Autonomous Solar-Powered Beach Buggy Challenge

Cecilie Barreto, Drew Curry, and Grace Yoo

Department of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450, USA

***Abstract* — The Florida Solar Beach Buggy Challenge presents a unique opportunity to explore autonomous vehicle navigation and solar energy incorporation. The design of the beach buggy apparatus involves integrating various technologies, such as ultrasonic sensors, stereo cameras, GPS, microcontrollers, motor controllers, solar panels, charge controllers, and voltage regulators. This challenge is to develop a vehicle that can detect, avoid, and navigate down a 10-mile stretch of Daytona beach and return with no human interference while completely powered by solar energy. Progressive automobile companies use high-end sensory equipment to accomplish similar tasks that are achieved with this vehicle. This project exhibits a compilation of affordable and practical mechanics that can be combined to produce a surmounting product. This group is working in conjunction with a mechanical engineering team and a computer science team to design and construct this buggy. The beach buggy challenge allows for the continued research and discovery into the affordable, and energy saving potential of autonomous solar power vehicles.**

***Index terms* — autonomous, ultrasonic sensors, charge controller, photovoltaic (PV), Microcontroller Unit (MCU) printed circuit board (PCB), Maximum Power Point Tracking (MPPT).**

I. INTRODUCTION

Duke Energy, a utility company that provides electricity to approximately 7.4 million people across the United States, sponsored and presented The Florida Beach Buggy Challenge to the students of the College of Engineering and Computer Science at the University of Central Florida. The challenge is a local competition enticing undergraduate, senior-level students to expand their understanding and awareness of autonomy and solar energy. Three teams, each consisting of electrical and computer engineering (ECE), mechanical engineering (ME), and computer science (CS) groups, were formed to contend in this competition.

Duke Energy asked students to develop an entirely solar-powered beach buggy vehicle that can autonomously traverse a 10-mile stretch of beach from Daytona to the Ponce Inlet and return within an 8-hour time span. Not only should the beach buggy be capable of transporting one passenger with the maximum weight of 120 pounds, but the vehicle should also be able to detect and avoid stationary objects, such as rocks, docks, chairs, etc., as well as moving obstacles, such as people, animals, other vehicles. Safety is a major priority for everyone involved this project, therefore the apparatus should cause no harm to the environment or people. Its top, approved speed is 3 miles per hour (mph).

II. OVERVIEW

One of the unique challenges of this project is the fact that the electrical scope of this project would be completed before the mechanical and computer science scopes due to differing graduating schedules of all three groups. To overcome this challenge, it was necessary that the three disciplines meet, solidify, and understand a stand-alone system design that would cover the most imperative functions that electrical design would impact on the project as well as a design that would prove useful regardless of small changes in design due to unforeseen conditions in the upcoming semester. Shown below, in figure 1, is the initial sketch of the mechanical team's design for the buggy.

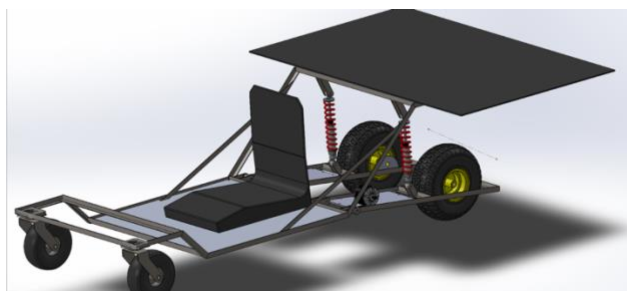

Fig. 1. Model of solar beach buggy designed by the mechanical team. The black rectangle is where the solar panel is planned to be placed.

The ECE team was tasked to design a communication system in which different types of sensors would be able to transmit information to the navigation software of the Beach Buggy. The ECE team decided that a printed circuit board (PCB) will interface with ultrasonic sensors and relay sensor data to a Raspberry Pi for navigation. The sensor data must be decoded and formatted in a useable form that may be processed by the CS team to create logical autonomous movement decisions. For the purposes of demonstration, the ECE team provides a small-scale prototype of the ME design to demonstrate performance of sensor data collection and interpretation.

