Electri-Surf: Electric-Powered Surfboard

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***Abstract* — This paper presents the motivation and design process of creating an electric powered device that is to be used in an aquatic environment. This device will be user controlled via Bluetooth, from an application that can be downloaded on the user's phone. The app provides the user with the capability to change the speed of the motor and be completely in control of the mobility of the device. Certain safety features are included in this device that keep the user aware of battery life as well as an emergency power off switch to avoid injury or loss of the product. The purpose of this project was to develop something people could have fun with. Other applications of this project could even be integrated as a rescue device for lifeguards. The details discussed in the design process consist of mobility of the device, power supply, user interface, and safety precautions.**

***Index Terms* — Electronic Speed Control (ESC), Android, jet drive, Battery Eliminator Circuit (BEC)**

I. Introduction

Electri-Surf is a project that was developed to test the capability and effectiveness of applying land based applications to an object that is used solely in water. The idea was to take similar applications used for a wirelessly controlled skateboard and apply them to a surfboard. Electri-Surf was also designed in order to provide both individuals that are familiar with surfing and those that are not, the ability to enjoy close to the same experience as traditional surfing without needing an outside source, such as ocean waves. Our electric powered surfboard should be operable with little to no prior surfing experience, but some physical stamina and balance is required. A few electronic features will be added to our electric powered surfboard to make it more user-friendly and safer for both the rider and nearby objects and bystanders.

In our design, there will be a handheld wireless throttle communication system implemented by a custom cell phone application for android that the rider can use to adjust the speed of the board while being able to focus on maneuvering and balancing. Not only will the rider wirelessly have control of the board's speed, but it will also have an electronic and a physical emergency cut-off system built in to the design to protect the rider as well as nearby people and objects. The wireless cut-off system will be implemented using the phone application that will be triggered pressing a button on the center of the application window and the motor will cut off regardless of the current throttle speed setting. The physical kill switch implemented on our surfboard resembles that of one used on a jet ski. As the rider falls off the board and the board separates from the rider, the physical kill switch lanyard that will be attached to the rider's ankle will disengage and terminate the connection between the rechargeable LiPo battery and the rest of the electrical components, terminating current flow. The concept of the design is shown in Figure 1.

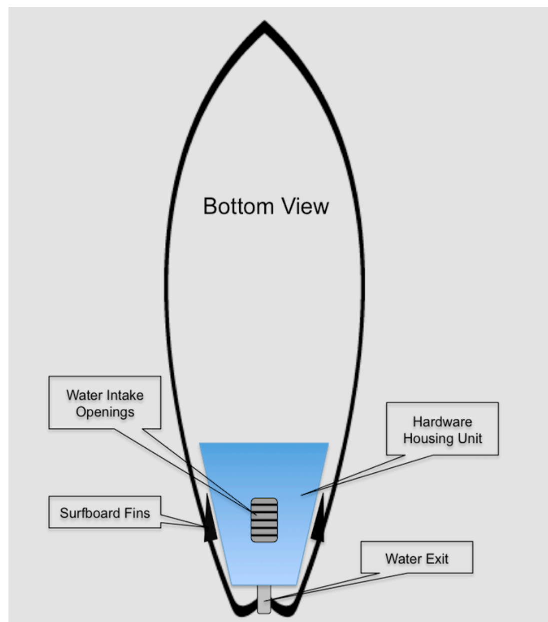


Figure 1: Overall construction of the project

II. System Components

The project can be best presented by dividing it into multiple subsystems. Each subsystem, both physical modules and software modules, work together to execute an operational electric powered surfboard.

