBER	ITEM	PRICE PER	SUB TOT
3	202302514	3/4 in. x 4 in. x 8 ft. Cedar Board	7.32	21.96
1	100322337	1 in. x 12 in. x 8 ft. Common Board	18.88	18.88
1	203183545	1-gal. Shield and Seal Polyurethane Water-Proofing Sealer	28.99	28.99
3	B006FLZ0R6	0.236" thick plexiglass sheet 12" x 24"	20.25	60.75
12	204633635	1/4 in. -20 tpi x 4 in. Stainless Steel Coarse Thread Carriage Bolt	1.4	16.8
9	595-TLC5971PWPR	LED Driver: TLC5971PWPR	3.26	29.34
6	595-MSP430F5510IPT	MSP430F5510IPT	5.17	31.02
48	720-LTRBGFSFABQKYOZ	RGB LED: LTRBGFSF-ABCB-QKYO-Z	0.832	39.936
24	720-LWQ38EQ1S23K6L1	White LED: LW Q38E-Q1S2-3K6L-1	0.227	5.448
6	7840	7 x 4.5 in. Mono-crystalline Solar	34.95	209.7

		Panel		
6	8484	Polymer Lithium-Ion Battery	29.95	179.70
6	12885	Sunny Buddy-Maximum Power Point Charger	24.95	149.7
6	841-MMA2241KEG	Accelerometer: MMA2241KEG	7.08	42.48
			TOTAL	834.704

6.2.1 – Finalized Budget

Purchased	
Item Category	*Cost*
Solar power and charge controller materials	$ 556.44
Structure materials: wood, screws, plexiglas etc.	$ 329.81
LED strip lights, connectors and mounting brackets	$ 118.25
Breakout boards for prototyping with ICs	$ 213.74
Voltage regulation components	$ 52.82
Pressure sensing: Accelerometers and FSRs	$ 112.90
Bluetooth Modules	$ 49.95
Electrical components: resistors, capacitors, etc.	$ 161.78
PCBs from Osh Park	$ 353.80
Miscellaneous Items	$ 276.68
Total Spent:	**$ 2,226.17**

Grand Totals	
Leidos & Duke Total Granted Funding:	$2,190.00
Total expenses covered by group members:	*$36.17*
Total Spent:	**$2,226.17**

7 – Appendices

7.1 – References

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7.2 – Emails and Permissions

RE: MAXIM6969

DELETE REPLY REPLY ALL FORWARD

Ferda Millan <Ferda.Millan@maximintegrated.com>
Tue 11/4/2014 6:41 PM
Inbox

Mark as unread

To: amanda.ross <amanda.ross@knights.ucf.edu>;
Cc: Phillip Dunlop <phildee27@gmail.com>;

Bing Maps | Action Items | + Get more apps

Hi Amanda,

Thanks for getting in touch.

Yes, you can use the image in your paper. When doing so, please state, "Drawing courtesy of Maxim Integrated. © 2014." As long as you do not alter the drawing in any way, this will suffice. (You'll notice that Maxim is not written in all caps.)

I appreciate you getting in touch with us about this.

Best of luck on your research paper!
Regards,
Ferda

Ferda Millan
PR Manager, Corporate Communications
160 Rio Robles | San Jose, CA 95134 | USA
Office: +1 (408) 601-5429 | Mobile: +1 (408) 373-1854
Maxim Integrated | www.maximintegrated.com

From: amanda.ross [mailto:amanda.ross@knights.ucf.edu]
Sent: Monday, November 03, 2014 8:36 PM
To: Ferda Millan
Cc: Phillip Dunlop
Subject: MAXIM6969

Good Evening Ferda,

My name is Amanda and I am a student at University of Central Florida. I am currently doing research for a senior design project and I came across the part mentioned in the title of this email. I am interested in using this image (http://www.maximintegrated.com/en/images/qv/4809.gif) to describe a concept in my research paper. I wanted to ask so as not to commit any copyright infringement. I will provide references to the part and all the appropriate credit to MAXIM Integrated within the paper, I just wanted to run this by you guys first. Please let me know if this would be acceptable or not.