Additionally, the ECE team will develop a power distribution system for handling input from the solar panels and power distribution for all electrical components of the vehicle. Therefore, the ECE team must design and implement a functional charge controller that will ultimately be attached to a solar panel and effectively control the amount of charge the battery receives as well as output sufficient charge to the necessary devices attached. By the end of the term, the functionally of the charge controller will be tested and demonstrated by using a DC power supply, ensuring the battery is charging and appropriate voltage is outputted. This power system will be responsible in providing power to all the devices on the beach buggy which includes the motor selected by the ME team.

III. SYSTEM DESIGN

Shown below, figure 2 is the initial proposed system diagram for the ECE scope of the buggy. This visibly reflects how the different components of the ECE scope will ultimately interact with the rest of the design. For example, the MPPT charge controller that the ECE team will be designing will be in place to regulate the voltage and current coming from the solar panel to ensure that the battery is charged effectively and not over charged or damaging the battery.

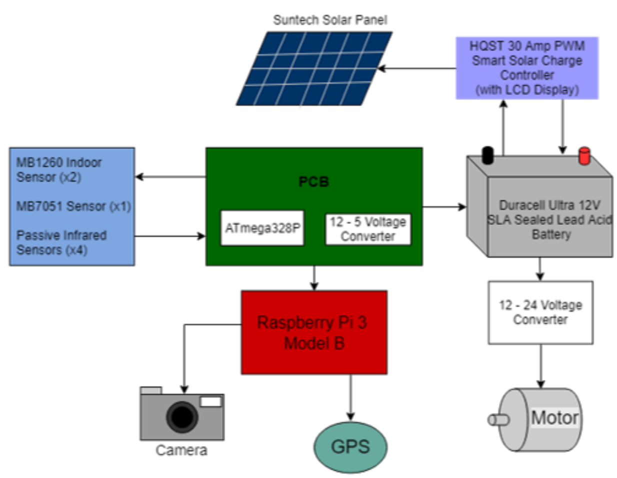

Fig. 2. System Diagram

The battery that was chosen was a 12 V lead acid battery with an amp-hour rating above 50Ah. The battery will supply power to the motors, which will be selected by the mechanical team, and will be connected according to the voltage requirements determined by the motor selection. 24 V motors will require a boost regulator with high current allowance, whereas 12 V motors can be directly tied to the battery source and charge controller. The battery will also supply power to the Beach Buggy PCB which will contain the ATmega328p MCU, the LM2677 switching voltage regulator to step down voltage from 12 V to 5 V, and lastly the FT232RL serial to USB communication port. The PCB will supply 5 V to the various sensors, stereo cameras, Atmega328p, Raspberry Pi 3 development board, and other components added to the project requiring a 5 V input. The Atmega328p MCU will be receiving the initial raw data input from the sensors. This data will be processed into usable, logical data, and transmitted to the Raspberry Pi. The Raspberry Pi will be connected to the stereo cameras and will handle image processing by the CS team. To conclude, the Raspberry Pi will process the data received from the Atmega328p and use this, the images received from the camera, and data gathered from the GPS system to control navigation.

IV. PROTOTYPE

To effectively demonstrate the functionality of the autonomous features of the ECE scope, a smaller-scaled version of the mechanical team's initial structural design of the buggy was 3D printed to be used to demonstration. The prototype mimics the wheel setup of the mechanical design as well as the mechanism by which the vehicle will be propelled. The mechanical design can be seen in Figure 1, whereas the prototype can be seen in Figure 3.

Fig. 3. Small-Scale Prototype.

