Solar-Powered Blinds Senior Design Project

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Abstract **—The main feature of this project is the collection of solar energy. Far too much electricity that powers the world today comes from the consumption of fossil fuels. It will soon become increasingly important to find alternative methods of electricity generation before our limited resources run out. This project will introduce just one of many envisioned products that will be commonly found in residential homes in the future which will collect energy to be stored in a central power storage unit which will power the entire residence. These central electricity storage units are essentially large rechargeable batteries. To this end, our project will modify the traditional residential window blinds to complement the power infrastructure of a modern home.**

Index Terms **— Solar energy, photovoltaic systems, renewable energy sources, maximum power point trackers, Bluetooth, Internet of Things.**

I. Introduction

Since the main focus of this project is to provide additional natural energy to a residence, it is only logical that it should maximize the energy it collects by minimizing the energy it consumes while still providing features that a consumer expects from a technologically-advanced product in the current market. To meet these goals, the blinds will aim to be lightweight, relatively low cost, and use minimal energy to perform basic operations such as opening and closing.

The current state of technological development is seeing an increasing amount of products developed for the "Internet of Things". These blinds aim to be a member of this category of products by being interconnected wirelessly with the user's mobile device to allow for greater control over their home. Motor operation for these blinds opens up the ability to widen our demographic to the elderly or disabled by making the device easier and more convenient to operate.

The main objective of this project is to provide a supplementary power source for an energy-conscious home. The operation of the product itself will be self-powered so that it will not use up disposable batteries or require external electricity. Additionally, the excess energy gained through the solar cells can be stored in a battery for use in other areas of the home. A USB charge port is included on the product as the only provided interface for accessing this excess energy. However, if a central home battery storage device is used, it is assumed that it will have additional interface ports to utilize the energy provided. Multiple installations of this product can provide a significant boost in the home's electricity reserves.

II. Design Structure

A. Blinds Design

In order to maximize the power capable of being captured by the system while maintaining the roller shade design, a combination of crystalline solar cells and amorphous silicon solar panels is used. The reason for this is an attempt to utilize as much surface area as possible within reasonable cost to harvest solar energy. There are three main design structures for blinds: vertical slats, horizontal slats, and rollable canvas.

The most common of these, at least in the U.S., is the horizontal slat design. The problem with using this structure for this project is that wiring could pose a problem, and it would also be difficult to roll up the blinds. While there are some blind designs that use the horizontal slats and do not roll up, we felt that this was more of a hindrance rather than a solution. Next, we considered a design with vertical slats. This provided a reasonable solution to the other concerns we had with the horizontal slats. However, we decided to go a step further to ensure that we had considered all the options. Upon evaluating the practicality of a rollable canvas design, we realized that using this type of design would allow us to reduce the motor requirement from one motor to two motors. Using only a single motor simplified the project as far as programming, hardware, interface, and other departments. The only drawback to a rollable canvas was that we would also have to use a thin-film rollable solar cell to mount on the canvas, which was more expensive than other types of photovoltaic technology.

B. Solar Panel Mounting

Once the design structure of the blinds was determined, the next consideration was the placement of the solar cells and other components. Fig. 1 and Fig. 2 show the design concept for the project.

