FAMU-FSU College of Engineering
Department of Electrical and Computer Engineering

FINAL DESIGN REVIEW

EEL4915C – ECE Senior Design Project II

Project title: **Autonomous Water Quality Sampler**

Team #: 8

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EEL4915C – ECE Senior Design Project II
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Project Executive Summary

This detailed design review is in response to :

Contract: Project #8

AWQuSam Engineering has provided a turn-key autonomous water quality sampler to be utilized for acquiring hydrographic and water quality data by the Florida State University Department of Oceanography. As requested in the solicitation, the system was designed and implemented to support the gathering of water quality and hydrographic data along Florida's coastal environment. The AWQuSam is a propeller-driven kayak capable of driving itself across a bay, at least 5km, navigating with GPS, recording key oceanographic parameters, and relaying samples of data to a base station.

To accomplish these tasks, the AWQuSam employs means that facilitate acquisition of useful scientific data, such as temperature and salinity, in the shallow environments of the Florida shelf. Signal processing is performed via a PIC microcontroller aboard the AWQuSam. All acquired data is logged onto an SD memory card for analysis by researchers.

A GPS system has been incorporated into the AWQuSam for use by the navigation, guidance and recovery systems. In addition to the AWQuSam, a base station was developed in order to receive streamed data from the AWQuSam.

The primary objective of the AWQuSam is to remain autonomous, navigating and performing the aforementioned tasks, for the duration of the trip.

Prior to the implementation of this design, there was no such autonomous system for effectively collecting hydrographic data in shallow environments. The team believes their creative and potentially transformative design implementation will revolutionize oceanographic research by advancing discovery in this area.

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1 Introduction

1.1 Acknowledgements

AWQuSam Engineering would like to thank the FAMU / FSU College of Engineering and the Florida State University Department of Oceanography for monetary contributions toward the development of the Autonomous Water Quality Sampler, hereafter referred to as the AWQuSam. Thanks, also, to researchers within the Florida State University Department of Oceanography for contributing oceanographic expertise and equipment necessary for developing the AWQuSam.

1.2 Problem Statement

There is a need for water quality and hydrographic data from the coastal environment in order to understand the processes that mix and transport nutrients, carbon, pollutants, and other material entering the ocean from sources on land.

Ship-based measurements are expensive because of the operating cost for a sea-going vessel and crew. New platforms for sampling the ocean at high resolution are being used now in many coastal regions around the United States. These platforms, called gliders, are roughly torpedo shaped and, like gliders in the atmosphere, have a relatively large glide ratio in order to translate vertical motion into horizontal distance.

In the shallow environment of the Florida shelf, there is no room for large vertical excursions to provide for the buoyant force to drive the horizontal motion and gliders are not practical.

A new kind of platform is needed that moves across shallow bays and estuaries and measures key water quality parameters like temperature and salinity.

The AWQuSam is a fully autonomous surface vehicle designed to navigate the shallow waters along the Florida coast. Routes can be programmed into the AWQuSam prior to excursion, and the AWQuSam will navigate the route, collecting key oceanographic data along the way. A GPS system has beeen incorporated into the AWQuSam for use by the navigation, guidance and recovery systems.

The AWQuSam processes scientific information, such as temperature and salinity, from sensors located in the water. Signal processing is performed via a PIC microntroller aboard the AWQuSam. All acquired data is logged onto a SD memory card for analysis by researchers. Samples of data are streamed via license-free channel to a receiver for real-time analysis. A base station has also beeen developed in order to receive streamed data from the AWQuSam.

1.3 Operating Environment

The AWQuSam will be operated in the shallow environment of the Florida coastal shelf. It will be operated and/or stored in a salt-air atmosphere with humidity levels potentially reaching 100%. While operating, the AWQuSam may experience extended exposure to sunlight. During the summer months, the AWQuSam may be stored in temperatures of up to +70°C and while operating, may be exposed to temperatures of up to +55°C. In addition, the AWQuSam may experience winter storage temperatures as low as -20°C and operating temperatures of -5°C. The AWQuSam may experience crashing waves of up to 1m in height, winds of 40knots, and driving rainfall. These conditions have all been considered in the design of the AWQuSam.

1.4 Intended Use(s) and Intended User(s)

The AWQuSam is intended to be used by oceanographic researchers. It will primarily be deployed by users with at least a Bachelor's degree and knowledge of the system. However, the AWQuSam may be deployed by individuals with no knowledge of the system, and it shall be designed to allow such a user to deploy the system with the aid of user documentation which will be provided among project deliverables (See Section 1.6). Untrained personnel will be able to program a new mission path into the AWQuSam with only the aide of instructional documentation which will be provided by the project team. Once deployed, the AWQuSam will be fully autonomous. Collected data will be analyzed by oceanographic researchers.

