Autonomous Hydrographic Survey Vessel

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I. Introduction

The purpose of this project is to design and build a watercraft that autonomously navigates bodies of water to collect depth measurements with the use of sonar technology. These depth measurements will then be used to create a bathymetric map of the body of water for scientific study. The specifications that were provided for this project include the following. The boat must autonomously navigate the body of water. The boat should travel at 1-3ft/s. The weight of the boat should be light enough to be easily portable. The data from the sonar sensor should be streamed to a monitor to be viewed by the user. In case of an emergency, the boat will be able to abort data collection and return to the user.

II. Subsystems

The following will be a description of each subsystem developed for the project along with their specifications followed by the detailed design of each subsystem.

A. Navigation System (Manual Control)

The manual control portion of the navigation system will assist in meeting the specifications that the boat will be autonomous and that the boat will have an abort operations function. For the boat to be able to autonomously navigate the body of water, the GPS coordinates of the perimeter of the lake must be measured. This process will require the user to manually drive the boat around the lake with a controller. The manual control system also needs to have programmable inputs for the abort function. In an emergency the user will press a button on the manual controller that tells the boat to stop collecting sonar data and return to the user. The user will also be able to tell the boat when to start collecting perimeter data, when to switch to manual control, and when to begin autonomous navigation. These will be assigned to inputs on the remote controller by the user. These functions were determined to be necessary to improve autonomy or ease of use.

The components that will be used for this system include the Spektrum DX6E controller and the Spektrum AR620 receiver. The decision to use this controller and receiver is based on its available programmable switches and its ability to operate the current boat model that was built by the Water Center at TN Tech. This was observed when a test run was conducted with the current boat model on Cane Creek Lake. The Spektrum controller will allow the project to meet the specification that the boat will be able to collect bathymetric data, the boat will be autonomous, and the boat will have the ability to abort data collection in case of an emergency. For the boat to begin collecting bathymetric data, it will need to be driven manually around the perimeter of the lake so that GPS data for the lake can be recorded. To do this, the Spektrum controller and receiver will need to output a signal that is capable of controller the electronic speed controllers (ESCs) that control the motors of the boat. This was observed by test driving the current model of the boat which implemented the Spektrum controller and receiver as well as Blue Robotics Basic ESCs and Blue Robotics T200 brushless thrusters. These are the same ESCs and thrusters that will be implemented in the autonomous boat. The range for the receiver is listed as 2 kilometers [1]. This distance is suitable for the purposes of navigating Cane Creek Lake. The length of Cane Creek is just over half a mile and since the user must always be able to see the boat, it will be easy for the user to stay within range. This controller also has extra switches on it that can be programmed for desired functions [2]. These switches can be assigned to the receiver outputs which will connect to the Raspberry Pi 4 in the onboard navigation system. These will control the boat's mode of operation.

Figure 1: RC controller and Receiver

B. Navigation System (Autonomy)

The autonomous portion of the navigation system will directly meet the specification that the boat will be autonomous. It will use a GPS device to record data for the perimeter of the body of water. A microcontroller will process this data and create a path for the boat to travel that is optimal for sonar data collection. The microcontroller will then send signals to the motors that control the thrust to steer the boat along the created path. Signals from the user will be sent to the microcontroller to adjust the boat's mode of operation.

The autonomous navigation system will require two Blue Robotics T200 thrusters, two Blue Robotics Basic ESCs, a Raspberry Pi 4 B, a 4-channel analog multiplexer, a simpleRTK2b medium range kit, and an adapter to connect the simpleRTK2b to the Raspberry Pi 4 B.

The Blue Robotics T200 thrusters are currently what the Water Center has for an old model of the boat. The Blue Robotics T200 thruster will be able to meet the specification that the boat should move at 1-3ft/s. Using the CAD files for the hull of the boat, an estimate of the weight was calculated. The total volume of the hull was found to be 9,381 cm^3. To be safe with the calculation of the hull's weight, the highest density 3D printed material was used which was 2.16g/cm^3. Multiplying these two values results in a total weight of 20.264kg. This equates to an estimated weight is 44.67lb. The total weight of the hull and other components turns out to be about 52.18 lb. The maximum thrust of the T200 motors is 11.6lb of force [3]. Assuming the boat will accelerate to the desired speed of 3 ft/s or 0.9144 m/s within 1 second, the acceleration will need to be 0.9144m/s/s. Using the equation F = m*a, the force needed to accelerate a mass of 52.18lbs or 23.67kg at a rate of 0.9144m/s/s would be 21.64 Newtons or 4.86lbf. This is well within the capabilities of the T200 motor.

Figure 2: T200 Thruster

The Blue Robotics ESCs will be able to control the motors since these ESCs are specifically designed to control T200 or T100 motors. These ESCs are what the Water Center is currently using for their model of the boat. Here is a performance chart that displays the thrust of the T200 motor with different operating voltages while using the Blue Robotics Basic ESC R3 [3]. From the chart the thrust is highly adjustable using the Basic ESC R3 and adjustments to the operating voltage.

