Solar Powered Bike Rack System

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University of Central Florida | Senior Design Project

ABSTRACT

The main goal of this project is to help to solve the problems that the students who own bikes currently have to deal with every day when it comes to storage place, security, and convenience. Also, with a few add-on features being designed and installed on the system, it will surely provide many great benefits to the bike owners.

The objective for this project is to apply our knowledge and experiences in electrical engineering studies to solve real world problem. We want to plan, design, and engineer a product that not only deliver a better solution to the problems, but also brings the benefit to the users. As electrical engineering perspective, we want to build our own circuit systems in the most cost effective way, yet maximize the performance. Addition to cost effective strategy, we also want to design a project in energy efficiency. Our system involves the renewable technology as main power supply and designs with the low-power device technology.

IMAGE [1] 3D Model Illustration

I. INTRODUCTION

In the recent years, more and more students are using bicycle as their main transportation to campus because of numerous benefits it offers. Firstly, by using bike to school, it can help students from being stuck in horrified crowed traffic every time they are heading to class. Secondly, riding a bike to school can potentially prevent environmental pollution issue. However, there are few problems that bike owners usually have to deal with daily. Those problems can become significant if they are not addressed seriously. One of the first things that students are afraid to use their bike to class is that their bike can get damaged due to many external factors such as harness of weather (raining), colliding with other bikes, etc. Bike is not an inexpensive thing to buy, and it can become extremely costly to the bike riders if it is not maintained properly.

So the first problem we identify is a proper bike storage place for bike owner. Another factor that can become a major issue is the security and convenience for the bike owners. Whoever owned a bike would concerned more about this issue, which is bike theft. Even with a new modern bike lock technology available in the market nowadays, bike theft rate is still at an alert level. According to an article regarding bike theft "the article link is in the reference section", the number of the bike being stolen which was reported by the Federal Bureau of Investigation nearly reached to 200,000 bikes across the US in 2008. Therefore, students who own the bike are afraid to take their bikes to the public due to this concerned issue.

The Solar Powered Intelligent Bike Rack System (S.R.I.B.R.S) is a new concept for bike storage system. The bike rack will be fully covered by a roof where the solar power will be mounted on top of it. The purpose of having the roof cover for the bike rack is to protect the bike, and to have a strong foundation that can support the solar panel system. The solar power will be the main power supply to the whole bike rack system, and it is an off-grid type so the whole system can be installed at any desire place. The main purpose for the idea of choosing an off-grid type over the tie-to-grid type solar system is to be easily relocated and installed. The lock system for the bike rack is designed especially for security and convenience purposes.

II. SYSTEM DESIGN

Our system is divided into four main groups:

- Power System (Photovoltaic Solar System, Charge Controller, Battery)
- Power Distribution System (DC-DC, DC-AC, Power Protection),
- Application System (Lighting System, Security Camera, Motion Sensor),
- Embedded System (Microcontroller, Digital Locking System, Magnetic Card Reader).

A. Power System

The power of the system of the project is divided into four parts:
-Power Generation (Solar Panels)
-Power Storage (Deep Cycle AGM Battery)
-Solar Charge Controller (Between power generation solar panels and power storages)
-Power Distribution (DC-DC Converter)

1. Charge Controller

On/Off Solid State Charge Controller

1.1 Circuit Design Motivation

To have a better system, our goal is to design a charge controller circuit that requires less in maintenance work but is still able to perform efficiently.

1.1A Plan A: MPPT Charge Controller

Since most of the charge controller available today are MPPT type (Maximum Point Power Tracking), which has the central microprocessor that detects voltage and current at their maximum point and regulate them at a certain point that can minimize the power loss rate. If the voltage rating value is exceeded a certain requirement for the storage system, it can be converted into current value that can supplied to the battery storage for faster charging time. However, there is a big risk to be considered when working the MPPT charge controller circuit design. That is the code algorithm used in the MPPT is very sensitive and can cause the system not function properly if it is not designed in the right way.

