P.R.E.S.S. – Pressure Reactive Electronic Solar Stones

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***Abstract* — The objective of this project is to utilize solar energy to control and power user programmable multicolor LEDs within a weather proofed structure from an android mobile device. This device is capable of providing the user with a safe lighted pathway in a vast array of customizable, user defined color preferences. Selection of this project was based on a necessity to create both a functional and unique design. The system is self-contained and uses renewable energy in an effort to be conscious of environmental matters in regards to power consumption.**

***Index Terms* — Application programming interfaces, Battery management systems, Bluetooth, Lighting control, Microcontrollers, Power integrated circuits, Pressure measurement.**

I. INTRODUCTION

The intention of this design project was to apply the skills and knowledge gained throughout the groups educational careers at the college of Electrical Engineering and Computer Science. Integration of all of the group's interests in diverse technologies led to the creation of P.R.E.S.S. This project utilizes power integration, embedded processers, Bluetooth, renewable energy, and mobile application development. The stones will be made of a waterproof wood and Plexiglas structure that can withstand substantial weight and varying weather conditions. Inside these Plexiglas topped units, will be an array of LEDs, a solar panel, power management circuitry, a microcontroller, a force sensitive resistor, and a Bluetooth module that can make wireless connections between the user and the microprocessor.

The solar charger used to regulate output from the monolithic photovoltaic solar panel uses maximum power point tracking (MPPT) to charge a Polymer Lithium Ion Battery. The battery supplies power to a DC-DC voltage regulation system that outputs the appropriate voltages needed to power the components on the PCB.

The mobile application is operational on Android devices. From this application the user can connect to each individual stone, and send information wirelessly using Bluetooth standard communication. Inside this application is an extensive color library comprised of industry defined colors. An option is available to create a custom color by changing the RGB intensities inside the application.

The MCU utilizes various communication protocols for input and output as well as analog to digital conversions. Primarily using the Internal MCU clocks are used to generate random integers for part of a randomized color feature in the Android application. The intentions of each member of this team was to research, design, prototype, and successfully test each aspect of the P.R.E.S.S. system.

II. STRUCTURE

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. These rods are tapped and threaded making it possible to thread a bolt through the bottom of the structure into the center of the rod therefore fastening the Plexiglas in place. This was designed and modeled in AutoCAD prior to development of a prototype. Below in Figure 1.1 is a side view is shown emphasizing the height and width dimensions.

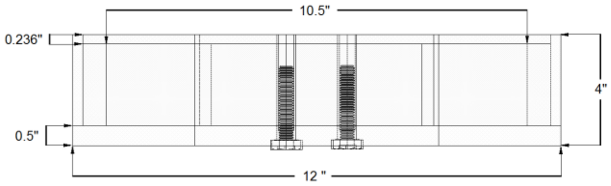


Figure 1.1 - Side x-ray view in AutoCAD 2012©.

Figure 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 and threaded bolts.

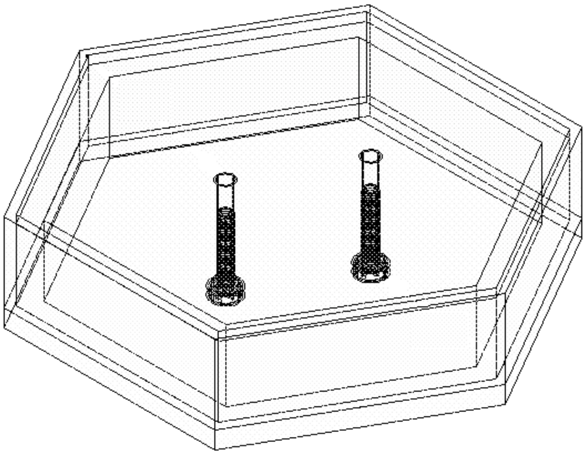


Figure 1.2 - Diagonal x-ray view in AutoCAD 2012©.

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 1.3 – Diagonal view of final structure build.

Above is Figure 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.

III. POWER MANAGEMENT

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) [1]. 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 3.1 below, it shows testing of the solar charge controller.

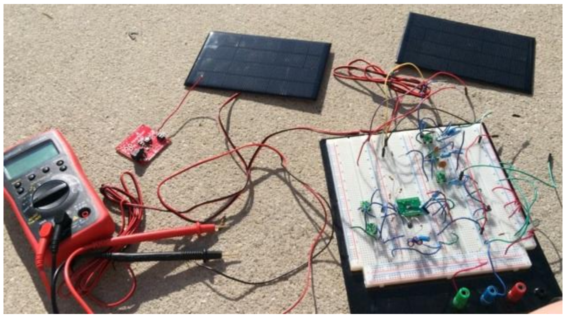


Figure 3.1 - Solar Charger Test.