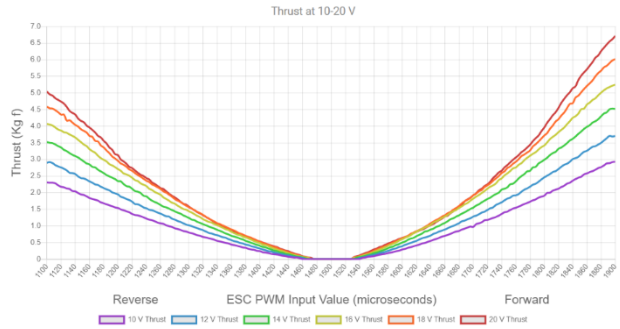

Figure 3: T200 Thruster Performance Chart

Figure 4: Blue Robotics Basic ESC

The Raspberry Pi 4 is necessary to meet the specification that the boat will be autonomous. The Raspberry Pi 4 will have ROS installed and the appropriate drivers necessary to process the GPS data from the simpleRTK2b board. The Raspberry Pi 4 will be capable of controlling the ESCs based on the documentation for both components. There are designated pins on the Raspberry Pi that can produce a PWM signal which is the required input signal for the ESCs [4][5]. Also, the voltage output of a Raspberry Pi 4 is 3.3V which is within the 3.3V-5V range required for the operation of the ESC [4][5].

Figure 5: Raspberry Pi 4 B

The simpleRTK2b long range kit will allow the project to meet the specification that the boat will collect bathymetric data and that the boat will be autonomous. This kit will allow the Raspberry Pi to know its latitude and longitude to within a few centimeters [6]. The boat will be driven around the perimeter of the lake before the sonar data collection begins. The GPS data for the perimeter of the lake will be processed by an ROS program in the Raspberry Pi to create a path that the boat will travel while it is collecting bathymetric data. Centimeter level accuracy is necessary to produce sufficient data to create bathymetric maps. The simpleRTK2b LR kit will be able to communicate NMEA protocol data messages that contain the