1.1B Plan B: Solid State Charge Controller

To minimize the risk in coding, and maximize the cost effective solution for the project, we choose our alternative solution: The On/Off Solid State Charge Controller. The on/off solid state charge controller is the first commercial used charge controller for the off-grid solar energy system. The advantage it offers is the maintenance-free feature. Since the circuit only requires the basic timer 555 and the comparator device, the chance for it to be not working is very low and also the cost to build the circuit is at a very affordable for our group. Since this plan met our group budget goal, we chose this circuit as our component in design.

Charge Controller Circuit Design Technique:
This charge controller has two main function:
(1) Check the state of the battery, (2) Cut off the current flow into the battery if the battery is full or reach at a certain value.
The design for the circuit is based on the method of logic circuit. The Flip-Flop Or Output is implemented into the circuit that acts as the main major role.
The image [1] is the actual design implementation of the flip flop logic circuit used in the charge controller:

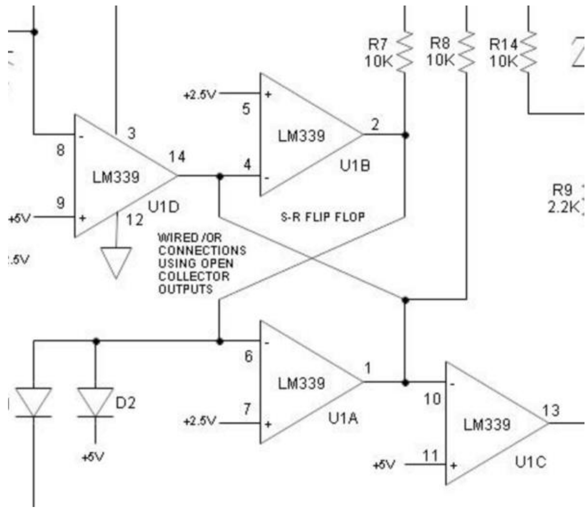


Image [2]: Flip-Flop Logic Control Circuit

The Control Stage- The comparator chip LM339 is used to perform as the S-R flip flop. When the Reset State (pin 8 on the comparator) received the voltage rating above the reference voltage 5V (pin 9).

The Cut-Off Stage - The pin 13 output can produce the signal to cut off the P-Channel MOSFET which stop the flowing current from the solar panels to the battery. The MOSFET is powerful that it can also acts as the protector to protect the current flow backward from the battery into the circuit.
The Image [3] is demonstrated the actual cut-off state of the charge controller

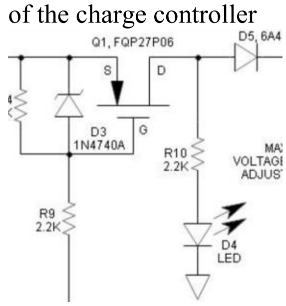


Image [3] Cut-Off State of the Charge Controller

The Protection Stage- The protection stage for this circuit is performed by the Diode D5 6A4 and the P-Channel MOSFET FQ27P06. This diode is used to protect the current flowing into the battery if the current value is exceeded the limitation. The P-MOSFET protects the circuit from the current flowing backward from the battery

Charge Controller Efficiency- This circuit is designed to obtain two main goal for our group: Low cost production and low maintenance requirement. It has some trade-off when it comes to system efficiency. Since this is not the MPPT circuit, the maximum voltage and current cannot be detected, therefore, it cannot give out the maximum value of power. The power loss seems to be an issue to this circuit, although there is a very less to little power consuming from the circuit itself.