Mimicking the mechanical design, the prototype is equipped with two servos in the rear that are fitted with wheels. The front is fitted with a set of caster wheels. The prototype is also fitted with an encased Raspberry Pi and the ECE team's PCB design, and the sensors used for the autonomous system.

V. PRINTED CIRCUIT BOARD (PCB) DESIGN

The Beach Buggy PCB houses many components, all of which are crucial to the effectiveness of the board. This PCB is responsible for powering all of the 5V devices utilized by the system design, collecting and interpreting the raw sensor data supplied by the ultrasonic sensors, and delivering information to the Raspberry Pi. The main components of the PCB include the ATmega328P microcontroller unit (MCU), 12V-5V LM2677 switching voltage regulator, and the FT232RL serial to USB communication port. Figure 4 shows the entire layout of the PCB and has color-coded outlines highlighting these three prominent features of the board.

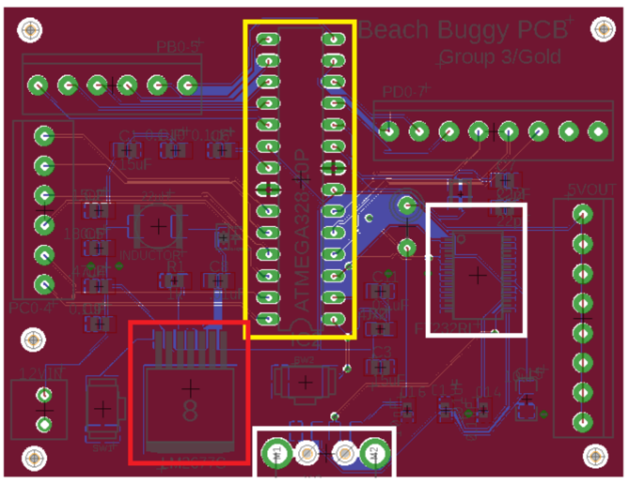

Fig. 4. Outlined Final Printed Circuit Board Design

Outlined in yellow is the through-hole ATmega328P microcontroller. It was housed in the middle of the board to ensure there was equidistance between most of the semiconductor devices assisting the microcontroller, and simple connections for all other on-board components. All the GPIO pins have been routed to the 3.5mm through hole header pins along the outer edges of the PCB for data input purposes. This allows for complete access to the microcontroller, so all available pins can be taken advantage of. This also allowed early production of the PCB while decisions were made about which I/O pins to utilize.

Outlined in red is the LM2677 surface mount 12-5 volt switching regulator. The regulator supplies power for the microcontroller and any additional components requiring 5V. The regulator is routed directly to the microcontroller and additionally to a 3.5mm 8-pin header that allows for external 5V devices to be powered.

Lastly the FT232RL serial to USB surface mount IC is outlined in white, along with the USB A terminal that will provide serial communication capability for external devices to the microcontroller. The convenience of the USB A makes it easy for many components and devices including the Raspberry Pi to access the ATmega328P simply and effectively. The next three sub sections will provide details about the primary IC's and devices on the Beach Buggy PCB.

A. ATmega328P Microcontroller Unit

The ATmega328P is an 8-bit AVR microcontroller typically found on the Arduino Uno. Due to this similarity, the microcontroller unit on the PCB is programmable through the Arduino integrated development environment (IDE). This MCU is ideal because it is rated to have low power consumption, yet adequate processing power for sensor data analysis.

All ultrasonic sensors have data output pins connected to digital data pins on the MCU. Then a Pulse Width Modulation (PWM) signal produced by the ultrasonic sensors is measured and deciphered into the binary data packets. The on board 16MHz crystal assists in the timing measurement of the PWM signal. The ATmega328P also decodes and arranges the binary message bits into a legible and applicable format. This decoded information is then sent as serial to the FT232RL via the RX/TX pins to be transferred to the Raspberry Pi through USB. Lastly the Raspberry Pi takes interprets this code and is used for navigational purposes.