The AWQuSam will be used to collect precise hydrographic and water quality parameters near the surface of the Apalachicola bay area and other shallow water environments. It will record water temperature and conductivity information. The AWQuSam will be used to collect this oceanographic data in an environment where there is presently no effective method for collecting such data. It is not intended to collect data on land or in deep ocean environments.

1.5 Assumptions and Limitations

The AwQuSam should measures and records water temperature to a precision of 0.01ºC (objective) at a rate of 8 samples per second (objective). It should measure and record water conductivity to 0.01 S/m (objective) at a rate of 8 samples per second (objective). Most recently acquired temperature, conductivity, and position will be transmitted to a base station receiver every 5 minutes. The AWQuSam will not be deployed for missions longer than 12 hours. The system is to be used only for surface water applications, and is not to be deployed in areas with ocean currents in excess of 5 knots or with waves greater than 2m in height. The end user will program paths into the AWQuSam using GPS coordinates.

The end product facilitates easy transport to and from a launch site by one to two persons. An AWQuSam prototype has been designed and delivered by April 13, 2011 with expenditures not exceeding $2000.

1.6 Expected End Product and Other Deliverables

One (1) Autonomous Water Quality Sampler prototype has been delivered to facilitate the gathering of oceanographic data in shallow coastal waters. Its path are programmable by the end-user. Once programmed, the AWQuSam propels itself across the surface of bays and estuaries recording water temperature and conductivity.

The AWQuSam has been delivered with documentation detailing instructions for programming new paths. Data formats found in the data log and transmissions have been documented to facilitate analysis by researchers. Documentation has also been provided with instructions for performing maintenance and for servicing the system or components. Prototype and documentation have been delivered on time (by April 13, 2012).

2 System Design

2.1 Overview of the System

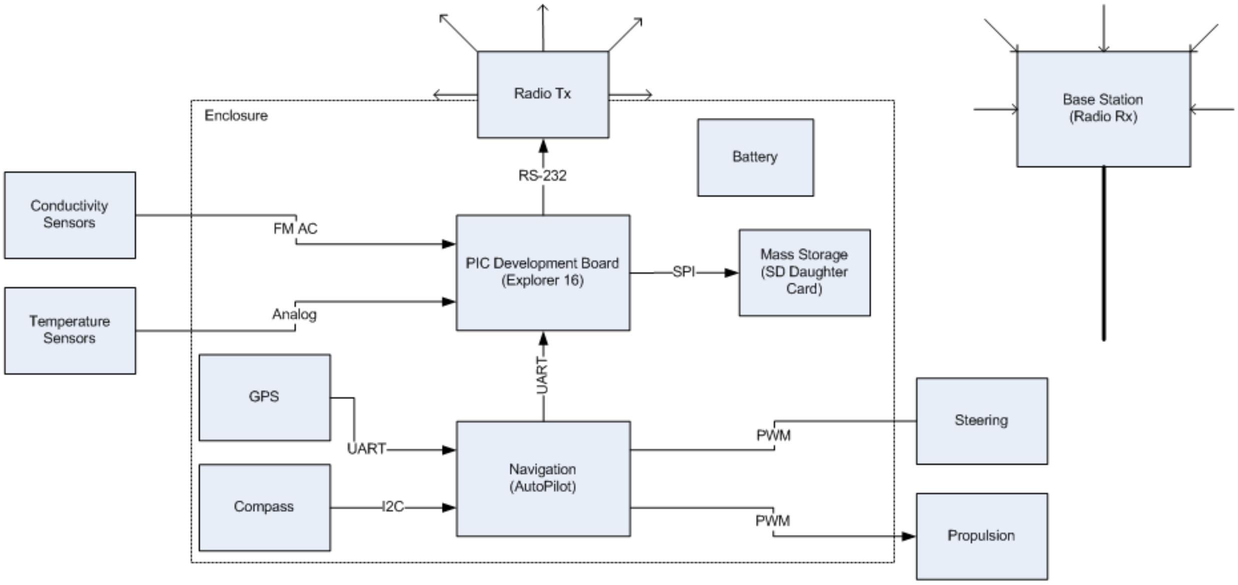


Figure 2.1.1: Top-level architecture of AWQuSam

The AWQuSam's design revolves around the Explorer16 PIC development board. This is a microcontroller based board. It receives inputs from conductivity and temperature sensors. This information is logged to an SD card. A separate navigation subsystem receives inputs from a compass and GPS module that are used to drive the steering and propulsion systems.

2.2 Major Components of the System

2.2.1 Explorer16 Development Board

The design revolves around the Explorer16 PIC development board. This is a low cost, efficient microcontroller based development board. It includes the dsPIC33FJ256GP710 microcontroller, which features up to 85 I/O pins. It also has a 12-bit A/D converter, two UART interfaces, two SPI interfaces, and two I2C peripheral interfaces. In addition, this microcontroller offers input capture, compare, and pulse width modulation peripheral functionality that will be utilized in the design.