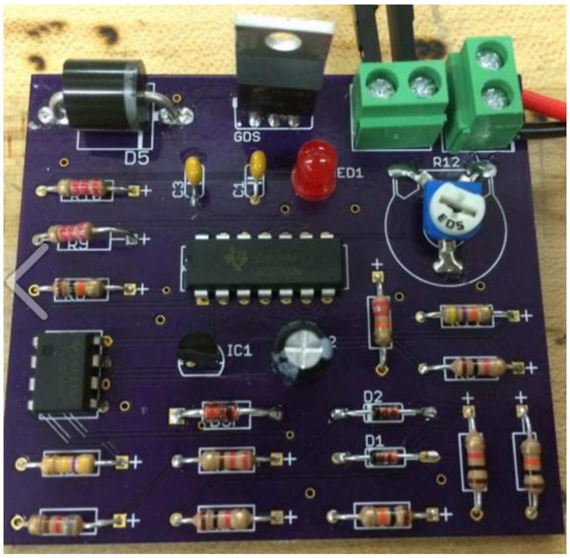


IMAGE [4] CHARGE CONTROLLER PCB

B. Power Distribution System

Our overall system requires a power distribution system that can be compatible with all the devices in the system since they all have different voltage rating value. To meet this goal, we designed three step-down circuits that can supply power to all the devices properly. Since all of the powers are supplied from the deep cycle AGM battery, an appropriate power distribution system must be designed. The following three circuits are designed for the system:
- 3.3V Output DC-DC Voltage Converter
- 5.0V Output DC-DC Voltage Converter
-12V Output DC-DC Voltage Converter

*Note: Our input is 14.5-14.9 V rating voltage which comes from the batteries. However, in the actual product, these batteries only give out around 13V to 13.5 V max measured by the digital multimeter in the lab.

Circuit Design Method- These circuits are designed using TI Webench software on TI website. This software allowed users to design a specific converter circuit according to its input value and expected output value. After advantage of using this technique is that it shows us what is the best IC for the circuit and it also give us a better solution in term of efficiency. The ICs from TI use is mostly switching regulator, this is why it does not have much of the heat generating from the device comparing to the linear regulator.

For 5V OUTPUT converter, the IC we used is the TPS563200, but it does not give us the correct value as expected.
The image is the IC from TI that used to step down voltage from 14.5V to 5V

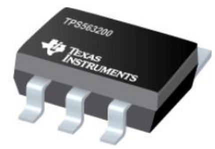


IMAGE [5] TPS563200 Synchronous Step Down Regulator
Result Table:

Attempt	Input Voltage Value	Output Voltage Value
1	12V	8.35
2	14V	8.35

After two of the attempts, we assumed that there is some error for the component. The result shows that we get regulated 8.35V output, but not 5.0V output as expect. Since all the resistor we used to design for this circuit are all calculated correctly according to the data sheet, but we did not get the correct result as we expect. Therefore, a new alternative solution applied.

B.1 Alternative Solution for 5V Output Buck Converter Circuit

A new buck converter for 5V output circuit is designed to replace for the the old 5V output. For this new converter, a linear regulator is used.
Linear Voltage Regulator L7805CV is the IC used to design the step-down voltage to 5V with the current at 1.5A as in the photo below

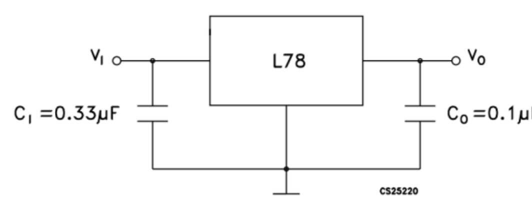


Image [6] Linear Voltage Regulator Circuit Schematic

The advantage for this new circuit is that the value will always be regulated at 5.09V, easy to build, and very low cost. The disadvantage for this circuit is power loss occurred due to heat generated by the ICs. Required a heat sink attached to the IC

Attempt	Input	Output
1st	12V	5.09V
2nd	14.5V	5.09V

B.2. 3.3V OUTPUT Buck Converter

The image is the IC from TI that used to step down voltage from 14.5V to 3.3V

IMAGE[7] TPS54335A Synchronous Step Down Converter

The 3.3V output buck converter circuit works properly by the data shown in the table below

Attempt	Vin	Vout
1st	12V	3.28
2nd	14V	3.29

B.3. 12V OUTPUT Buck Converter Circuit

Similar to 5V output converter circuit, the 12V output buck converter is not working properly as it is supposed to. Although all the components in the circuit were correctly used based on the calculation from the manufacturer's datasheet. This could be the error made by TI WEBench Software. We replaced the 12V Buck Converter of TI by a linear regulator. The advantage is that the error is fixed and the voltage is regulated at 12V. The disadvantage is that the current is limited and the power loss is unavoidable due to the heat generating from the power.