A. Battery

The power source for this design needed to be very large in order to support the components we needed to use. Because the Electri-surf board is intended to support the weight of a human, the motor needed to be very powerful which means the battery needed to be powerful enough to support this type of motor. In addition to powering the motor, the battery will be used to power the rest of the hardware on the board including the electronic speed control and the PCB. When deciding on the type of power supply for this design, recharge ability was a necessary component. The battery we are utilizing is composed of lithium-ion polymer and is considerably lighter weight than other rechargeable batteries. Unlike a NiCad and a NiMH battery, LiPo batteries don't have a "memory" which improves the overall life of the battery. LiPo batteries can be used repeatedly with little to no effect on the battery itself and can be charged several times a day. Some of the other battery materials deteriorate when drained and charged repeatedly. LiPo batteries have a more efficient power/weight ratio than other batteries and are overall lighter in general, making them perfect for water applications. We wanted a battery big enough that could support running our motor and jet drive without over heating or dumping charge too quickly. We limited our search to larger batteries over 300 grams and came across the FlightMax 4500mAh 6S1P 45C made by Zippy. This particular battery is a 6 cell LiPo with a weight of 789 grams and is used for RC aircrafts and boat applications. It has a 4500mAh capacity and voltage of 24V. Wires, plug, and shrink-wrap are included in battery package.

B. Propulsion Unit

The propulsion unit used for our project is a combination of a high performance brushless electric motor and a jet drive pump unit.

Upon our project research conducted in the fall of 2015, we determined brushless was the way to go in terms of motor selection due to a nearly negligent amount of internal resistance. Our brushless motor is a powerful electric motor used primarily for large remote controlled boats designed to withstand high speeds and torque. More specifically, we are utilizing the Turnigy AquaStar motor with a max voltage of 37V and motor (can) diameter of 39mm and a 5mm shaft diameter, which is fully compatible to connect directly to our jet drive unit shaft. To connect the motor's shaft to the jet drive's impeller shaft we simply insert the motor's shaft into the jet drive shaft unit and secure them together using pressure of the given fastening hex screw.

We went with a smaller jet drive than initially expected, primarily to due financial constraints. Initially, we were determined to use a very large unit comprised entirely of aluminum with an impeller diameter of 53mm that came with a hefty price tag of $400. To try and stick to the lower end of our projected budget of around $500, we decided to go with a smaller more economically friendly jet drive unit that better suites are needs and has an impeller diameter of 28mm. The smaller 28mm jet drive unit is roughly a tenth of the weight of the larger, 39mm jet drive. Just as the motor, the 28mm jet drive pump unit is also design for radio-controlled watercrafts and therefore more compatible with one another. Figure 2 represents the functionality of the jet drive unit used for this project. The water intake valve is located on the bottom of the unit and the water exit nozzle is located to the far left of the unit.

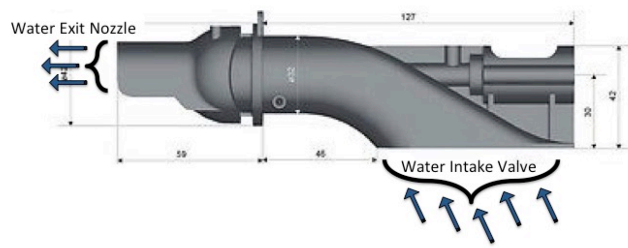


Figure 2: Jet drive propulsion system

C. Electronic Speed Controller

The electronic speed controller is a device that was implemented into the design so that the speed could be calibrated and controlled with the microcontroller. The electronic speed control serves as a gateway between the motor and battery with the microcontroller being the decision maker between this connection. The electronic speed controller has the ability to be programmed via pulse width modulation, which provides the capability for it to be programmed to control the speed exactly as desired. The process is quite simple. A code is generated to the microcontroller, this code is then sent through a data line to the electronic speed controller, and the speed controller is calibrated for this code and awaits further instructions from the microcontroller. Once the microcontroller is given information from the user to increase the speed it sends this to the electronic speed control, the electronic speed control then begins to output a low signal to the motor to start the speed at the minimum value. The user can then increase and decrease the speed and the electronic speed control will follow the commands using this same process.

Initially we ran into problems when trying to select and purchase an electronic speed controller (ESC). Being unaware of a few different features available for different ESC's that appeared to be similar, we wasted time and resources.