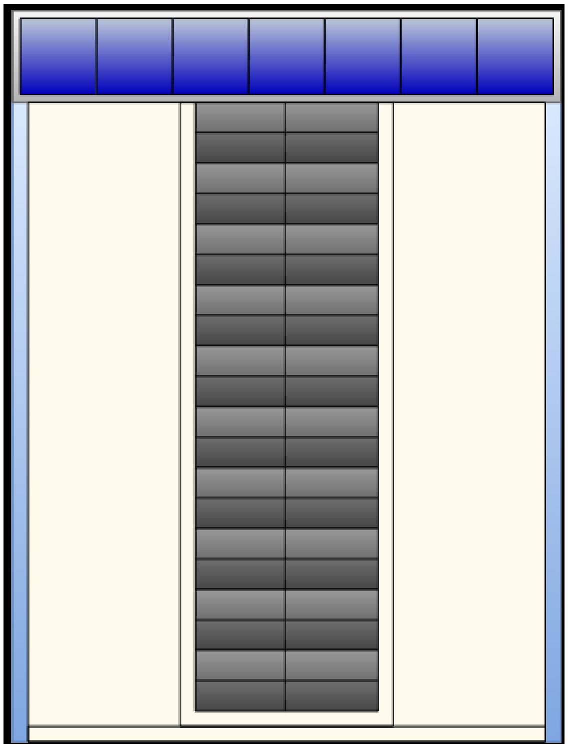

Fig. 1 Final design for the blinds structure and mounted solar cells as would be seen from standing outside the window looking inward.

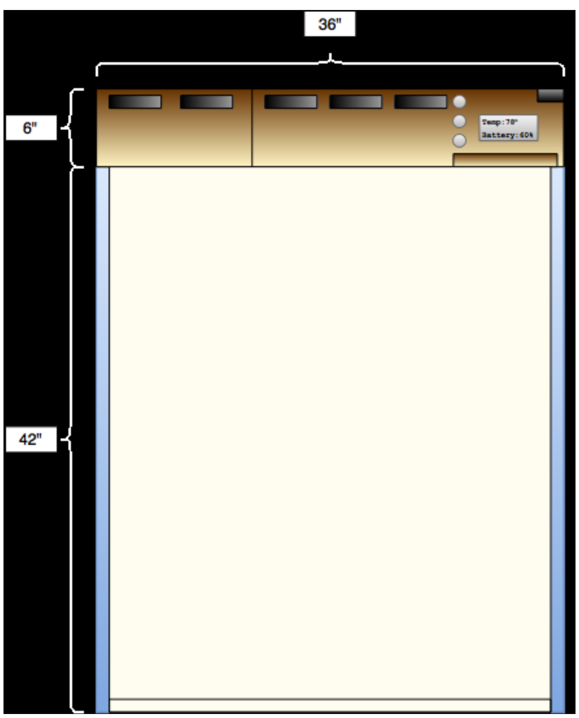

Fig. 2 Design concept for the control interface as would be seen from standing inside the room.

C. Housing Design

The housing is the wall-mounted compartment that contains the motor, circuit boards, LCD, and other components. The monocrystalline solar cells are mounted to it, and are 5" squares, so the housing needed a height of at least 5". The depth needed to be at least 4" in order to contain the motor and retracted canvas and thin-film solar panel. Additional space would be required inside for the circuit board, MPPT module, wiring, temperature sensor, battery monitor, and buttons.

The resulting housing ended up being rather large, roughly 7"x4.5"x36", and constructed out of wood. We do not have a mechanical or industrial engineer in our group, so wood was the easiest material we could use to construct a prototype. The monocrystalline cells are mounted by recessing the window-facing side of the housing by about 1/4" and then sandwiching the cells between the wood and a large acrylic panel to secure them in place.

D. Wireless Communication Protocol

A wireless connection was required to communicate between our device and a mobile phone equipped with our application. There were several different options available to us to accomplish this goal, and we primarily considered: Wi-Fi, Bluetooth, and Zigbee [1]. Although power consumption is the primary focus of our project, we also needed to take into account other requirements. We looked into metrics for each connection method such as range and bandwidth as well. These metrics have been gathered and compiled into Table I for easy comparison [2].

TABLE I

WIRELESS CONNECTION PROTOCOL COMPARISON

Connect Protocol	Active Power	Idle Power	Max Range	Band-width
Wi-Fi	750 mW	negligible	32-95 m	54 Mb/s
Bluetooth	100 mW	negligible	10 m	1 Mb/s
Zigbee	80 mW	negligible	10 m	250 kb/s

If we choose to use a Wi-Fi chip on our microcontroller, it will require the user to purchase and set up their own wireless router. Also, it would take significantly more power to operate than either Bluetooth or Zigbee options. It also takes additional steps to set up through a router. The main benefit of this is the significantly longer range. If it's connected to a router, it can potentially be accessible from anywhere that has a wireless connection. However, the power drain from Wi-Fi does not make this a good option.