C. DC-AC Circuit Design

The DC-to-AC inverter is designed to provide a charge station for students' electric bikes and other devices of their needs. There are many types and brands of these inverter but we desire to build our own devices with lower cost and power consumption. The DC-to-AC Inverter which output Modified Sine Wave is chosen to use. The knowledge we used to build the DC-to-AC Inverter is Pulse-Width Modulation (PWM). A PWM square waveform is generated from battery 12VDC voltage via using one IC SG3525A from Texas Instrument. This signal would feed a Half-bridge MOSFET configuration in a desired frequency and amplitude. In the final stage, the voltage is boosted up by a power transformer from 12VAC to 110VAC. The converter at the end will output a modulated sine wave with 110 V and 60Hz frequency which is enough to charge electric bike properly.

The frequency of PWM is dependent on the timing capacitance and the timing resistance. The timing capacitor (CT) is connected between pin 5 and ground. The timing resistor (RT) is connected between pin 6 and ground. The resistance between pins 5 and 7 (RD) determines the dead-time (and also slightly affects the frequency).

The frequency is related to RT, CT and RD by the equation:

$$f = \frac{1}{C_T(0.7\, R_T + 3R_D)}. \qquad (1)$$

With RT and RD in Ω and CT in F, f is in Hz.

D. Locking Mechanism

In this project, pull-type solenoids are used for wheel locking system because of its reliability and easiness. However, because of the variety of wheel size and limited power supply, we have to look for a low power solenoid which are still able to secure any type of wheel. After the research, the TP8X16-C-12D Tabular Solenoid manufactured by Guardian Electric is considered to use. It leaves a wide space (1inch) for any type of wheel size and uses 12V DC voltage to operate.

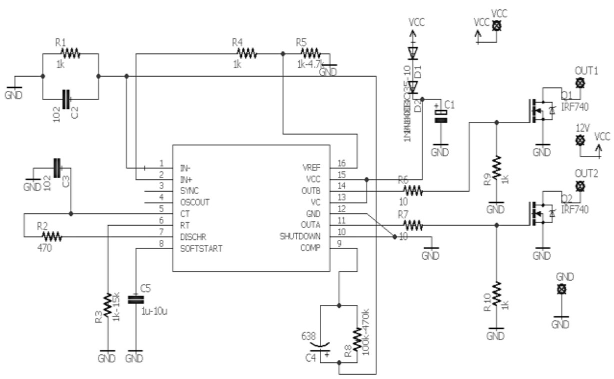
The control of solenoids is based the operation of switching MOSFETs circuit. Two power MOSFETs are used for each lock with the input Gate signal of 3.3V from an output pin of the Microcontroller. The locks only turn on open when signal is High. Otherwise, the locks are in close condition by the force of springs which are attached to the solenoids.

II. Hardware Details

A. DC-to-A Converter

The schematic for the PCB design is drawn by EagleCAD software. The only consideration of this converter is to calculate value for the RT and RD resistors and CT capacitor. Based on the datasheet, RT must be within the range 2kΩ to 150kΩ. CT must be within the range 1nF to 0.2µF. The oscillator frequency must be within the range 100Hz to 400kHz. The output signal will have frequency half that of the oscillator frequency that is calculated using equation (1). Because there is a flip-flop before the driver stage, in order to use this IC for a 60Hz inverter, means require drive signals of 60Hz, the oscillator frequency must be 120Hz. The value of CT, RT, and RD are 0.1 uF, 130 kΩ, and 470 Ω respectively. By plugging those values into equation (1), the output frequency is approximately at 55Hz.

The common values of the soft-start capacitance between Pin 8 and ground are within the range 1µF to 10µF depending on the desired soft-start time. Since we want soft-start time is short so the largest capacitance we can use is 10uF.



IMAGE[8] DC-to-AC converter printed circuit board schematic.