To begin initial testing, we purchased a small, cheap, brushless motor and a small, cheap, brushless ESC. Both ran flawlessly with our design because we powered our microcontroller developmental board we used at the time with a laptop. Naturally, we expanded to testing our design and speed setting communication with the MCU powered from the battery used to power the motor and found our small testing ESC had a BEC functionality that proved to be very useful. The BEC function allows the ESC to take a constant 5V from our rechargeable power source and redirect it to the MCU to power our circuit. Before discovering this function we were planning on using a step-down converter to power our MCU but the BEC function was more reliable, easier to use, and simplified our circuit design. However, an ESC that was capable of withstanding up to 120A was already ordered since the company had a slow delivery time and we learned after receiving the item, it did not have the BEC function.

D. Battery Monitoring System

A major aspect of this design is being able to always know how much battery life is left. This provides multiple benefits to the user such as knowing how long they can ride for or alerting them that there is not much ride time left. This serves as both a luxury and a safety precaution so that the user does not become stranded due to a low battery. The display of the battery life will be both on the app that is used to control the board as well as on the board itself, represented by LEDs. In order to keep track of the battery life a voltage divider will be used to decrease the voltage so that the ATmega328p microcontroller can read the voltage value using an ADC pin. Because the power supply being used has a maximum voltage of approximately 24VDC, the voltage divider needs to use 38kΩ and 10kΩ resistors to drop the voltage to 5V. Equation (1) was used to choose these resistor values.

$$Vout = Vin\left(\frac{R2}{R1 + R2}\right) \tag{1}$$

Since a voltage divider is being used to represent the battery life this will provide only an approximate representation of how much battery life remains in the battery. This will not reflect the true voltage level because as the battery begins the voltage divider will still be producing a 5V output and then it will begin to drop but not at an accurate pace. Table 1 shows the representation of the approximate percentage of battery life based on the values read by the microcontroller.

There will be three color LEDs that will be used on the board to represent the battery life. Based on what percentage of battery life is left, a single LED that corresponds to the percentage will be lit. The LED will stay lit until the battery life falls out of the given LED's range and then proceed to light the next LED to represent the change in battery life. A green LED is used to display that the battery life is in a range of 60% to 100%, a yellow LED is used for the range of 30% to 60% and a red LED is used to represent less than 30%.

Table 1
Battery Level Representation

Battery Voltage	Voltage Read	Approximate Percentage
24-22V	5-4.58V	100%-60%
21-12V	4.57-2.5	60%-30%
<11V	2.4V	<30%

E. Microcontroller

When it came to choosing a microcontroller, simple and straightforward is the only requirement that needed to be met. We decided to go with the ATmega328p TQFP package. We chose this microcontroller because we did all of our prototyping and testing with a prebuilt Arduino UNO that used the ATmega328 as the MCU. This made designing the microcontroller much easier because we had a guideline that could be followed in case any complications were faced. The Arduino platform was used to compile the codes we used so knowing that the ATmea328 was compatible with this was another reason we decided to use this as our microcontroller. The specifications of this microcontroller are shown in table 2.

Device	**ATmega328**
Digital I/O pins	14 (six PWM pins)
Analog Pins	8
Operating Voltage	1.8-5.5V

Table 2: ATmega328p TQFP package Specifications

One of the few tasks for the microcontroller was to manage the data that was being received/sent through the Bluetooth module back out and what to do with the corresponding data. While the board was on, the microcontroller is responsible for sending the current voltage reading from the board and the speed. These values sent would determine how much charge is left in the battery and the speed would be a safety net to determine the speed of the motor. The data sent to the application is sent in a specific format given so there would be no confusion on the Android application side and assure that the values sent are read correctly. The values sent from the microcontroller served also as a way to let the application know that is connected by sending data within a period of about one second. The format in which the data was being sent was: [V=$V_{voltage}$, S=S_{Speed}]. This was a safety net to notify the user that there is a communication issue between the board and the application. While the microcontroller was tasked by sending data in a specific format, it was tasked to also read commands sent from the Android application. The command sent from the application was a single value, which would determine the speed of the board from 0–100%. The data read from the microcontroller was read within one second period, to ensure that a connection is established from the microcontroller to the phone; any data that did not come within a one second period, give or take some milliseconds, the motor's speed would be set to 0 to prevent any injuries for the user and board. Another aspect of the microcontroller was the aid when connected. To ensure that the user has actually connected to the electric surfboard, once the connection is established, the microcontroller would control the LED lights flashing Green -> Yellow -> Red -> Yellow -> Green three times.