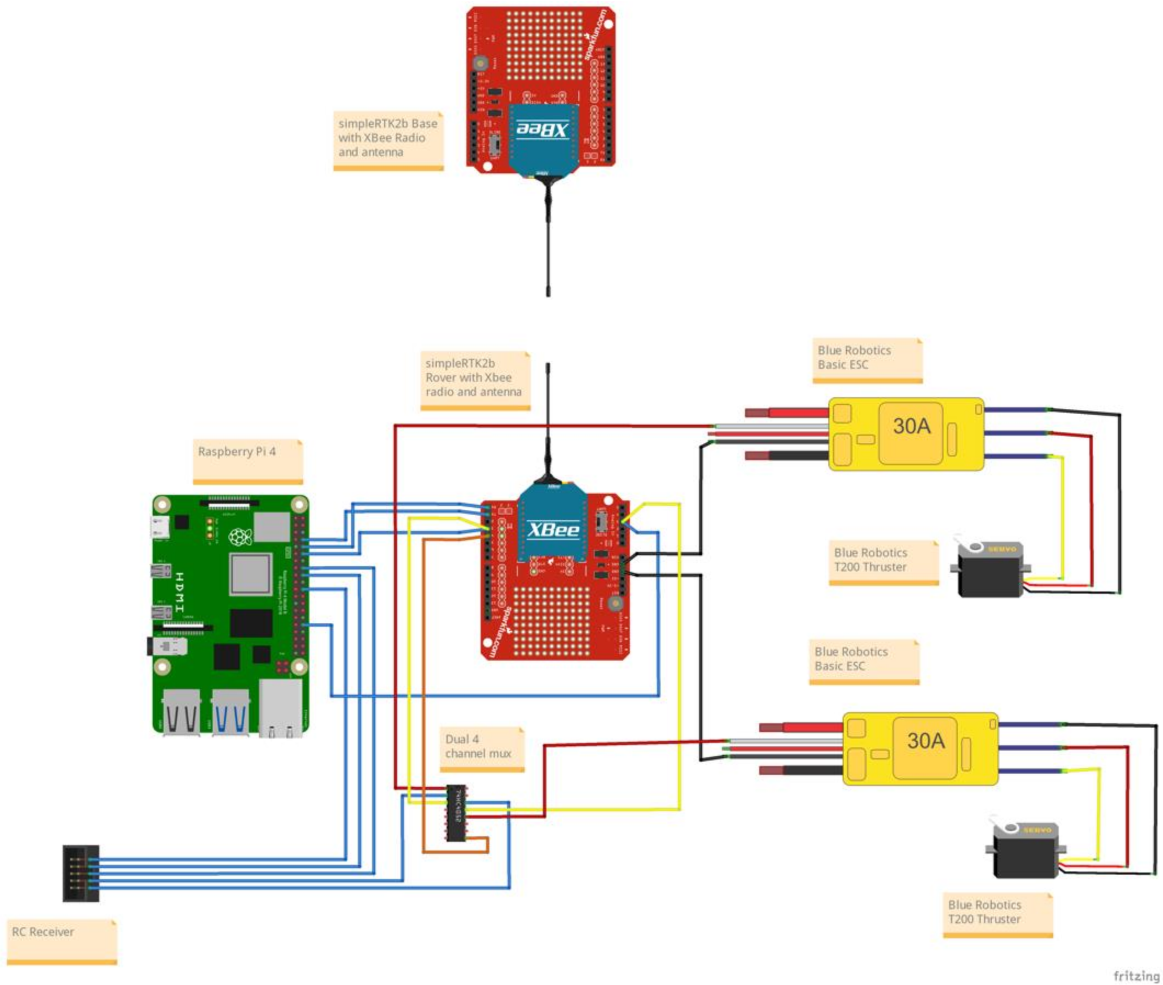

Figure 6: Navigation Subsystem Full Schematic

GPS coordinates [6]. This kit provides two simpleRTK2b boards. They will be set up in a “base and rover” configuration in which one board will be on the boat and one will be in a fixed position with a clear view of the sky. This allows the position of the boat to be calculated to within a few centimeters. This is necessary for the generated path to be optimal for sonar data collection. The GPS data is transferred between the boards using two antennas and two XBee radio modules [6]. The range of this kit is 10 km which exceeds any limitation set by the controller or other systems [6].

Figure 7: SimpleRTK2b Long Range Kit

The 4-channel mux will assist in meeting the specification that the boat will have an abort function. In case of an emergency, the user will flip a switch on the Spektrum RC controller. This will send a signal to the Raspberry Pi which will toggle one of the select lines on the mux [7]. The output of the mux will switch from the Raspberry Pi's motor control signal to the RC receiver's motor control signal.

Figure 8: 4-channel analog mux

The simpleRTK2b adapter for the Raspberry Pi 4 will be used for its intended use case which is to connect a Raspberry Pi 4 to a simpleRTK2b board [8].

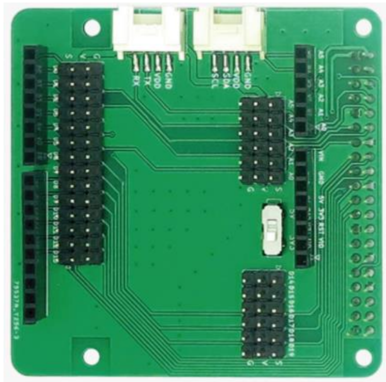

Figure 9: simpleRTK2b Raspberry Pi Adapter

BILL OF MATERIALS

Qty	Part	Total Price
2	Blue Robotics T200 Thrusters	$360
2	Blue Robotics Basic ESCs	$60
1	Dual 4-channel Analog Mux (10 Pack)	$13.98
1	SimpleRTK2b LR Kit (Headers Soldered)	$818.24
1	Raspberry Pi SimpleRTK2b Adapter	$20.45
1	Raspberry Pi 4 B	$110
1	Spektrum DX6E Transmitter and AR620 Receiver	$200
	Total	$1582.67

C. Data Acquisition and Transmission System

The objective of the Tennessee Tech Water Center is to collect accurate and complete bathymetric data for a body of water. This objective creates important specifications for the design of the survey vessel's data acquisition subsystem. The Tennessee Tech Water Center has expressed that the boat must be able to collect measurements completely and accurately for Cane Creek Lake in Cookeville, TN. Cane Creek Lake is a 56-acre body of water (current depth measurements were inaccessible). An additional objective set by the Water Center is to view the collected data in real time to ensure that the boat is obtaining accurate and precise measurements. The data acquisition and transmission subsystem will be designed to meet these specifications.

The data acquisition and transmission system includes the sonar system and a data transmission board. The sonar system will have serial connections to the data transmission board and any other data transmission component that is recommended by the sonar manufacturer or desired by the user. For example, in the current design, the SonTek M9 sonar is being used, and it is connected to the data transmission board and the SonTek Power and Communication Module (PCM). The transmission board consists of a microcontroller that will connect to the sonar sensors serial output. In addition, the microcontroller will have a serial connection to the USB port of the navigation system's simpleRTK2B module and will receive GPS data collected by this module. The microcontroller will then use an RF transceiver to transmit the collected data. Figure 7 shows the schematic for the onboard data subsystem.