Coding on the Raspberry Pi is running on startup and instantaneously reads the data coming into the serial port. It utilizes PySerial 3.0, a module that encapsulates and simplifies access for the serial port. The information being read from the serial port is the data read by the sensors that are hooked up to the ATmega 328p. The Pi script is then able to utilize this data to handle navigation processes. Depending on the location of the object, considering both the distance it is from the vehicle and the side of the vehicle the object is on, the Pi decides whether to slightly adjust the speed of the servos to alter the vehicles path or come to a complete halt. The logic is written to complete basic autonomous navigation and will be modified by the computer science team in the following semester.

B. LM2677 Voltage Regulator

The LM2677 is a monolithic IC buck switching regulator, providing a high efficiency of conversion above 90% with an ensured output voltage within 2% of the target voltage. The LM2677 has a built-in thermal shutdown, current-limiting, and ON/OFF control input that powers down the regulator to a 50uA quiescent-current that waits for safe reboot. The LM2677 is designed to supply power to the ultrasonic sensors, ATmega328P MCU, and the Raspberry Pi thereby acting as the power source for these devices. This voltage regulator will convert 12V received from the battery connection and step it down to a 5V rating. The LM2677 allows us to power any ultrasonic sensors or other components needing 5V. Using this approach, vs using the 3.3V/5V rails on the Atmega328, makes sure that any components will not be limited by the current that the Atmega328 can/cannot deliver. As previously mentioned the voltage regulator is rated at 5A, this gives us more than double the expected current load. The supplemental current potential was intended in its design to provide flexibility, such as for the case of increasing the number of sensors or adding other equipment that needs to be power, which may be prompted by any interdisciplinary group in the team. [6]

C. FT232RL Serial to USB

The FT232RL serial UART to USB communication device is an integrated circuit device that simplifies the process of programming the microcontroller unit and allowing the ATmega328P to be programmable using a USB port connection instead of through the UARTS Rx/Tx pins. The FT232RL is a solder mounted device and may be removed if the use of Rx/Tx pins is deemed necessary in future applications. The FT232RL features data transfer rates up to 3Megabaud with 7 or 8 data bit and 1 or 2 stop bits options. Choosing this device gives the group much flexibility with data transfer. This device was also requested by the CS team to allow them for simple communication to the Atmega328. It is essential for interfacing the Raspberry Pi as it will upload the program for sensor data analysis onto the MCU and the processed information will be relayed back to the Raspberry Pi from the MCU through this USB communication. [2]

VI. ULTRASONIC SENSORS

A variety of sensors, such as infrared, ultrasonic, and photosensitive sensors could provide potential solutions to obstacle avoidance systems. Due to the outdoor environment and the many natural challenges nature poses, it was critical that sensors were chosen that can perform optimally in this outside environment. After much research and consideration, ultrasonic sensors prove to be the most reliable and viable sensing device for outdoor environments. They have little to no interference caused by outside variables such as sunlight, magnetics, or temperature, unlike IR/PIR, or photosensors.

In terms of navigation the beach buggy uses the ultrasonic sensors as close proximity detectors for autonomous navigation. The ultrasonic sensors will aid navigation by detecting obstacles at distances of 0.2m to 2.5m to prompt an immediate and rapid response if necessary. The sole strategy for navigation is through imaging processing and object detection with the use of a stereo camera, tasked to the CS team. If the camera fails to detect an object in a timely manner or an unexpected figure jumps into the path of the beach buggy, the ultrasonic sensors responsible for detecting the obstacle and logically signaling the Raspberry Pi to stop the vehicle or formulate a new path, instructing the buggy to avoid the object.

The HC-SR04 is a cost-effective, low power, close range ultrasonic sensor that was also considered for close-range detection. For testing purposes, the HC-SR04 was connected to an Arduino board and the data outputted by the HC-SR04 was displayed on the Arduino IDE's serial plotter. Figure 5 below presents the results in a distance over time graphical view. The vertical axis displays the detected distance of an object in centimeters and the horizontal axis displays the instance in time the reading was taken in seconds, based on the time elapsed since the sensor has been recording data.