Due to the fact we are controlling the motor through an ESC using an Android Application, we lack the luxury to calibrate the ESC manually; through the means of a knob or a simple remote control that has throttle sticks in it, thus coding into the microcontroller to interact with the ESC was the only way. To do so, we had to find information about the certain ESC; the throttle values at starting values and the ending values and in addition how long do you have to wait between the first starting value and the second value. After calibrating the ESC correctly, the ESC takes values of about 800 to 2,300, which determines the RPM of the motor. To make calculations easy to see and data being sent and received easy to interpret, we shifted the values to have a certain percentage between 0 – 100%, thus a formula was created to achieve this behavior.

1. Take the difference between the lower and the higher signals that is sent. 2,300 – 800 = 1500
2. Take the result and divided by 100 then multiply it by a number, which represents a percentage speed. (1,500 /100)* (percentage speed)
3. Last step add the results the value of the minimal signal

Doing this, you have values between 800 and 2,300 as a function of a percentage, which would determine the speed of the motor.

F. Android Application

Providing the user with a way to control the board on a personal device is a perk that Electri-surf offers that no other similar devices implement. This design uses Bluetooth to communicate between the handheld throttle and the microcontroller; therefore, almost any cellphone can be used to serve as the throttle. The throttle was designed this way because a large amount of the population today has a smart phone, so this was a way of adapting to the rapid growth of technology. The only limitation is that the throttle was designed on an Android app so only users with phones that operate on the Android