Bluetooth and Zigbee are both very similar in terms of power consumption, range, and security protocols. However, with Zigbee being the newest standard to enter the remote connectivity lineup, there are still problems to be worked out. Some of these problems include interoperability [3] and a lack of development resources.

III. Power Input

A. Power Input Sources

The 3.3W 5”x5” monocrystalline photovoltaics are attached to the back of the housing unit used to store the battery and circuit boards.An image of the monocrystalline cells can be seen in Fig. 3. Each cell has an average power of 3.3W operating at a maximum voltage of 0.58V and a maximum current of 5.93A. Adding the 14W amorphous silicon rollable solar panel brings the total power of the system to 34.6W. An image of the flexible thin-film solar cells can be seen in Fig. 4. This system will be capable of capturing the amount of energy capable of being stored by our 60W-h battery in 1.73 hours under ideal lighting conditions.

Fig. 3 Monocrystalline photovoltaic cell by Sunpower.

Fig. 4 Thin-film solar panel by PowerFilm Solar.

The only tricky part of this configuration is that we needed to connect the rollable panel with the hard panels. Because the panels would be receiving varying amounts of power over time, we were concerned about some current flowing from one panel and into the other, rather than into the charge controller. To fix this, we added a boost converter to the hard panels to match the voltage of the rollable panel. The rollable panel has a blocking diode built-in so we do not have to worry about that one, but we added a diode to the output of the boost converter from the crystalline panels. After that, we were able to easily connect them in parallel and feed the output into the charge controller to be forwarded on to the battery.

B. Power Generated

Maximum Power Point Tracking (MPPT) compares the output voltage of the solar module to the terminal voltage of the battery. From this information, the maximum power that can be output by the solar module into the battery is calculated. The optimized voltage is then selected in order to maximize the current flowing into the battery. The efficiency is increased most when temperatures are below average. A 20-45% power gain in winter and a 10-15% power gain in summer can be achieved when an MMPT is used [4].

The Genasun GV-5 is a 65W 5A MPPT solar charge controller for lead-acid batteries. Inputs include a 27V maximum panel voltage input, a 12V battery input, and a load input with a continuous rated load current of 5A. The minimum battery voltage for normal operation is 7.2V and the maximum input current is 9A. A computer controlled four-stage battery charging profile is used in order to increase the battery life and maximize capacity. This includes an absorption voltage of 14.2V, a float voltage of 13.8V, and a load disconnect voltage ranging from 11.4V to 12.5V. A battery temperature compensator is also included which adjusts the voltage at -28mV/°C. The controller utilizes an MPPT tracking speed of 15Hz in order to adapt quickly to changing light conditions. This results in an electrical efficiency of 96%-99.85% and a tracking efficiency of over 99%.The GV-5 consumes 0.150mA when operating and 0.125mA when asleep.

The power generated by the solar panels obviously varies based on the weather, angle of exposure to the sun, and other environmental obstructions. Overall, the power generation from our combined solar panels should be very effective. See Table II for our estimates on power generation with the panels operating at varying levels of efficiency.

TABLE II
POWER GENERATION SUMMARY

Light Condition	Power Generated	Time to Fully Charge 60 W-h Battery
100% Ideal	36.96 W	1.62 hr
75% Ideal	27.72 W	2.16 hr
50% Ideal	18.48 W	3.25 hr
25% Ideal	9.24 W	6.49 hr

As can be seen in Table II, the power generated by our solar panels is significant. By using multiple products such as these blinds together in unison, a great amount of power can be generated. The fact that blinds are so easy and inexpensive to install when compared to traditional roof-mounted solar panels makes this the value of this project readily apparent.