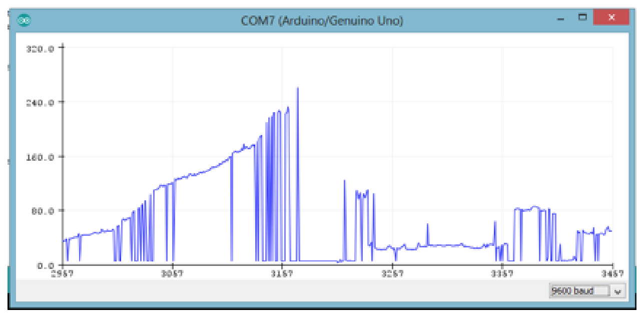

Fig. 5. Screenshot of the Arduino serial plotter results for the HC-SR04 ultrasonic sensors.

The device was tested in both indoor and outdoor environments. Though the HC-SR04 is rated for a range of 4 meters, the sensor was only able to acquire consistent and reliable readings for obstacles up to 1 meter away for both indoor and outdoor environments. There were also severe drops and spikes often that did not accurately reflect the distance measured to the object. The dramatic drops can be seen in the serial plotter image results above. Due to the partial inconsistencies scattered throughout the collected data, which are indicated by the dips on the overall graph, it was concluded that more accurate sensors were needed, and the effective data analyzing methods were crucial in providing reliable information from the sensors.

Automotive ultrasonic parking sensors are used to increase safety for passengers and pedestrians in and around a moving vehicle. They were designed to detect small children, low walls, other cars, and any other object that may possibly be in the vehicle's path. Automotive sensors are used to decrease the number of automobile-related accidents by preventing collusion through early detection; therefore, they are required to reliable. These sensors can adapt to freezing or sweltering environments, making them durable. Ultrasonic sensors that are automotive-grade are expectedly weatherproof and reasonably priced. These are ideal preconditions for reliable, short-range, object detection that will be used as a preliminary autonomous navigation system for the beach buggy, while the CS team work on object detection and image processing of camera data.

TABLE I
DS18 PRKDI4 ULTRASONIC SENSORS SPECIFICATIONS

Specification	Rating
Voltage:	12V – 16V DC
DC rated current:	10 mA – 250 mA
Detection Distance:	0.3 m – 2.5 m
Working Temperature:	-30° – 80° Celsius
Ultrasonic Frequency:	40 KHz

The DS18 PRKDI4 is the brand of ultrasonic sensors selected to be used for the beach buggy. The specification of the reverse backup sensors is noted in Table 1 [3]. This specific brand came with four sensors, and a color LED display that may be used to display distance between the sensor and an obstacle. The sensor are detachable units with waterproof socket connectors. They are quite durable, made from high quality components, and able to withstand extreme, elevated temperatures, which is ideal in a competition that takes place in a baking, humid beach environment.

A. Range of Detection

The angle of reliable detection was tested to determine the best mounting placement of the sensors for autonomous navigation. This is necessary to reduce the size of the buggy's blind spots and achieve successful object avoidance. It was found that there is an 15° angle of accurate detection radiating out from the center of the sensor, but only for the first meter. This is represented by the solid red cone are in Figure 6.

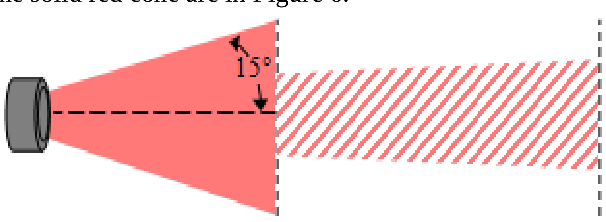

Fig. 6. Illustration of DS18 PRKDI4 automotive ultrasonic sensors measured degree and range of detection.