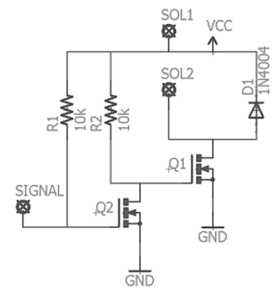
The outputs OUT1 and OUT2 are connected to two sides of primary coil of a power transformer. The VCC 12VDC from the battery is fed to the middle of the coil so only half of the coil run at a time. The secondary coil will output the voltage of 110VAC with the desired frequency of 60Hz. The transformer VPS24-3300 from Triad Magnetic has the power rating of 80VA which is suitable for an off-grid system.

The PCB is designed with a dimension of 2 x 2 (inch x inch). A test with an iPhone charger was done which yielded to an output voltage of 103VAC at frequency of 63 Hz. Current rating through the output terminal was measure around 907 mA. After 20 minutes of continuous charging a phone, the temperature at two power MOSFETs as well as transformer was unchanged so we do not attach any heatsink for the circuit. A picture of the converter is shown in Figure below

IMAGE[9] DC-to-AC Modulated Sine Wave Converter

B. Lock Controller

The printed circuit board schematic of the lock controller is drawn in EagleCAD. The R1 and R2 have the value of 10 kΩ. The MOSFETs model is IRFB20N50 from International Rectifier which has the switching speed of 150 nsec.



IMAGE[10]Lock controller printed circuit board schematic.

Since the solenoid is a coil of wire, it needs a power diode , in this design is 1N4004, to damped out all the current from the solenoid after it is turned off. The operation of the locks is pictured and shown in the Figure 4. The solenoid is in off condition most of time and the lock is hold by the force of a spring. When the Microcontroller send out the signal to the lock controller, the solenoid will start pulling and the lock will open.

IMAGE[11] Solenoid Structural Design

III. EMBEDDED SYSTEM

A. Microcontroller

The microcontroller(s) are essentially the brains of the system. There are two microcontrollers used in the project, the Tiva C Series TM4C1294NCPDT and the CC3200 Simplelink MCU, both manufactured by Texas Instruments and both are ARM Cortex-M4F based. The Tiva C powers a touch-resistive LCD screen produced by Kentec, providing the user interface and also interfaces with a magnetic card and

RFID reader via UART. The Tiva C was chosen based on the graphics library provided for the LCD screen and its multiple (8) UART peripherals. The Tiva C also offers 1MB Flash, 256kB RAM which makes it attractive for running the main program. The Tiva C interfaces with the CC3200 via UART as well. The Simplelink is also interfaced with a camera and provides WiFi capability for the system to connect to a server/cloud platform. The CC3200 SimpleLink offers 256-Bit AES encryption, 8 simultaneous TCP/UDP Sockets, 2 Simultaneous TLS/SSL Sockets, and a dedicated ARM MCU specifically to handle WiFi and Internet Protocols. [2]

B. Magnetic Card/RFID Reader

The magnetic card reader chosed for the project was the Osayde MSR90 dual track reader. The reason for choosing a magnetic card reader was to be able to read data from a student identification and authenticate student credentials. The RFID reader is a 125kHz contactless proximity reader produced by Roy electronics. The RFID tags were purchased from SeedStudio. The reason for the RFID reader was to identify a rental bike when returned to the station. Both readers are interfaced via USB.

C. Cloud Platform

The cloud platform to handle the real-time data chosen was Parse. Parse is a host backend cloud platform that allows, mainly, mobile application developers to utilize their site. One of the main reasons Parse was chosen was due to an SDK they had available for the TI CC3200 microcontroller. They created an SDK to encourage the development of IoT (Internet of Things). The second reason Parse was chosen was due to free access to an old account made before the announcement that Parse was shutting down in January 2017. Among the SDK written, Parse is a user friendly backend solution, allowing developers to easy store and get data, send push notifications, run queries and their “smart indexes” which are enabled through their REST API’s. Parse allows the system to easily identify a whether a student identification is valid is through a sendRequest, an “Equal To” query and a callback. The callback function will send a true or false back to the SimpleLink and from there, the SimpleLink will decide what functions to execute next. Another feature is when specific objects are created and called, there are time stamps made automatically for the object. What this means is that when a user swipes their card and is validated, there is a time stamp. When they rent a bike and that number is sent along with their student id number, it is timestamped. Besides the efficient use of indexing through database, Parse is also a great option for administrative end, as the UI provided makes it easy to make changes to data and user information.