IV. POWER OUTPUT

The load output of the charge controller is connected to the PCB which is designed to deliver a specified amount of power to each of the loads. The loads include the drive shaft motor, microcontroller, USB charger, LCD display, and temperature sensor.

A. Drive Shaft Motor

The motor operates at 12V and draws around 1.5A of current when operating. This is the largest current required by any of the components. However, the motor will have very infrequent use, and it will only take about 15 seconds of continuous operation to roll the canvas up or down. The amount of power the motor will take is determined by the amount of use by the user, but it is assumed to be far from constant. The actual motor can be seen in Fig. 5

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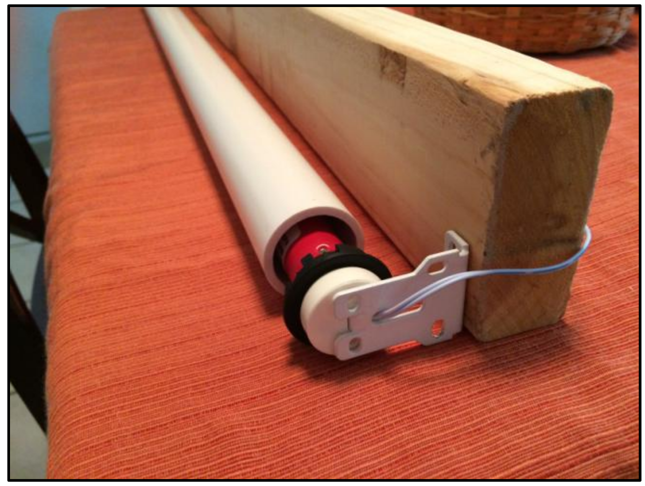


Fig.5 Drive shaft motor with PVC pipe extending it to the full 36” length.

B. Microcontroller

We considered two options for our MCU. The Atmel SAM3N00A is one of the low power options available by Atmel that was considered. Normal operation requires 1.62-3.6 Volts, with an active current consumption of 18mA and sleep mode current of 8.4mA. This is very much acceptable for the power requirements of our project.

The other option we considered for our MCU was the Texas Instruments CC2640. This chip takes 3.8V max voltage, with an active current of 2.938mA and sleep current of 0.550mA. The power consumption of the Atmel was good, but the CC2640 is over a dozen times more efficient. This was clearly the option we wanted to go with as far as power consumption was concerned.

After starting development with the CC2640, we realized that programming the Bluetooth protocols was tedious and challenging. Given the time restraints for the project, we sought an alternative solution. We decided upon using the LSR SaBLE-x Bluetooth Module. This chip uses the same CC2640 MCU, but with a more extensive development suite to simplify the programming of the device. Additionally, it had a built-in antenna circuit so we did not have to design our own.

C. USB Charger

The biasing of the four USB pins is important when deciding on what kind of devices will be capable of charging. Pin 1 is defined as Vcc and is always biased at

5V. A 5V voltage regulator will be needed in order to reduce the 12V battery voltages down to 5V. The TI L7805 voltage regulator will maintain a fixed output voltage of 5V with a maximum output current of 1.5A. Pin 4 is defined as ground and is always connected to ground. The charging port of a USB chargeable device contains hardware that detects when a charger is connected. Traditional USB ports have a maximum output of 0.5A; however, newer devices are capable of using higher currents, which results in faster charging times. Pins 2 and 3 are defined as the data pins. Pin 2 is the negative data pin and pin 3 is the positive data pin. If the data pins of a charger are left floating then the device will default to the traditional 0.5A rate. If the data pins are shorted then the device will be capable of drawing larger currents. This current will depend on the resistors used.