These automotive sensors are rated to detect almost 2.5m out, which proved to be true for a much narrower angle of detection beyond 1m, depending on the size of the object or obstacle. For a smaller object, the object had to be placed nearly centered to be detected. This is visually represented by the red-striped area in Figure 6. The overall dependable cone for short-range detection is 30° for the first meter, and approximately a cone of 10° degrees from 1m to 2.5 m.

B. Decoding Sensor Data

The process of decoding the sensors' binary messages was a tedious task due to the lack of documentation on this specific brand of sensors. Before deciphering the binary, the PWM signal produced from the sensors itself must be broken down into binary packets. Each port or channel sends the signal at the same frequency of ~40KHz. It is possible to send multiple signals over the same frequency because they are sent at separate times. Each port sends a signal about ~40ms between one another in a sequential loop. [5] In order to visually see the PWM signal, the data pin of the automotive sensors was connected to an oscilloscope, the result is shown in Figure 7. It was discovered that there are 17 voltage HIGHs or peaks of different lengths sent by the sensor, the first square pulse, being the longest pulse, indicated the beginning of a sensor's data. This starting pulse was typical around 800µs – 870µs long. The next 16 pulses were deciphered to form two bytes or 16 bits of sensor data. Pulses with the width 350µs or lower were bit 0, and pulses with pulse widths with 480µs or higher were bit 1. The first byte of data contains the distance the sensor detects an object in meters, and the second byte contains the address of the port that detected the specified distance. The mapping of detected distance to its respective sensors is crucial in formulating object avoidance algorithms.

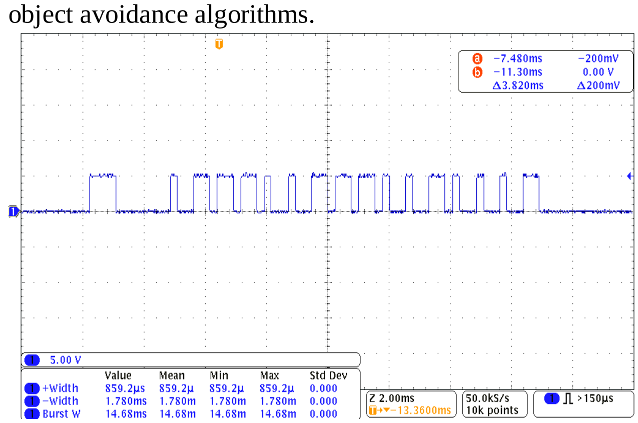

Fig. 7. Pulse Width Modulation (PWM) Signal measured using the Oscilloscope.

Upon further evaluation, it was determined that the sensors were sending signals in Least-Significant Bit, or

LSB bit order. Converting the binary data packet required reordering the bits in Most-Significant Bit, or MSB order per byte and then finding its complement. Then the binary number could be converted to decimal regularly.

VII. POWER SYSTEM

The system is responsible for providing power to each component of the system, which each require different voltages. The system is composed of several regulators and a charge controller to accomplish this. The overall power system design is shown in Figure 8.

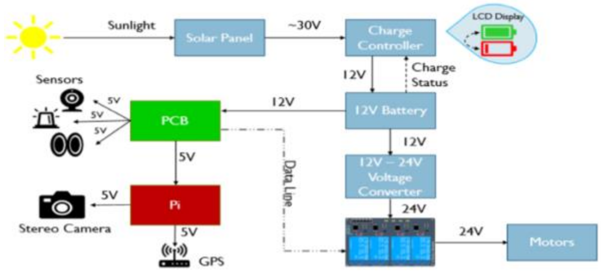

Fig. 8. Power distribution design.