The SonTek M9 Hydrosurveyor sonar sensor will be used to collect the water depth measurements. These measurements will be transferred to the SonTek PCM via a serial cable connection. The PCM has two battery compartments, each housing 8 AA batteries. These batteries supply voltage to the M9 to meet its 12-18 VDC requirement. In addition, the PCM uses multiplexing 2.4 GHz radio to communicate and send collected data to a USB radio dongle inserted in the user's mobile computer at the on-land observation position.

It was necessary to consider the range of the SonTek radio communication link to confirm that the system met the given range specification. It was determined that the range of the remote controller's optimal performance, about half a mile (~800 m), satisfied the specification and would be the limiting factor for all wireless communication onboard the boat. A 2 dBi gain external antenna will be connected to the PCM to improve the range. The PCM has three different options for transmit power: low (10 dBm), medium (19 dBm), and high (22 dBm). When using the external antenna and the high-power setting, the range is estimated to be around 1500 m. This well exceeds the limiting factor and will meet the range specification. The relevant analysis of the M9, the PCM, and the discussed radio communication has been done by SonTek and the results can be seen in their documentation.

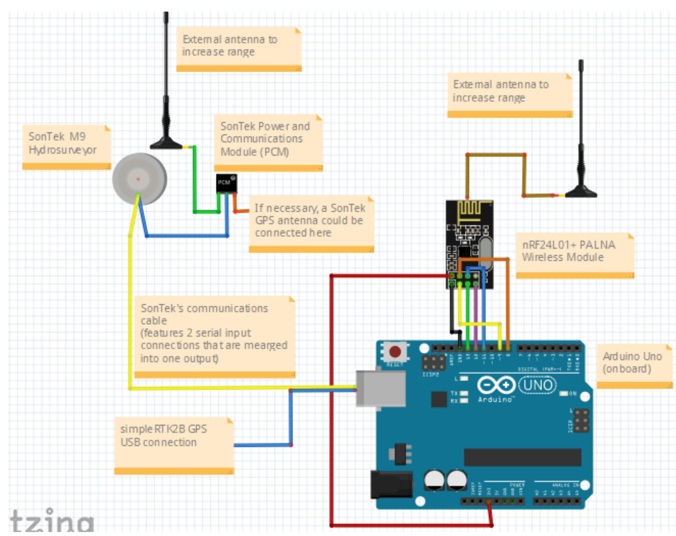

Figure 10: Data Subsystem (on boat)

The Arduino Uno was selected to be used as the data transmission board because of its ability to handle a serial input baud rate of 9600, the serial output baud rate of the SonTek sonar sensor. Additionally, the Uno can communicate using a Serial Peripheral Interface (SPI), making it compatible with the selected RF transceiver for data transmission. Using the SonTek direct connect communications cable, the serial output of the M9 and the microUSB connection on the simpleRTK2B GPS module will be connected to the USB-B port of the Arduino

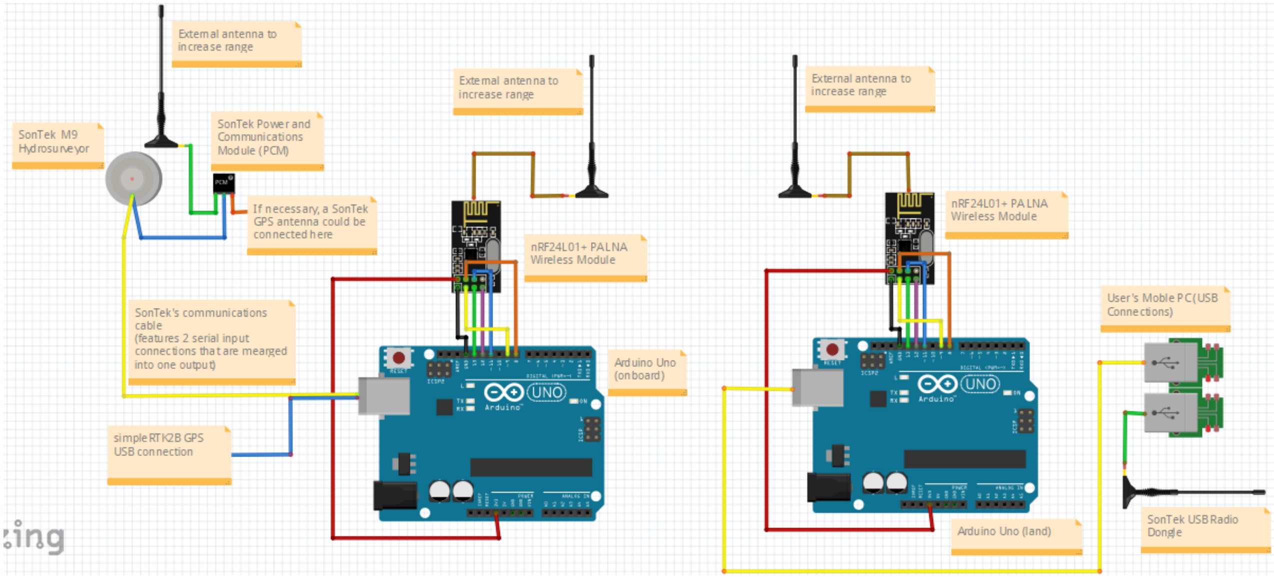

Figure 11: Data Acquisition and Transmission System Full Schematic

Uno. This communications cable combines two serial inputs into one serial output. The validity of this approach is pending on more information from SonTek. However, the GPS module was confirmed to meet the specifications for a GPS compatible with the M9. The specifications were as follows:

- Data output rate between 1-10 Hz (10 Hz recommended)
- Baud rate set to 38400
- NMEA output sentences: GPGGA and GPVTG (if used for position) and/or GPHDT (if used for heading).

The nRF24L01+ PA LNA wireless transceiver module has been selected for the transmission of collected data. This module supports programmable output power and has low power consumption. Available output power levels include 0 dBm, -6 dBm, -12 dBm or -18 dBm, and the module only consumes around 12 mA during transmission at 0 dBm. All the parameters can be configured through an SPI. This type of interface uses the concept of Master and Slave. In this case the Arduino Uno will be the Master and the transceiver will be the Slave. Also, this version of the module uses an external antenna, a power amplifier, and a low-noise amplifier to increase the transmission range from 100 m to 1000 m, a distance that satisfies the range specification. The correct operation of the transceiver modules has been analytically tested by reviewing the functionally and intended purpose for each pin and confirming that the Arduino has the appropriate pins to satisfy the requirements. For example, pins 5,6, and 7 on the transceiver have unique role pertaining to the SPI, and pins 11, 12, and 13 on the Uno directly correspond to these roles.

After the data is transmitted, it will be received on land to be viewed by the user. This system will consist of a radio frequency receiver and a microcontroller. This system will mirror the transmission system in that it will use a Arduino Uno and a nRF24L01+ PA LNA wireless transceiver module in the same configuration. The schematic can be seen in Figure 8. The radio frequency receiver module will receive a message signal encoded with collected data and will decode the signal to extract the measurement data. The microcontroller will be used to control the radio frequency module that receives an encoded radio wave. Once it has been decoded, the microcontroller will transport the received measurement data to a connected computer via a USB-B to USB-A serial connection. In addition, the SonTek radio dongle will be connected to a USB port on the computer and will receive measurement data collected by the M9 and transmitted from the PCM.

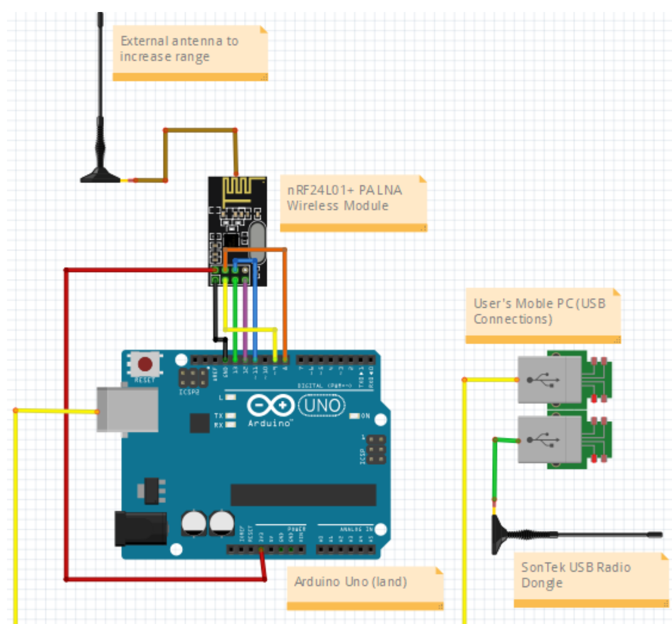

Figure 12: Data Subsystem (land)

BILL OF MATERIALS

Qty	Part	Total Price
2	Arduino Uno Rev3	$41.96
1	NRF24L01+PA+LNA RF Transceiver Module with SMA Antenna 2.4 GHz + NRF24L01 8 Pin Socket Breakout Adapters Compatible (3 pcs each)	$29.18
1	SonTek M9 Hydrosurveyor	Purchased
1	SonTek PCM	Purchased
1	SonTek 2 dBi gain antenna	Purchased
1	SonTek communications cable	Purchased
1	SonTek USB Radio dongle	Purchased
	Total	$71.14

D. Power System

A single battery will provide power for each system on the vessel, and the appropriate power will be distributed through a power distribution circuit [9]. The initial design included a power bus which will distribute power to the data acquisition system, the propulsion system, the navigation system, and the transmission system. However, the number of connections at the battery terminals can be reduced to three, so power will be distributed through two Blue Robotics DC-DC converters and the Raspberry Pi. The Raspberry Pi will receive power from the battery through a Blue Robotics converter and then provide power to the multiplexers and the GPS device through its own pins.