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 3.1 and 3.2 below.

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

Equation 3.1

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 3.2

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 [7]. 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.

IV. MCU CONTROL & COMMUNICATION

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 shows the general flowchart as to how the MSP430 is programed.

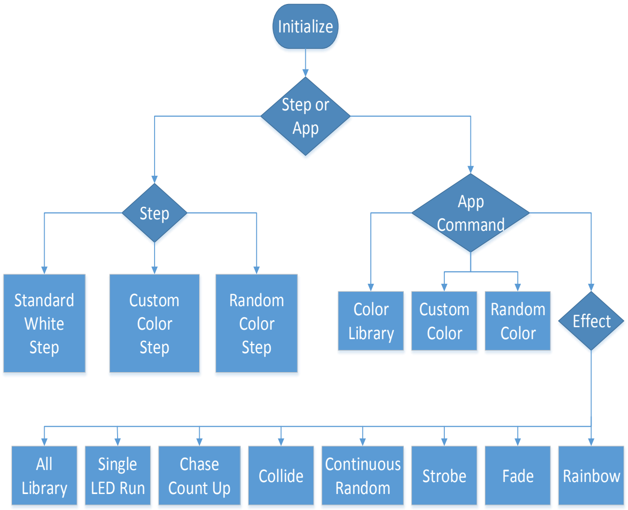


Figure 4.1 – MCU Software Flowchart.

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 4.2 shows control sending 10 LEDs to light in red at 583 kHz.

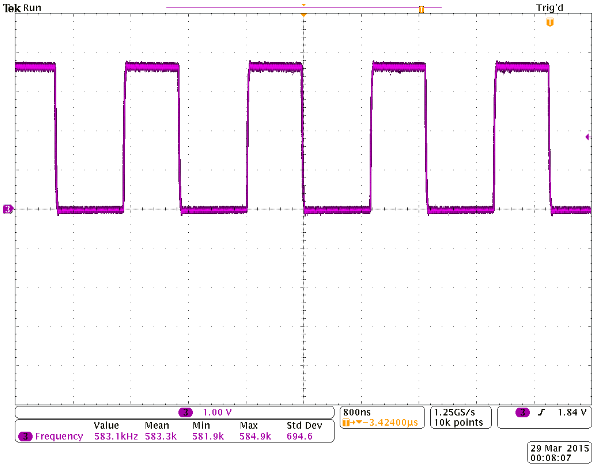
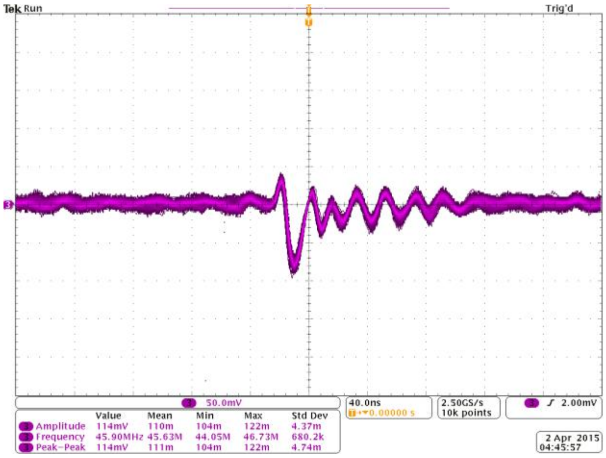


Figure 4.2 – Red LED Output Frequency 583 kHz.