Thank you for your time,
Amanda Ross

RE: Arduino Uno Schematic

DELETE REPLY REPLY ALL FORWARD •••

trademark=arduino.cc@supportbeemail.com on behalf of Nidha Syed <trademark@arduino.cc>

Thu 11/6/2014 12:58 AM

Inbox

Mark as unread

To: amanda.ross <amanda.ross@knights.ucf.edu>;

Cc: Phillip Dunlop <phildee27@gmail.com>;

Action Items

+ Get more apps

Hi Amanda,

Thanks for writing to us.

Yes you can use Arduino schematics in your paper but you will need to follow our trademark rules.
- You cannot use the Arduino logo in your paper,
- You will need to ensure to use Trademark (i.e. TM in superscript) next to Arduino at all times,
- You have to use images of original Arduino boards only.

Hoping this was clear.

Best,
Nidha Syed
Arduino SA
On Tue, Nov 4, 2014 at 10:13 AM, "amanda.ross" <amanda.ross@knights.ucf.edu> wrote:

> Good Evening,
>
> My name is Amanda Ross and I am a student at the University of Central Florida. I am currently in Seni or Design and am writing a research paper for our final group project. I found that all of Arduino's schematics are open-source but I wanted to email and make sure that I would not be infringing on any copyrights if I were to include your reference schematic in my paper in order to explain a concept (of course, while providing all the appropriate credits to Arduino). I wanted to run this by your team in order to have written confirmation that this act is (or is not) acceptable. Please let me know at your earliest convenience.
>
> Thanks for your time!
> Amanda Ross

Hello National Cancer Institute,

I am senior electrical engineering major at the University of Central Florida. I am currently working on a PV solar charging system for my senior design project and I am currently in the research and design phase of my project.

I was hoping you would grant me permission to use an image off your website for the documentation portion of my design project.

The image I would like to use is a table found on your webpage:
http://gis.cancer.gov/tools/uv-exposure/

Please let me know if I can use this image as part of my documentation. This is strictly for academic and informational purposes.

Thank you,

...

SRP Web Projects 12:12 PM (6 hours ago)

to me

Hi Mariah,

The majority of the content on the GIS website is in the public domain, however some of the graphics may not be. Which image are you interested in using? The US map of average global solar radiation levels from the linked page below or another image or table?

Thanks,
Ginger

Ginger Carter
SRP Web Site Support
IMS, Inc.
srp@imsweb.com

Hello Battery University,

I am senior electrical engineering major at the University of Central Florida. I am currently working on a PV solar charging system for my senior design project and I am currently in the research and design phase of my project.

I was hoping you would grant me permission to use an image off your website for the documentation portion of my design project.

The image I would like to use is a table found on your webpage:
http://batteryuniversity.com/learn/article/whats_the_best_battery

Please let me know if I can use this image as part of my documentation. This is strictly for academic and informational purposes.

Thank you,

...

John Bradshaw <John.Bradshaw@cadex.com> Nov 26 (6 days ago)
to me

Hi Mariah,

Yes, you may use the material as requested. Please cite source where appropriate.

Regards,

John Bradshaw - Marketing Communications Manager
Cadex Electronics Inc. | www.cadex.com
Vancouver | Minneapolis | Frankfurt

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7.3 – Datasheets

Osram White LED:
http://www.osram-os.com/Graphics/XPic9/00078914_0.pdf/LW%20Q38E%20-%20CHIPLED%200603.pdf

Osram RGB LED:
http://www.osram-os.com/Graphics/XPic2/00062752_0.pdf

TI MSP430:
http://www.ti.com/lit/ds/symlink/msp430f5506.pdf

TI LED Driver:
http://www.ti.com.cn/cn/lit/ds/symlink/tlc5971.pdf

Freescale Accelerometer:
http://cache.freescale.com/files/sensors/doc/data_sheet/MMA2241KEG.pdf

Li-Ion Battery:
https://cdn.sparkfun.com/datasheets/Prototyping/6000mAh-3.7V-P-1S3804AD.pdf

Sunny Buddy Charge Controller:
http://cdn.sparkfun.com/datasheets/Prototyping/LT3652.pdf