The Electronic Speed Controllers are the only two components that will be powered directly from the battery. The ESCs require 12-16 V for optimal operation. The device used to collect data from the SonTek M9 sonar device is the SonTek Power Communications Module, which requires 6 V. This PCM has an internal power system that uses AA batteries, which will be supplied by the user. The PCM is also used as the power source for the M9.

Blue Robotics provides a converter circuit that is designed to step down the voltage from the same power supply used for the ESCs to supply 5 V for a Raspberry Pi or similar device. Each converter circuit has two terminals to connect to a 7-26 V input power supply, and 4 pin outputs to supply power to two devices [10]. Two converter circuits will be used, one to power the Raspberry Pi and the RC receiver, and one to power the Arduino board, all of which requires 5 V. The SimpleRTK2B GPS system requires 5 V and will be powered directly from a 5 V output pin on the Raspberry Pi, using an adapter which fits directly into all GPIO pins on the Raspberry Pi [8]. This adapter uses a 5 V pin to receive power, a 3.3 V pin to define logic values, and will block the other 5 V power pin. In this case, the Raspberry Pi will need to be powered from the USB-C connection. A USB cable will be adjusted to connect to the converter circuit output pins and plugged into the Raspberry Pi directly. The multiplexers require 3-15 V and will be powered directly from the available 3.3 V output pin on the Raspberry Pi. The land-based GPS also requires 5 V, and it will be supplied by the user's on-site PC via a USB connection.

A microcontroller will keep track of the current power level of the onboard battery. If the boat is still in autonomous operation when the battery level begins to drop below a percentage that risks the boat being left inoperable in the water, the boat will automatically stop data collection and begin navigation back to the starting point. This issue was addressed by Team 1 during the presentation of Design Phase 1.

Additionally, there is a risk of components short circuiting into the water while the boat is in operation. According to the National Institute for Occupational Safety and Health (NIOSH), a current of 100mA is considered fatal; however, only 10mA is needed to cause paralysis in water. To rectify this problem, a breaker circuit will be built onto the power bus that will detect any fluctuations in the currents of each component. If there is any change due to a short, the breaker will trip which results in the boat powering off.

The battery that will be used on the boat is a 14.8 V, 15.6 Ah Lithium-ion battery provided by Blue Robotics. [9] This single battery is designed to power a Blue Robotics Remotely Operated Vehicle with six thrusters onboard for approximately 2 hours under normal use. Since the autonomous boat will have only two thrusters, the battery capacity is large enough to handle the load in addition to the small amount of power required for the computing electronics. The thrusters have a maximum current draw of 20 A at 14 V each, when operating at full throttle. The battery can meet those requirements, as it can provide a maximum continuous current draw of 60 A. The required thrust calculated to maintain the specified boat speed is 4.86 lbf or 2.20 kgf. The thrusters can provide this amount of force while drawing approximately 6 A at 14 V [3]. This can be assumed to be the average current required from a single thruster. The Raspberry Pi 4 B has a maximum current draw of 1.2 A, which includes any peripheral components that are connected and powered on [11]. The RC receiver, when the boat is operating in manual mode, will allow the thrusters to draw the same amount of current that they would draw operating in autonomous mode. Then the total average current draw of all systems during normal operation is approximately 13.2 A. The current draw may be more or less, depending on the throttle of the motors, data collection, and data transmission. The Blue Robotics battery has a capacity of 15.6 Amp-hours, which will provide approximately one hour and ten minutes of runtime under a current draw of 13.2 A.

BILL OF MATERIALS

Qty	Part	Total Price
2	Blue Robotics 5V 6A Power Supply	$44.00
1	Blue Robotics Lithium-ion Battery (14.8V, 15.6Ah)	$290.00
	Total	$332.00