D. Graphical User Interface

The GUI was built using the graphics library provided by Texas Instruments for the Kentec LCD touch display via Code Composer Studio IDE. It was developed using C. The libraries are vast, providing plenty of macros to choose from ranging from circular buttons, push button images, keyboards and indicator widgets. The implementation of creating a panel as a widget made for efficient energy use, as removing a widget on turned off the pixel used rather than having to light up the entire grid “black”.

The GUI was planned to keep as simple as possible. Multiple buttons or options on one screen can create confusion, especially for new users. The initial screen is a welcome screen that prompts the user to press a button to begin using the system. The following screen prompts the user to swipe a valid UCF identification. User authenticity is handled via Simplelink/cloud interface and reported back to the Tiva.

Image [13] GUI for the system bike lock control

The user is either told to swipe again or is directed to the options menu, where they can either rent, charge or store/pick-up a bike. The panels to do so have a customized number pad which will display to the user the number that they entered. The numbers call their own individual functions, which initialize a character and call a function to write the bike number that the user enters. The delete button on the bottom right of the keypad, removes the bike number that a user enters, in the case that a user entered an incorrect number. The main menu button returns the user to the options panel, which was implemented in the event a user mistakenly pressed the wrong option button. The bike number will also be sent to the cloud once the user presses Enter. There is no need to verify the bike number being received at the time the user requests the bike. This doesn't impede the user from retrieving a bike cause inconvenience. Upon the Enter button being pressed, a high voltage (3.3V) on a GPIO pin will enable the switching to occur for the solenoid to unlock the lock, with a delay set for 10-20 seconds. Once the delay is complete, the GPIO pin will return to low voltage (< 0V). The bike number will be reset and the screen will return to the main menu after a 10 second delay, awaiting the next user.

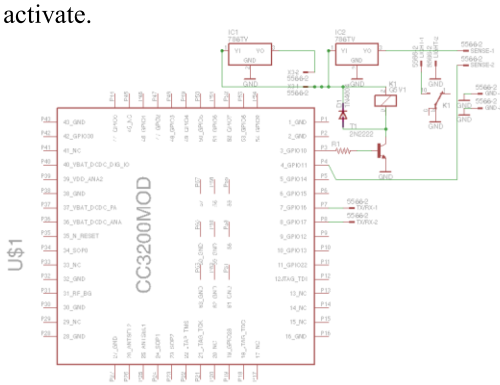
E. Magnetic Card/RFID Reader interfacing

The magnetic card and RFID reader are both interfaced to the Tiva C via UART. In order to do this successfully, an FTDI board is required which will convert USB data to serial UART via a FT233R chip. [1] To enable communication, specific UART pins must be enabled and configured to the desired specifications for functionality. The hardware wiring connections must also be made appropriately and lastly, matched baud rates. Once these configurations are made, implementation of filtering the data from the magnetic card can be done. Authenticating a student's information requires only the student id number, as this is the only number unique to them specifically. There is an ISO number, but it is a 16 digit number (read as ASCII characters from input) and it is easier to check for authentication because the first 8 digits may be the same for many students, creating latency in the program for a larger scale. Hence, the 7 digit student id is checked.

Once matched, the user is granted access to continue with the rental/store/charge process. It is important to note that the magnetic card reader is the dictator of its' own clock, therefore the MCU doesn't need to continue polling to see if data is available to be transmitted. Also, there are almost no misreading's from the magnetic card reader. A user has to start the card from one end and swipe to the end for the track to be fully read and even a single bit to be sent through. It is important to note that a user's card information cannot be read prior to a user being prompted to swipe as the function is not called. The RFID reader is interfaced the same way as the magnetic card reader. To implement the code is less strenuous, as the RFID reader only submits a 10 digit tag number. The tag number is paired with the bike number the user sees and enters into the system. The tag number only needs to be read when the bike is returned, stored and paired on the server to the user who returned the bike. The logic behind this is simply due to the activation of the RFID reader. The reader only detects the RFID tag when it firsts enters the EM field. If the tag remains stationary, no detections occur and the same occurs when the tag leaves the field. This means that only when a user would be returning a bike will the tag be detected, hence we do not need to worry about a misreading or an unexpected interrupt.