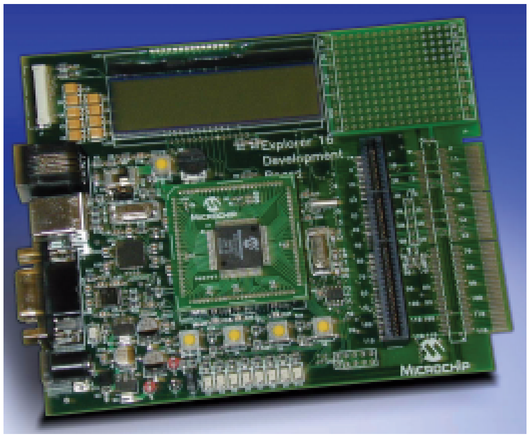


Figure2.2.1.1: Explorer16 Development Board

The Explorer16 offers expansion capabilities in the form of daughter cards and plug-in-modules. This easy integration feature will be utilized in the design of the AWQuSam. The development board also features pushbuttons, a 16x2 LCD display, and LED indicators that will be useful for debugging and programming. The development board, when powered from 9V supply, draws about 250mA of current.

2.2.2 Conductivity Sensors

A number of vendors were consulted in order to determine the conductivity sensor best suited for this design. The most practical option from YSI is their 600R model conductivity/temperature sensor. This series can sample at 10Hz. However, the sensor costs $2062 per unit, plus $85 for each pigtail connector for integration with the development board

Forston Labs offered a conductivity sensor for $125 per unit, but they only resolve to 0.02 parts per thousand (ppt). In addition, the response time of this conductivity sensor is too slow for this application.

PME offered a rapid-response conductivity sensor, as well. However, this option is not very stable. Engineers at PME advised the team that their sensors are not well suited for twelve hours of unattended operation. These sensors do not resist fouling and are quite fragile.

Figure 2.2.2.1: SBE-4 Conductivity Sensor

The SBE-4, by Seabird Electronics, has been used in the design to gather water conductivity data. This sensor provides a precise, rapid response that satisfies the design requirements. Seabird Electronics is a premier manufacturer of marine instruments and sensors. This sensor outputs a variable frequency square wave signal (from 2.5kHz to 7.5kHz) corresponding to the conductivity (from 0S/m to 7S/m). When powered by a 12V source, these sensors draw about 12mA of current each. The aluminum chassis is used to mount the sensor to the AWQuSam.

2.2.3 Temperature Sensors

A variety of temperature sensors are available. Thermocouples offer a fast, almost immediate, response to temperature changes. However, they are best suited for extremely high temperature. RTDs are stable temperature sensing devices. However, because they are best suited for a wide temperature range, detailed precision is not guaranteed.

This application requires measuring a relatively limited temperature range. However, accuracy and sensitivity to small changes is important over this range. A fast-response thermistor is the best solution.

Figure 2.2.3.1: OL-710 Thermistor

The design utilizes such a thermistor for acquiring temperature data. In particular, the design uses the OL-710 device by Omega Engineering. This instrument is designed for immersion in fluids, and it offers a level of precision in the range of temperatures experienced in the Apalachicola river and bay system. It features 1/8 NPT threading that is utilized to affix the sensor to the AWQuSam.

2.2.4 GPS

Figure 2.2.4.1: EM-406A GPS Module

The EM-406A complete GPS module has been used in the design of the AWQuSam. This module revolves around the SiRF StarIII chipset, and it features an integrated patch antenna.

2.2.5 SD Daughter Card

Data acquired by the conductivity sensors, temperature sensors, and GPS are recorded to an SD card. Microchip offers a board for interfacing the Explorer16 with SD cards (AC164122).