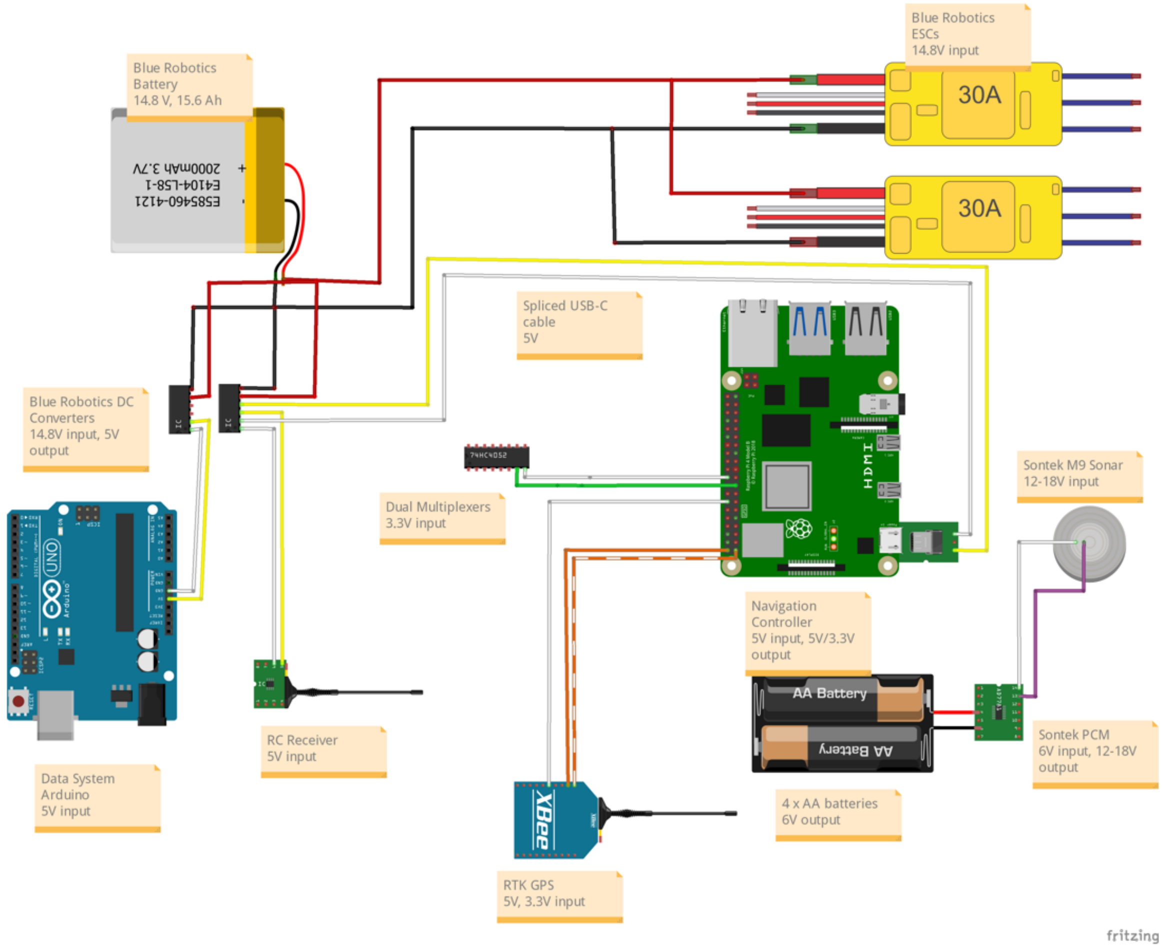

Figure 13: Power Subsystem Full Schematic

E. Boat Hull

The hull of the autonomous boat is provided by the Tennessee Tech Water Center. The hull is a trimaran, which is a multihull boat that comprises a main hull and two smaller outrigger hulls which are attached to the main hull with lateral beams. The main hull is approximately 5 feet in length and will have a hole in the center which will hold the SonTek in place when running trials. The outrigger hulls will be approximately 3 feet in length, and the CAD files will be displayed below. Based on the density of the filament used and an approximation of the hull's volume, it is estimated that the weight of the hull will be 45 pounds. The following pictures display the CAD models that have been provided to us.