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 4.3 and Fig 4.4 show oscilloscope readings of the Vout for the FSR circuit before pressure is applied and after respectively. [3] [4] [5]



```
             Value     Mean    Min     Max     Std Dev
3 Amplitude  114mV     110m    104m    122m    4.37m
3 Frequency  45.90MHz  45.63M  44.05M  46.73M  680.2k
3 Peak-Peak  114mV     111m    104m    122m    4.74m
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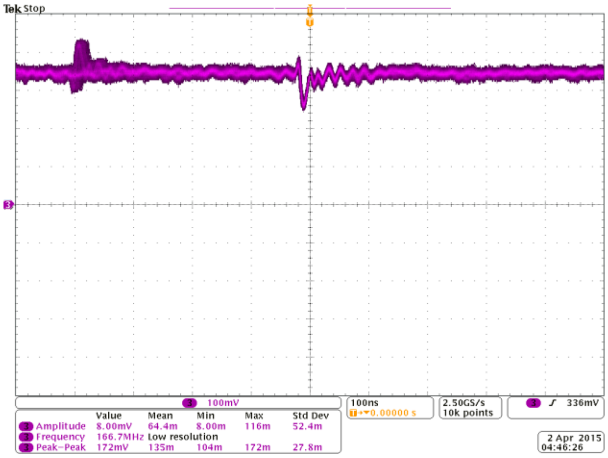
Figure 4.3 – ADC No Step: Peak-to-Peak Voltage 114 mV, Frequency 45.9 MHz.



```
             Value     Mean    Min     Max     Std Dev
3 Amplitude  8.00mV    64.4m   8.00m   116m    52.4m
3 Frequency  166.7MHz Low resolution
3 Peak-Peak  172mV     135m    104m    172m    27.8m
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Figure 4.4 – ADC Stepped: Peak-to-Peak Voltage 172 mV, Frequency 166.7 MHz.

V. MOBILE APPLICATION & BLUETOOTH

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 5.1 – 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 5.2.

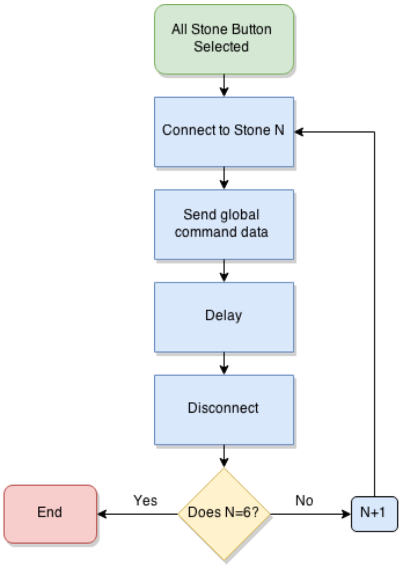

Figure 5.2 – All Stones Flow Chart.

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 5.3. 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 5.3 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.

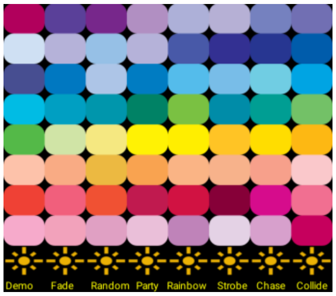

Figure 5.3 – Color Library and Features.

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 5.4.

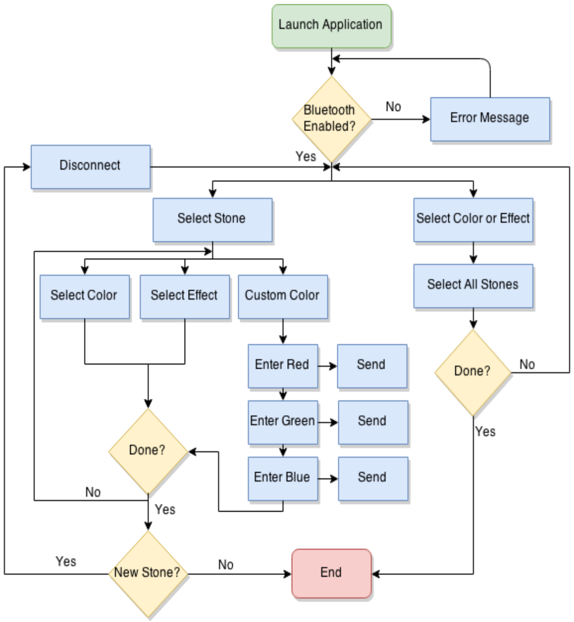

Figure 5.4 – Application Flow Chart.

VI. INTEGRATION - PCB

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 6.1.

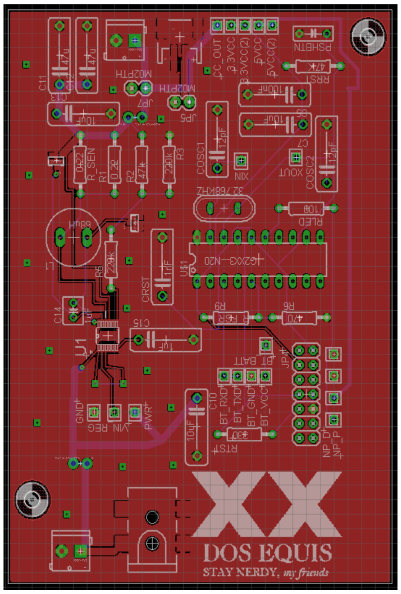

Figure 6.1 –Main board drawn in Eagle 6.6.0 ©.