A. Solar Power

Duke Energy has taken the liberty of supplying a Suntech STP235 solar panel to use in the challenge. The solar panel will be mounted on the top of the beach buggy to ensure the maximum amount sunlight will hit the surface, promoting the amount of solar energy produced. The solar panel has a current output at 7.79A with a maximum voltage output of 30.2V, supplying the system with 235W at maximum load. Considering these limitations, a charge controller design rated above 10A is utilized to ensure that the controller is powerful enough to regulate the charging of the 12V battery. The solar panel will only be able to supply partial energy while the beach buggy is on and under full load. For 12V systems the efficiency is above 96% and includes losses in the reverse battery protection MOSFETs.

The solar (MPPT) charge controller TIDA-00120 has been drafted from its schematic and created in Eagle CAD as a PCB, using the same required ICs. Some smaller components, such as resistor and capacitor values, were modified to adjust the design to best fit its intended use. Larger components such as the MOSFET's are modular for the board. By replacing the current MOSFET's with higher voltage and current ranged MOSFET's, a variable range of voltage and current values can be achieved. TI has recommended MOSFET's for this charge controller on its datasheet. Depending on mechanical requirements and power requirements these components can be easily replaced by soldering these higher rated surface mount MOSFET's. Additionally, this PCB features its own MCU to accommodate for optimization coding that will drive the charge controller. The code that drives the PCB operates on a specific tracking system that aims to regulate the output voltage based on previous measurements of power. If panel power increases, then the code modifies it to track in the same direction. Likewise, if the panel power decreases the code tracks in a decreasing manner. The PCB is powered directly from the solar panel via a voltage regulator on board. The circuit also features a low-dropout regulator that aims to help supply power to the device even if input and output voltages are similar.

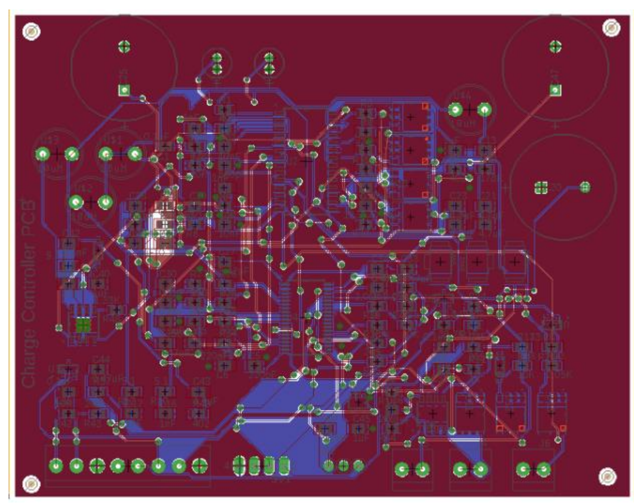

Fig 9. Charge controller PCB Design.

The solar panel is connected to a charge controller to monitor the charging of the power supply, preventing the battery from being over or under charged. The charge controller model selected was built using a schematic design on Texas Instrument's website [4].

B. Power Management

A substantial amount of solar energy must be converted for the buggy to have adequate charge to power the motors, sensors, Raspberry Pi, PCB, and all the on-board equipment. It is imperative the power management system was designed with this load in mind. Two popular types of batteries were considered for the system, lithium-based batteries, and lead acid batteries. Lithium based batteries outclass lead acid batteries in almost every factor, but for almost entirely budgetary purposes, a lead acid battery was chosen for the power supply. The lead acid battery is 12V vehicle battery with upwards of 75 amp-hours. The actual amp-hours of the battery will be decided with the remaining budget after much of the mechanical and computer science expenses are determined. The battery will be connected to the charge controller design, the 12-5V voltage regulator on the PCB, and the mechanical team's motors. The solar panel and charge controller will help to mitigate power taken directly from the battery and provide charging of the battery when it is not under load. Devices requiring 3.3V can receive power from the GPIO pins on the ATmega328P.