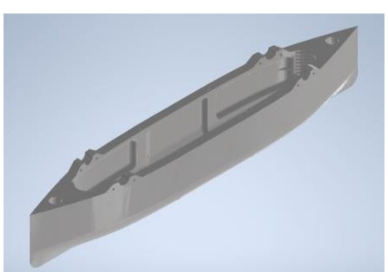

Figure 14: Side Piece of the Hull

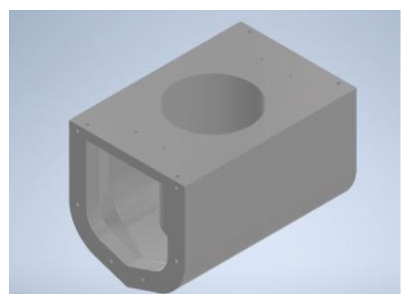

Figure 15: SonTek Sensor Middle Piece

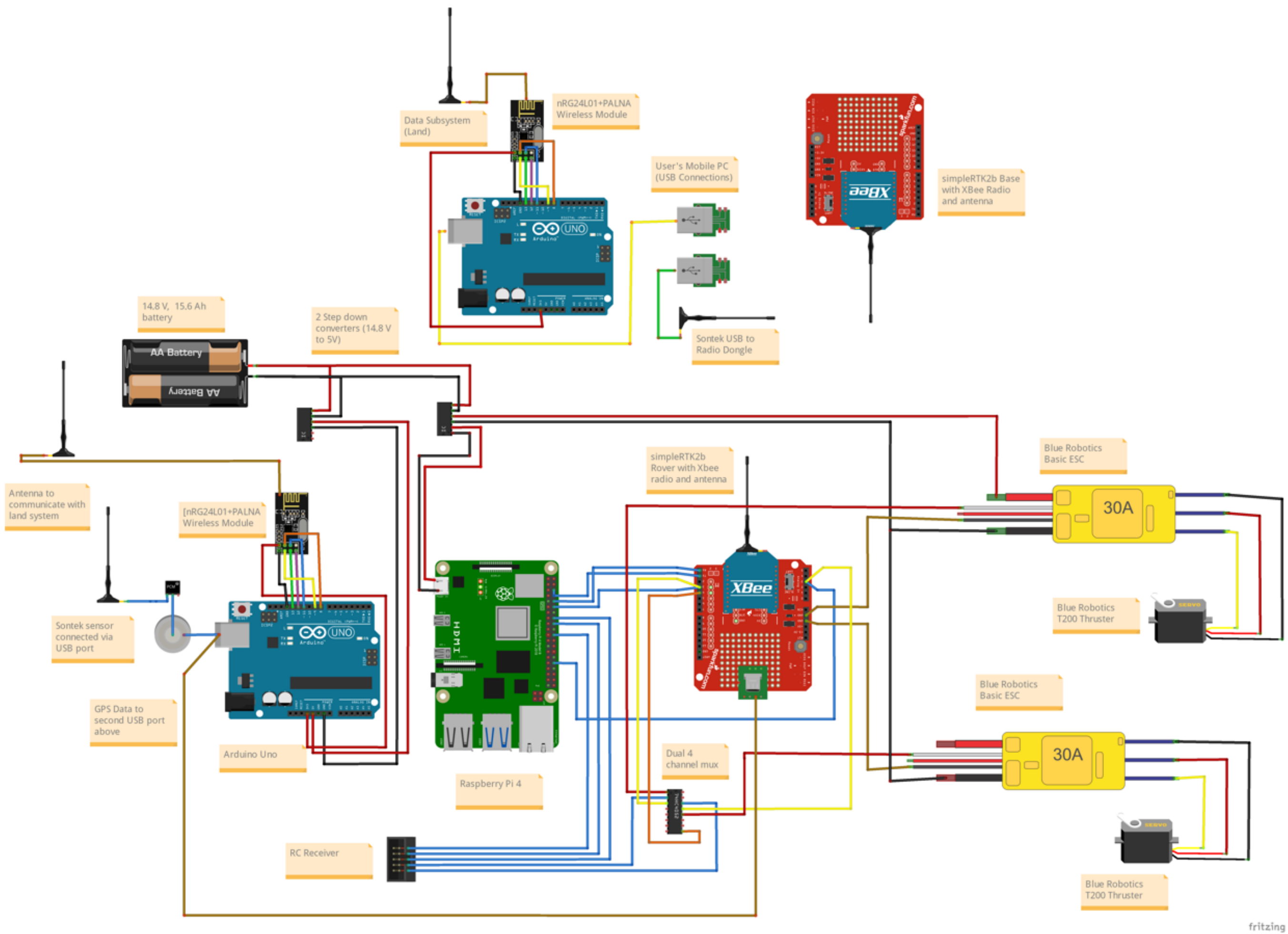

Figure 16: Full Schematic

COMPLETE BILL OF MATERIALS

Qty	Part	Total Price
2	Arduino Uno Rev3	$41.96
1	NRF24L01+PA+LNA RF Transceiver Module with SMA Antenna 2.4 GHz + NRF24L01 8 Pin Socket Breakout Adapters Compatible (3 pcs each)	$29.18
1	SonTek M9 Hydrosurveyor	Purchased
1	SonTek PCM	Purchased
1	SonTek 2 dBi gain antenna	Purchased
1	SonTek communications cable	Purchased
1	SonTek USB Radio dongle	Purchased
2	Blue Robotics T200 Thrusters	$360
2	Blue Robotics Basic ESCs	$60
1	Dual 4-channel Analog Mux (10 Pack)	$13.98
1	SimpleRTK2b LR Kit (Headers Soldered)	$818.24
1	Raspberry Pi SimpleRTK2b Adapter	$20.45
1	Raspberry Pi 4 B	$110

1	Spektrum DX6E Transmitter and AR620 Receiver	$200
2	Blue Robotics 5V 6A Power Supply	$44.00
1	Blue Robotics Lithium-ion Battery (14.8V, 15.6Ah)	$290.00
2	Blue Robotics 5V 6A Power Supply	$44.00
	Total Price	$1985.81

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[10] "5V 6A power supply," *Blue Robotics*. [Online]. Available: https://bluerobotics.com/store/comm-control-power/elec-packages/bec-5v6a-r1/. [Accessed: 26-Jan-2022].

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