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 6.2.

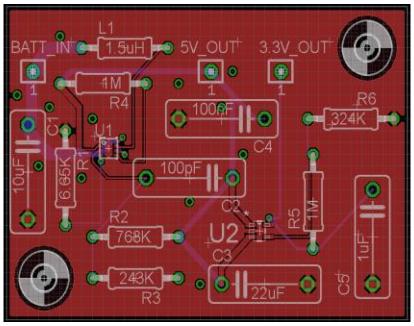

Figure 6.2 –Voltage regulator drawn in Eagle 6.6.0 ©.

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 6.1 and 6.2 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 6.1 – Trace Cross-sectional Area

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

Equation 6.2 – 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. [6]

VII. CONCLUSION

The P.R.E.S.S system involved integrating renewable solar energy, charging circuits, power regulation systems, microcontroller units, Bluetooth communication, lighting control, mobile applications, and printed circuit board fabrication. In order to accurately and efficiently design and build this project countless man hours of research, development, and testing were put in by each group member.

This project has been challenging, fulfilling, and beneficial to the growth of the group members as young engineers. It honed the useful skills of conducting research, time management, problem solving, working in group settings, creating and giving presentations, managing budgets, and most of all useful electrical engineering design, troubleshooting, and testing skills. All of these are invaluable to the possible future educational careers as well as the future hopefully successful careers of the group in the engineering industry.

Without the knowledge and experience gained during the time as students at UCF this project would be nearly impossible. This is due to not only to the group’s hard work and dedication, but to the hard work and teaching ability of the UCF staff.

VIII. ACKNOWLEDGEMENTS

This group would like to extend the most sincere gratitude to UCF's wonderful professors and sponsors who helped in making the group's vision into a reality.

The P.R.E.S.S. project gained sponsorship from Leidos and Duke Energy of central Florida. These companies generously donated the funding for the group's efforts and made it possible for the use of cutting edge technology and reliable components within the design.

A thank you would like to be given to Professor Richie for his guidance, mentorship and leadership over the past year in this senior design class as the group has been finding a footing in design engineering. Without such wonderful provision, this group would never have had the opportunity to complete such an undertaking.

IX. REFERENCES

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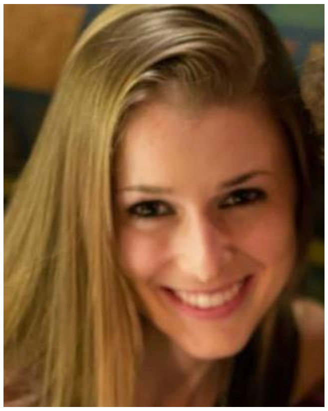
X. BIOGRAPHIES

Mariah Kenny is a senior Electrical Engineering student at the University of Central Florida due to graduate in May 2015. Following graduation she will be joining Leidos Engineering as an Electronic Utility Design Engineer. She aspires to become a project management professional for renewable energy developments at a leading power company.



Amanda J. Ross will be graduating cum laude in May of 2015 with her Bachelor's degree in Electrical Engineering. Over the course of her high school and collegiate careers she has had the opportunity of interning for wonderful companies such as Universal Studios, The Walt Disney Co. and Lockheed Martin. Following her graduation, Amanda has accepted an offer from Texas Instruments for an applications engineering position in Dallas Texas and is excited to be starting this new chapter in her life.

Phillip L. Dunlop will be graduating cum laude in the spring of 2015 with a Bachelor of Science in Electrical Engineering with a minor in Mathematics. Phillip is greatly looking forward to obtaining a position at a reputable engineering company that will utilize his skills and personal interest in digital electronics while also helping him continue his education into graduate school.

Benjamin Gafoor is a senior student of the department of Electrical Engineering at the University of Central Florida. He will pursue a Master's of Electrical Engineering starting in the fall of 2015 focusing in signal processing field, as well as take the Fundamentals of Engineering in July. While working on his master's Benjamin plans to work on projects that will one day be the foundation for a business venture of his own.