VIII. MOTOR / MOTOR CONTROLLERS

Motor selection was done the mechanical engineering team with their understanding of the physical needs of the project. The selection was two my1016 24V brushless motors. At maximum load the motors could demand current draw in the 15-20A range. A 12-24V voltage regulator that can accommodate the high current demanded has been recommended for the mechanical engineering team to procure for the power system.

A motor controller unit will be used to gradually power up and power down the motors and maintain under the allotted 3 mph speed. This will also help diffuse power spikes and current spikes demanded from the battery. Because of the nature of the project, a relay board is recommended to transmit power to the motors in the case that a motor controller unit is not feasible. The relay board would not able to accommodate for gradual powering up and down of the motors but will provide a simple and reliable means to operate the motors. The relay circuit can be operated by single data lines sent from the Raspberry Pi development board.

IX. SOFTWARE DETAIL

The CS team plans to use the Robot Operating System (ROS) for the basis their software for autonomous navigation algorithms. ROS is a powerful and versatile, open-source, middleware framework for developing robotics applications. Its publish-subscribe messaging model, services, diverse libraries and packages, and bustling community have eased the robotics development cycle and made it feasible to develop modularized and versatile robotics software.

ROS's open-source nature also makes it ideal for incorporating into any robotics project. The various libraries and packages can be altered to suit the needs for any given project. Research into the potential drawbacks of utilizing ROS revealed that scalability is a common concern among developers given the nature of its messaging model. However, given the anticipated size of this project and the relatively small number of concurrent processes involved, this scalability factor is not a point of concern.

X. REFLECTIONS

One of the most important aspects of the project is the sensor selection. Most of the research was limited to sensors that the group has become familiar with through education in their degrees. It would have been beneficial to explore more practical sensors that are already in the market. The parking sensors utilized is an excellent example of general sensors that can be used for improved use.

The current PCB that was developed for the charge controller operates on its own MCU. There are designs that should be able to overlap with an MCU that could also provide GPIO pins for data lines. This would reduce the bill of materials and save budgetary money. The difficulty in this project was finding reliable charge controller designs that would accommodate the project and the given solar panel. Overall a better understanding of the electronics and software behind the charge controller would have simplified the creation of that PCB.

XII. CONCLUSION

In conclusion, the team gained valuable experience in circuit design, power system design, and sensor implementation by participating in the Solar Buggy Beach Challenge. The final prototype demonstrated a small-scale version of the ME buggy design, capable of the short-range object detection for autonomous navigation, and solar power conversion, storage, and distribution that will be adapted on a larger scale vehicle in the Fall 2018 semester by the ME and CS team.

The unique implementation and administrative challenges posed by the electrical and computer engineering scope of the project have better prepared the team for the engineering industry and real-life design process. The project has also allowed the team the unique opportunity to build something that combines two topical areas of innovation: solar power and autonomous vehicle navigation.

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BIOGRAPHIES

Cecilie Barreto is a graduating computer engineering student at the University of Central Florida. She currently holds a co-op position with the City of Orlando as a Project Manager with the Energy Management Department. She hopes to continue her career in energy management operations upon graduation. She also enjoys web design, hiking, and is in the process of launching a kite hobbyist website.

Drew Curry is a graduating Electrical Engineering student at the University of Central Florida. He has accepted a full-time position with Power Design Inc. in Tampa, Florida as an engineering coordinator. He hopes to further his career with this company where he can learn more about the electrical design aspects. He will continue to use his free time to enjoy simple embedded systems projects as a hobby.

Grace Yoo is a senior computer engineering student at the University of Central Florida, currently a part of UCF's College Work Experience Program. The program allows her to work with embedded systems as a student contractor for the Modular Active Protection Systems (MAPS) program at Lockheed Martin, Sensors and Global Sustainment, located in Orlando, Florida. She is planning to work full-time for the MAPS program after graduation. Her hobbies include traveling, rock climbing, learning new programming languages, and spending time with family and friends.

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