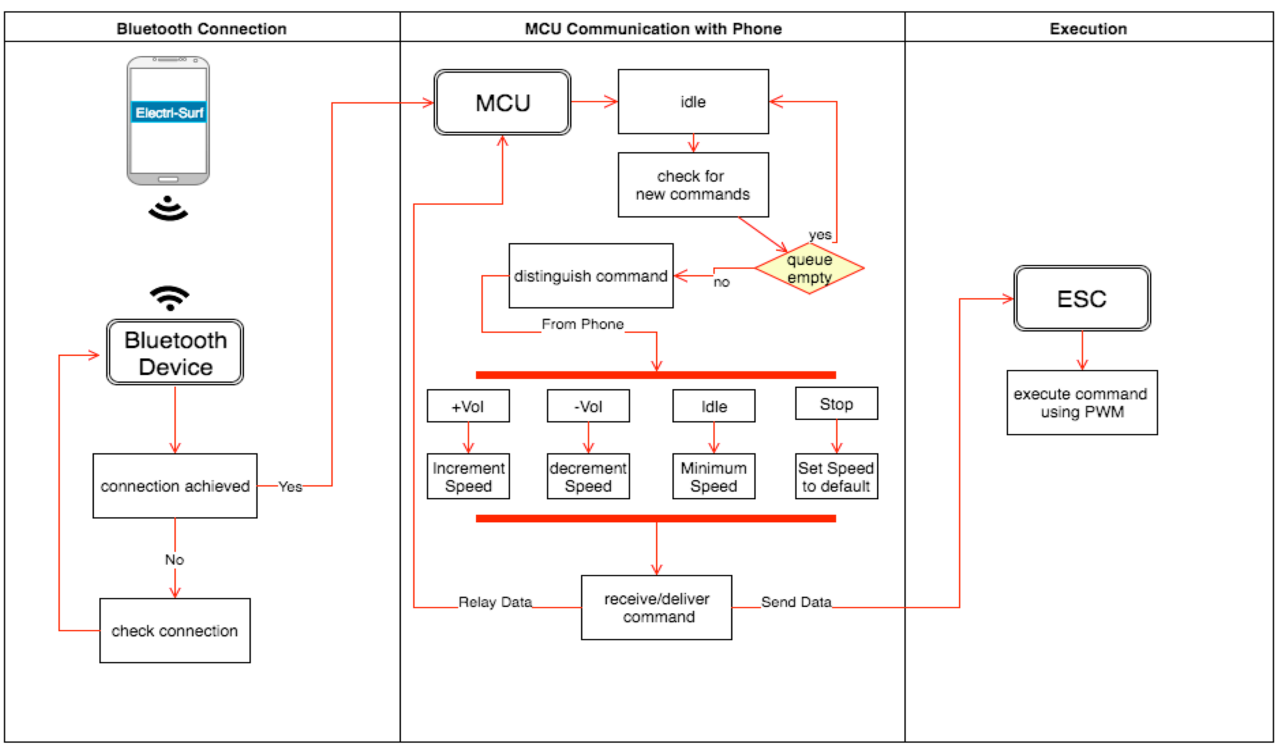


Figure 3: Represents the data flow of our system between the android phone, Bluetooth module, MCU, and ESC

platform can download the app. The application in general will have a Home screen in which it would have a "Get Surfing" button and on the bottom of the application labeled "Advanced Settings," which will prompt the user to be cautious of changing the settings and it will also have a quick help settings to help the user out as seen in figure 4. Looking at the screen after the user presses "Get Surfing" is the graphical user interface (GUI) in which the user will interact to control the Electric Surfboard and also display the corresponding information. Before this screen is showed, the app will communicate with the microcontroller to know there was a connection established between the devices. If there is no connection that has been made, the user would be taken back to the Home Screen. The volume keys located in the user's phone will increase or decrease the speed of the electric surfboard the same way you would increase/decrease the volume of your music. A display of the screen after the user has pressed "Get Surfing". In the GUI shown, the battery life is displayed as a bar, with the current speed of the board as well. The user is also given the option to stall/idle and stop the motor at any given time.

Figure 4: "Get Surfing" home screen

One of the features of the advanced settings is that there is a GUI in which the user can choose the values of how the speed incremental is, the stall/idle speed, the max speed, and the stop for the values. Since each person that rides the board has a different weight, we took consideration of this, and opted these options for the user to choose from. Figure 5 shows the control screen on the application that the user will see when operating the board.

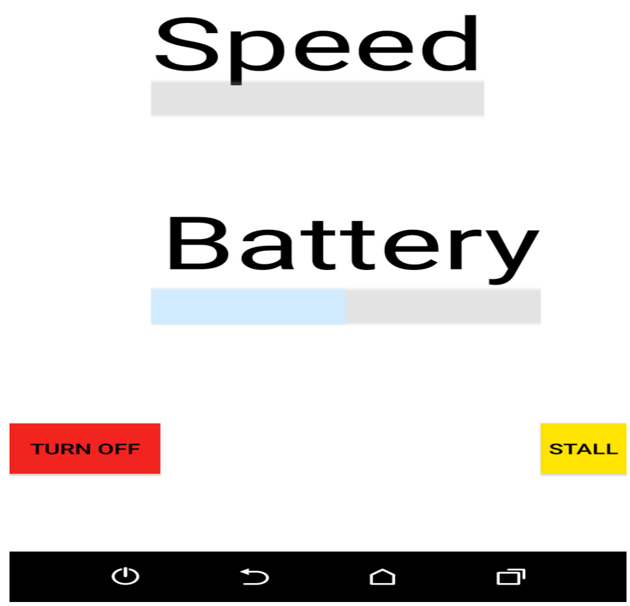


Figure 5: Application control screen

The application will run in normal setting as if the user presses the "Get Surfing" button. The purpose of this section is to know what is happening under the hood of the application. This section of the app timestamps everything from incoming data to outgoing data and simple actions. Having to log and apply timestamps to every action would provide feedback of fixing any issues that the system would throw.