IV. APPLICATION SYSTEM

The lighting and security camera subsystems are controlled by the CC3200, thus being operated by the same code and working in conjunction. The CC3200 and the LEDs were both picked because they consume little power. This is important because we are trying to reduce the amount of power we take so we do not run out of our back up power. This schematic shows how everything connects to the CC3200. Input voltage from the system is 12 volts, so some voltage dividers had to be used to take it down to 5V for a few of the components. The camera, motion sensor, and the lights use signals either to or from the MCU to activate.



IMAGE[12] Lighting and camera system hardware diagram

The motion sensor has a intterupt attached to it, whose routine is used to activate the camera and lights. It may sense motion within a 7 meter range and 120 degree cone, so it can see users coming from a distance. When no motion is detected, the CC3200 will be in Low Power Deep Sleep mode and the camera and lights will not be active. Once again, this is for maximum conservation of power as we do not want to drain the system's resources. If the motion is detected, and thus the motion sensor sends a 3.3 V high signal to the MCU, the LED strip will turn on. A high GPIO output signal will be sent to the base of the transistor, which will saturate and in turn energize the coil of the relay, allowing power to flow to the LED strip. A flyback diode has been put in paralell with the relay to protect against voltage spikes from the relay. When motion is not detected anymore, no signal will be sent and the relay will switch off, turning the lights off. It is important to note the strip has a lifetime of 50,000 hours. Considering there are 8760 hours in a year, this equates to 5.7 years before the strip needs to be replaced. This makes it very low maintenance.

The security camera system is also activated when motion is detected. It utilizies the CC3200's wireless capabilities to stream the footage it captures to a server. When motion is detected,the code will have the CC3200 connect to the internet and then ask the camera to start taking pictures. When no motion is detected anymore, the CC3200 will disconnect from the internet and stop streaming footage.

V. CONCLUSION

Overall, the project is a good learning technique for us to learn and prepare for our future as an electrical engineer. There are still lots of improvement needed for this project to make it more energy efficiency. The software side of the project can be added more in the future of in term of wireless communication. The hardware can be improved by more advanced components like low power consumption products, and less power loss devices. The bike rack station can still add more features such as portability, and solar tracking system. In term of maintenance, the battery system is the main concern. The weather can be the number one major problem to cause degrading in battery life. Therefore, periodical maintenance is required to ensure proper battery operation.

VI. ACKNOWLEDGEMENTS

The success of this project is achieved by the help of everyone who has made a big contribution to our group. Many thanks to all of our supporters such as parents, friends, donors, advisors, mentors, and professors. Their contributions meant a lot to our group in term of financial support and excellent advisement and is greatly appreciated.

VII. REFERENCES

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[2] TI CC3200 Datasheet Specifications http://www.ti.com/product/CC3200/datasheet

[3] TI Tiva C TM4C1294NCDPT http://www.ti.com/tool/ek-tm4c1294xl#Technical Documents

[4] Texas Instrument Site http://wwww.ti.com

[5] UCF Senior Design Website http://www.eecs.ucf.edu/seniordesign/projects.php

VIII. BIOGRAPHY

Dan Adarme is a 27 year old Electrical Engineering student graduating in August 2016. His primary interests include embedded systems, hardware design, and RF engineering. He is currently seeking employment in the Electrical Engineering field.

The Pham is pursuing his Bachelor degree in Electrical Engineering major. His goal is to be employed by a power engineering firm or any engineering related company. He has his interest in power system, hardware design, and electronic application.

Christine Erwin is an Electrical Engineering student who spent her entire college career at UCF. Her focus on the project was designing and implementing the lighting and camera subsystems.

Nha Nguyen is a 26 year-old graduating Electrical Engineering student at the University of Central Florida. Nha hopes to pursue a career in the specialized area of power and control system, and plans to continue his Master as well as work for a power company after graduating