We decided to leave the data pins floating to simplify this aspect of the project and also to simplify the current draw requirements, which makes it easier to determine average power consumption since it will always discharge the battery at 0.5A. We also decided to add a MOSFET to the design so that we can toggle the power to the USB charger if the battery is detected to drop below a certain defined threshold. This allows for the battery to retain enough power to perform more necessary functions such as motor operation.

D. Display Screen

We initially wanted to use e-paper for our display screen. The reason we liked the e-paper display over some other options is that it only requires power to change the display and then refresh it once every several hours. The resolution is very good too, as can be seen in the example image in Fig. 6. All images displayed on the screen will persist even without any power. This is perfect for our project because the only time we need to update the screen is when there is a temperature change or a significant change in the battery charge.

Fig.6 Example e-paper display from Pervasive Displays.

We had to move away from using the e-paper display because there was a significant lack of documentation to aid in development, and we did not want to go through multiple iterations of the PCD to get it working. E-paper is still a relatively new technology, so this should have been expected, but the benefits of it caused us to spend a lot of time considering it as an option for our display.

After we had ruled out e-paper, we decided to look at alternatives for our display. The screen we chose to use was an LCD, Newhaven Display International model NHD-C0216AZ-FN-GBW, shown in Fig. 7. It does not have any backlighting. Because of this, it operates at a lower power level than other LCD screens we have seen, which was the main reason for choosing this particular model. According to the data sheet, the LCD operates with an average voltage of 5.0V and a current of 1.0mA.

Fig.7 LCD screen that was purchased, manufactured by Newhaven Display International.

Admittedly, the screen was smaller than expected at 2”x3/4”, but it serves the purpose of what we wanted. All we need to display on it is the temperature from the temperature sensor and the battery life percentage.

E.Temperature Sensor

We needed to add a temperature sensor to the project, since we had outlined it as one of our main requirement specifications. The probe does not take much power at all, and is actually the least power-consuming component of the project. It operates at 3V with a current of 1.5mA.

F. Cumulative Power Consumption

Table III shows the breakdown of the power consumption of each component. These values were taken straight from the components’ corresponding data sheets. When we look at the combined power consumption of all the various components, it is apparent that the most power-hungry components are the motor and USB charger. Fortunately, the motor will only operate for about 15s at a time, and the USB charger will only draw current while a device is connected.

TABLE III

TOTAL POWER CONSUMPTION

Component	Voltage (V)	Current (mA)	Power (mW)
Motor	12	1500	18000
USB	5	500	2500
MCU	3.8 max	2.94	11.17
Bluetooth RX	3.8 max	5.9	22.42
Bluetooth TX	3.8 max	9.1	34.58
Display	5	1	5
Temperature Sensor	3	1.5	4.5

As an additional analysis, we took a look at how long it would take for a phone to fully charge with the USB charger. This analysis was based on a phone with one of the largest batteries, the Samsung Galaxy S5. With a current drain of 2.5 amp-hours, the power drain comes out to 14 W-h. This, in turn, means that it would take 5.6 hours to fully charge the Galaxy S5.

Since some of these components would not be running full time, we decided to normalize the component power drain by comparing them all in Watt-hours. The table to use for comparison can be seen in Table IV.

TABLE IV

NORMALIZED TOTAL POWER CONSUMPTION

Component	Current Usage (A-h)	Power Usage (W-h)
Motor (operating for 15s)	0.00625	0.075
USB Charger	2.8	14
MCU	0.00294	0.011172
Bluetooth RX	0.0059	0.02242
Bluetooth Tx	0.0091	0.03458
Display	0.001	0.005
Temperature Sensor	0.0015	0.0045

As we can see, the USB charger takes a significant amount of power to use and would not be able to fully charge a Samsung Galaxy S5 with the battery capacity we have. However, regular operations take very minimal power to operate. Considering that our battery has a capacity of 60Wh, if we don't use the motor or USB charger, the product will continue to operate normally for about a month without recharging.