G. Bluetooth Communication

The Bluetooth module that was chosen was the HC-05. This module was chosen because of the low cost and low power. The short connection range happened to be a plus for this module. It has a range of about one meter. This is ideal for this design because we want the connection range to be limited to the user being on top of the board and no further. This is to prevent the motor from running when the board is not in use. Maintaining the connection with the Bluetooth is one of the most uncontrollable factors for this design. Being in the water makes keeping the connection a difficult task due to the random dips underwater the board will take while in use. These dips cause the connection to break due to the blocking of the transmitted signal from the Bluetooth. In order to lower the chances of this happening, the Bluetooth module was placed as close to the surface as possible. Doing this minimizes the chances that the Bluetooth will break the surface of the water whenever the board goes underwater. The only barrier the signal has is the container it is in to keep from getting wet which is not expected to cause major issues in connectivity.

III. System Concept

To understand the completely integrated system, a flowchart can be used to accurately represent the subsystems in a combined fashion as seen in Figure 6.

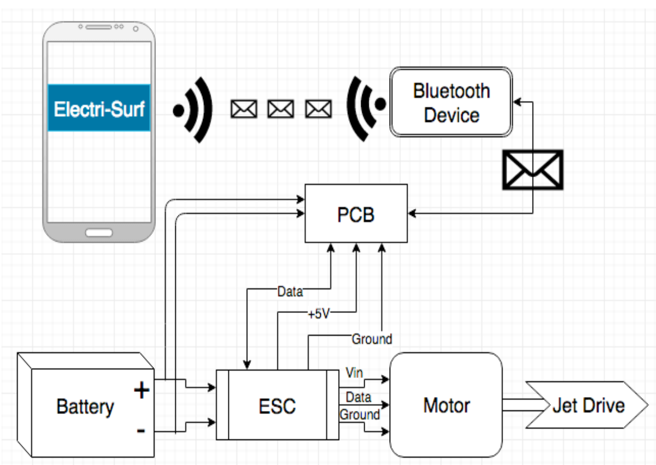


Figure 6: A complete overall flowchart that shows the how the subsystems work together

As shown in the overall flowchart, our complete system is designed to be fairly simple and extremely user friendly. Simplicity is desired in our project because we wanted anyone with an interest in watersports, remote controlled technology, or a combination of the two, to theoretically have the opportunity to easily use our electric powered surfboard with little to no previous knowledge in our specific design.

The user will have full control of the motor with their Android smart phone, as well as remaining battery voltage levels in a simple, easy to use custom Android application. Simply connect the rechargeable LiPo battery to the intended connectors, make sure the emergency disconnect is engaged, and then connect the phone (throttle) to the wireless Bluetooth device. As the battery is connected and the PCB, ESC, and motor are powered up, the motor will automatically calibrate itself and multiple audible tones can be heard. Once Bluetooth connection is achieved, the user will have control of the motor's speed and have access to the estimated battery voltage remaining.

Hardware components consisting of the PCB, motor, battery, ESC, Bluetooth device, and the jet drive unit are enclosed in a housing unit integrated directly into the board and partially protruding from it to allow the jet drive's intake valve and exit nozzle to have access to water. The housing unit is a small confined package intended to reduce drag and not obstruct the rider's movements.

Data flow for our system is primarily designed to execute two main functions: wait for a command from the user or execute a command once a command is inputted. Once the wireless throttle is connected to our Bluetooth module integrated into the printed circuit board, the MCU will wait for a command from the user and send the given command to the ESC, which will use pulse-width modulation to vary the speed of the motor. If no command is being sent to the MCU via the Bluetooth module, then the speed setting will remain unchanged from the previous command, unless of course, there is a break in the Bluetooth connection. Figure 3 is a representation of the data flow between the android phone, the Bluetooth module, the MCU, and even the ESC.