V. SECURITY

Due to the nature of this project, being that blinds double as shade and also as a privacy screen, we had to take security into consideration. Since we used Bluetooth protocol for remote connectivity for the mobile application, it leaves it vulnerable for anyone to connect to the device and open or close the blinds without authorization from the homeowner. Our solution for this problem is for the microcontroller to only accept commands sent by a synched device.

The device synchronization utilizes an NFC chip, a subset of RFID technology. It requires a very close proximity to register with a mobile device, on the scale of just a couple inches. This is assumed to only be possible if the user has access to the inside of the residence. With such access, it's also assumed that the person would be authorized by the owner to connect to and control the blinds via the mobile application.

Cell phones from most major manufacturers such as Acer, BlackBerry, HTC, LG, Motorola, Nokia, and Samsung have come equipped with NFC capabilities for several years now [5]. One notable exception to this are that all iPhones older than the iPhone 6. This is not a major setback for us since we are currently only planning to support Android devices with our mobile application. Also, NFC is supported after Android 2.3.3, SDK version 10, which was released on February 9, 2011.As we can see in Figure 19, the amount of people that would not be able to use this feature is only 0.3% (Froyo) of Android users (as of June 1, 2015) [6]. A picture of the NFC tag we purchased from TagStand can be seen in Fig. 8.

Fig.8 NFC tag, with size comparison to a U.S. quarter.

All that is required is to tap the mobile device to the NFC chip which is mounted by adhesive to the housing and the blinds are added to the phone's list of devices. This way, one phone can be used to switch between multiple blinds in a household and control them remotely, and the blinds will only accept commands when the proper RFID is given.

VI. MOBILE APPLICATION

The mobile application has several functions. It is meant to complement the physical interface on the blinds housing. Being able to perform the same operations with a cell phone makes the product more user-friendly for a wider demographic, such as individuals who may not be able to reach the motor controls on the housing.

A.Motor Control

The motor controls for the mobile application are as simple as just three buttons. The physical buttons act on a push-and-hold basis to make the blinds go up or down. However, in order to require less data transfer from the mobile phone, the up and down buttons on the application act as toggles instead, with a third "Stop" button as seen in Fig. 9.

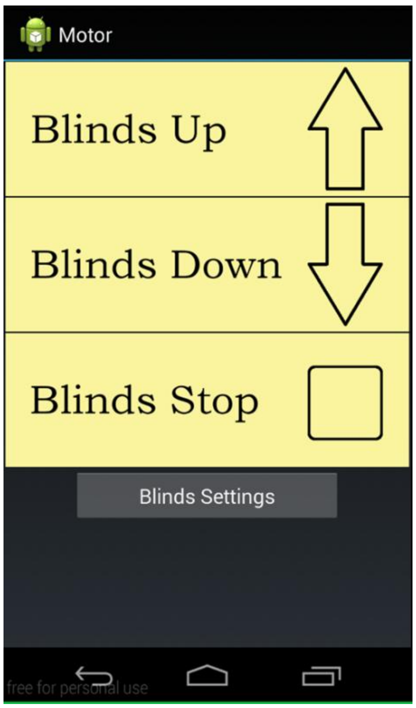


Fig.9 Screenshot of the Motor controls in the mobile application.

B.RFID Synchronization

Two main problems we foresaw with the RFID synchronization were controlling multiple blinds with a single cell phone, and also taking commands from multiple cell phones on one set of blinds. The latter turned out to not be much of a problem. In order to overcome the problem of controlling multiple blinds, we had to save and add ways to manage a list of blinds. An example of the device management screen can be seen in in Fig. 10.