III. Project Management

A major guideline that was set in developing Electri-surf was using resources responsibly. In order to do this a limit as to what the spending conditions would be was set and agreed upon by the group. The amount also had to be within a reasonable range of the funding that was provided. We were fortunate to have this project sponsored by Boeing and Leidos who generously provided a budget of $459.00. In addition to the budget we agreed to set an out of pocket budget of $200.00 between all of the group members for any extra spending that would be required. A total of $450.00 have been spent in designing Electri-surf. Maintaining proper spending habits was not too big of a concern in designing Electri-surf. A few of the purchases made needed to be redone because of ordering parts that did not have the correct specifications but no extra spending was made on unnecessary items that were not used in the design.

In addition to monitoring spending, distribution of work was important in maintaining steady progress toward completion. Each member was assigned a particular task that they were responsible for completing. Although each task was done with the help of the entire group, one individual was responsible for the overall completion of their given task. As time began to progress so did the frequency of meeting; from weekly, to every other day, to daily in order to make sure each member was not only doing their part but to troubleshoot and make sure that each function was compatible with each other's work.

IV. Design Method

Before any designs were finalized, all of the components were first tested on a breadboard in case any complications occurred. Most of the parts tested worked with no trouble at all but we did face an issue with our battery monitoring design. Originally the battery life was going to be monitored using the DS2438 smart battery monitor. The DS2438 chip is capable of reading a voltage from an input pin and then sends this value to the microcontroller via 1-wire bus. This was ideal because the voltage could be accurately monitored and a good representation of the battery life could be given. However, after weeks of constantly testing multiple DS2438 chips it seemed there was no way this chip would work with the design. This created a major issue because the PCB had already been designed and ordered to implement the DS2438. After every possible solution was exhausted we decided to cut the chip from the design and implement a voltage divider to serve as the battery monitoring method. Fortunately, the board layout that was generated for the PCB included a voltage divider circuit in the circuit made for the DS2438 that was used to drop the voltage before entering the chip. The board layout used is shown in Figure 7. We were able to use this voltage divider to serve as our battery management circuit without having to design another PCB, however, it did require making some adjustments to the PCB that made it look less desirable but still functional.

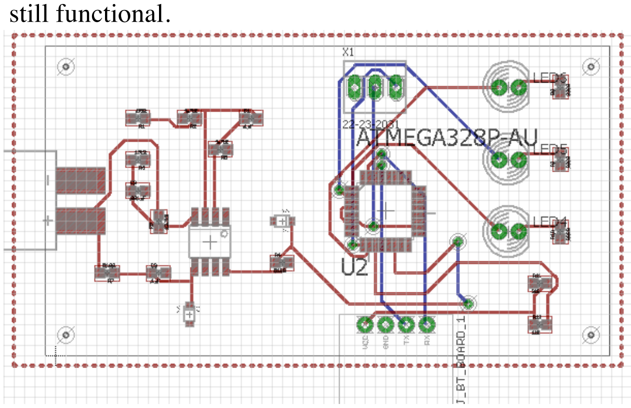


Figure 7: PCB board layout

V. Safety Precautions

A. Rider Safety

Electri-surf is theoretically designed to be used in a large body of water; because of this there are a few safety concerns that needed to be addressed. Injury prevention is an unavoidable obstacle since the environment the board is required to operate in is unstable and unpredictable. When a rider is using the Electri-surf board, he must be aware of the possible risks involved riding may result in. The precautions that were taken into account were rider injury due to falling off the board or injury to others in the water. The surfboard has a leash installed on it already, which is used to prevent the board from being completely separated from the rider but keeping it within about 6 feet from the rider. Because we have a motor on this board we do not want it to continuously run when the rider falls off and pull their leg or possibly drag the rider through the water against their will. These concerns were addressed by implementing what we call, an emergency kill switch. Initially the connection range was going to be relied upon as the kill switch. After the Bluetooth connection is terminated the microcontroller will tell the motor to cut off. However, after running multiple tests we found this was not the most reliable method. Sometimes it worked and at other times the Bluetooth connection was broken but the motor did not stop. A physical kill switch was then implemented into the board. This kill switch is directly connected between the electronic speed control and the motor. The kill switch has a leash that can be attached to the user's ankle so in the case of them falling off, the leash would be pulled, engaging the kill switch and disconnecting the battery from the electronic speed controller and any power being sent to the motor will be instantly cut off. Not only does this reduce the chance at harming someone else in the water, this also aids in making sure the rider does not lose the board. The instant cutoff of the motor will keep the board from moving away from the rider.