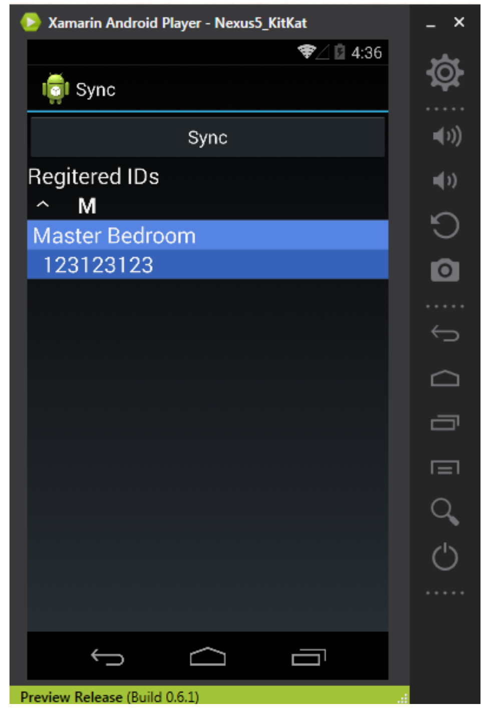


Fig.10 Screenshot of the RFID management list from the mobile application.

When the synchronization is first performed, the new device is added to the list. It displays the ID of the chip it just synchronized with, and a nickname. The nickname can be changed by the user so that they know which set of blinds they are selecting. Whenever they want to change the blinds they are using, they can come back to this screen and make their selection. There are also additional commands to delete a registration and to change the nickname.

E.Weather Information

Since the efficiency of the solar panels depends partly on the weather, we decided it would be convenient to add a weather forecast to the mobile application as well. A screenshot of our weather forecast can be seen in Fig. 11.

In addition to the weather API from Open Weather Map, we also display the temperature of the room gathered by the temperature sensor that is mounted on the housing. This is not as relevant to the solar efficiency as the weather, but it is information that is collected by the device so there is no reason not to display it wherever convenient.

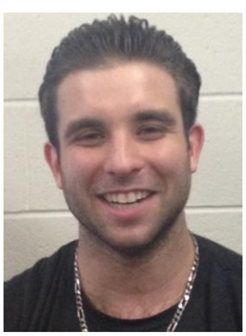
Fig. 10 Screenshot of the current weather forecast activity from the mobile application.

E.Battery Information

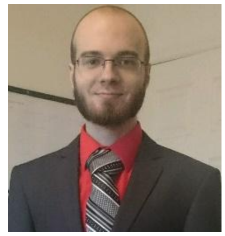
Our project includes a battery monitor for several of its various functions. One of these functions is the enabling and disabling of the USB charger on the housing. The USB charger is designed to disable via MOSFET once the battery charge drops below a defined threshold. This is also displayed on the LCD on the housing, and is again displayed on the mobile application.

Along with the current charge status of the battery, the mobile application also keeps track of previous battery information. It then uses this information to display a graph of the charge history. It can also use short term data points to determine an approximate present charge rate. A total amount of money saved on electricity can also be calculated based on the charge history and an energy billing rate defined by the user. This allows the user to see a quantifiable value of the product.

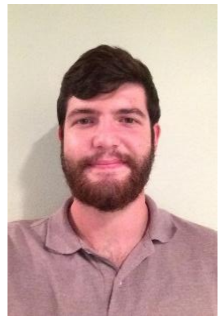
VII. BIOGRAPHY



Stephen Walsh is an Electrical Engineering student enrolled currently at University of Central Florida. He is graduating on December 19, 2015 with my Bachelor of Science in Electrical Engineering. He has plans to pursue a Master's degree after graduation and work for an engineering company.



Dakota Jordan is a Computer Engineering student at the University of Central Florida. He intends to pursue a career in software development here in Orlando. His interests range from mobile applications to database server administration.



Sean Diamond is currently a senior at the University of Central Florida pursuing a Bachelor's of Science in Photonic Science and Engineering. He is working as a network engineer for Verizon Wireless and plans to continue working there after graduation. His interests include fiber optic communication systems, image processing, and nanophotonics.

Artis Coleman is a senior computer engineering student at the University of Central Florida who will be graduating in December 19, 2015. Artis's goals after college are to acquire a software related job in either mobile application design and development or software quality assurance and testing.

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