B. Waterproofing

As one would expect, waterproofing the electrical components of an electric powered surfboard would be a very important part of the construction. However, for our intended purposes, we are intending to test the proof of concept of our project and therefore, we are not submerging our surfboard in water. Dry testing will provide sufficient proof that our project is functioning the correctly without taking the risk of damaging or ruining our electrical components.

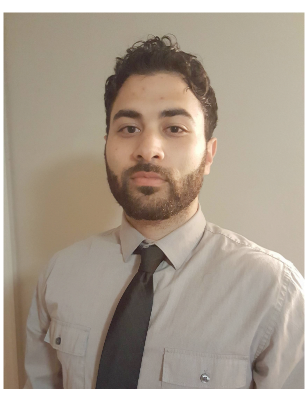
If we were to waterproof our electrical components we would use epoxy and resin to create a waterproof seal around the joints of our component enclosure and as well as around our jet drive unit water intake valve and exit nozzle. Not only does water pose a threat but also salt water poses and even greater threat and calls for even more adaptations to ensure product safety and longevity because of the harsh corrosive properties salt water contains.

The android cell phone used as our wireless throttle would also need be waterproofed. If necessary, we would purchase a waterproof bag that would be used to house the phone and would allow the user access to all the controls as well as a flotation device and wrist strap for extra security. This type of throttle waterproofing is reliable and inexpensive. As previously mentioned, to limit the risk of damaging or destroying our components, we will not be testing our design in water but are going to test the functionality of the components through dry tests.

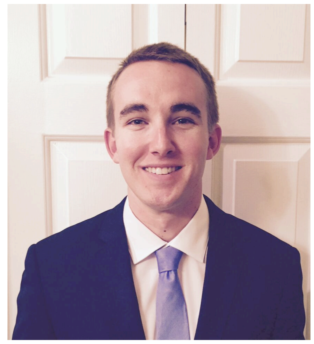
VI. Conclusion

Completing Senior Design is considered to be a right of passage into the real-world industry of engineering to the students here at the University of Central Florida. We were not alone in our struggles of soon to be graduating seniors attempting to put together the best project we could. Tirelessly, we ran numerous tests that were both successful and unsuccessful, and had to constantly make changes and updates to our design as our stages of development advanced throughout the semesters. Wanting to create something that no one has ever done here at UCF, we dedicated two entire semesters to developing and making an electric powered surfboard. We would like to thank our sponsors; Boeing, Leidos, and ADDMG law firm. A special thanks is necessary for Dr. Richie and his patience and high level of expertise in many fields. Dr. Richie was always able to answer our questions, both technical and non-technical.

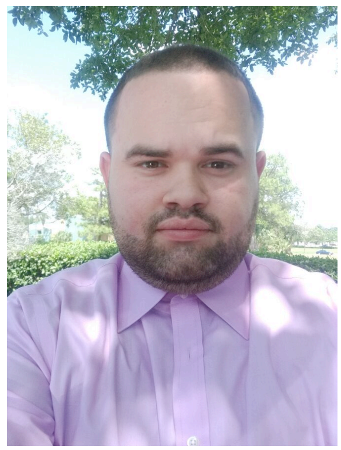
The Engineers



Dennis Higgins is a senior at the University of Central Florida. He will be graduating in May 2016 with a Bachelor's of Science in Electrical Engineering. He is currently looking to work in Power analysis and plans to pursue a Professional Engineer's license.



Ryan Taylor is a senior at the University of Central Florida. He will be graduating in May 2016 with a Bachelor's of Science in Electrical Engineering. He will be commissioning in the United States Air Force as a Developmental Electrical Engineering upon graduation.



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