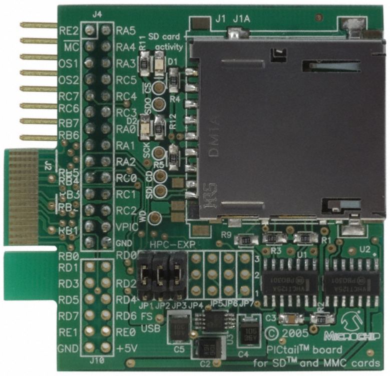


Figure2.2.5.1: SD Daughter Card for Data Logging

2.2.6 Ardupilot - Unmanned Aerial Vehicle Controller Board

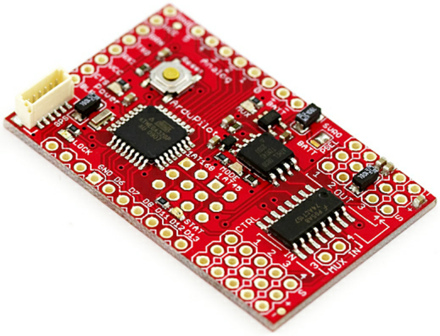


Figure 2.2.6.1: Ardupilot Development Board

The Ardupilot board has been modified to fit the automonous navigation requirements for the AWQuSam. It is equipped with an ATMega328 microcontroller The EM-406A GPS receiver is compatible with the board. The Ardupilot consists of 8 input and 8 output pulse width modulated points. The Ardupilot's PWM outputs interface with the propulsion systems speed and steering servo. The Ardupilot calculates angles for the rudder, and sets the angle of the speed servo to activate the throttle. This board is utilized to perform navigation calculations for autonomity. The Ardupilot initializes the EM-406A GPS receiver and receives National Marine Electronics Association (NMEA) messages which it outputs. It uses the NMEA GPRMC sentence to collect longitude (east or west) and latitude (north or south) coordinates, speed, course, and time information. It uses the GPGGA sentence to determine wheter or not it has acquired a valid satellite fix. The Ardupilot is also connected to the Explorer 16 board. It outputs all the NMEA messages it receives to the Explorer 16 for datalogging.

2.3 Performance Assessment

The system was designed to satisfy the requirements of the specification as discussed with the customer. Over the course of the project, it became apparent that cost and time would prohibit meeting some of the objectives indicated in the latest revision of the system specification, but all the requirements have been satisfied. The AWQuSam measures and records eight samples each second of water conductivity and water temperature. New position and time are acquired and logged each second. During each conductivity and temperature sample, a measurement is recorded at the surface of the water and at a level six inches below the surface of the water.

The AWQuSam allows for programmable mission paths in the form of GPS waypoints. It autonomously propels itself across the surface of the water to each waypoint before reaching its final destination.

The AWQuSam also wirelessly transmits a sample of recorded data to a base station receiver every five minutes. This will provide researchers a real-time glimpse of what is being recorded and where the AWQuSam is presently located.

2.4 Design Decisions

2.4.1 Obstacle Avoidance

The prototype design for the AWQuSam will **not** include an active obstacle avoidance system. It is the responsibility of the waypoint programmers to configure paths that will avoid known oyster beds and other potential hazards in the bay area. The AWQuSam has been designed, however, to minimize damage as a result of a collision with an oyster bed.

A future obstacle avoidance system could include a sonar system fixed to the front of the kayak. Such a system could feed back to the navigation system if an obstacle is detected. In the event an obstacle is detected, the navigation system would have to respond by intelligently choosing a new course and/or shutting off the motor. Such a system would be able to detect non-permanent obstacles such as boats.

2.5 Overall Risk Assessment

Technical Risks

ID	Risk Item	Probability	Impact	Mitigation Plan
1	Writing to SD card may adversely affect the ability to process data at the desired sample rate	Medium	Low	A high-speed SD card (class 10) was utilized and offered a significant reduction in time overhead when compared to slower models
2	While periodic real-time transmission is live, data cannot be recorded.	High	Low	This is true. For 1 second out of every 5 minutes during which data is streamed to base station, no samples can be collected, though the AWQuSam is still moving.
3	Much of code for data acquisition has been tested on PIC24FJ128GA010, which satisfies all requirements except A/D resolution. This poses a risk in achieving .01ºC	High	Medium	Team moved forward with designing on PIC24FJ128GA010 µC. Time did not permit porting to the more desirable dsPIC33FJ256GP710. *See Technical Risk 4

	temperature precision objective.			
4	The 12-bit A/D converter on dsPIC33FJ256GP710 may not be able to utilize such a narrow window of reference voltages to achieve .01ºC temperature precision.	Medium	Medium	This risk applies when future effort is performed to port the design to the dsPIC33FJ256GP710 MCU.
5	Explorer16 only has one PICtail expansion slot. Two cards needed (One to pull out all pins of MCU, one to interface with SD Card)	High	Low	Team carefully hardwired SD Daughter card to appropriate pins pulled out by Prototyping Board. Care was taken to minimize interference that may have resulted in flipped bits.

Scheduling Risks

ID	Risk Item	Probability	Impact	Mitigation Plan
1	Personnel Leave - Illness or absence of any engineer would require over-allocating other resources	Medium	Medium	One engineer was not present the entire semester. The team divided tasks amongst one another in order to meet the project deadline.
2	Design is moving forward with PIC24FJ128GA010. Time may not permit porting the design to the more desirable dsPIC33FJ256GP710.	High	Medium	Customer would prefer a functional prototype that does not have precision than risk delaying the prototype.

Budget Risks

ID	Risk Item	Probability	Impact	Mitigation Plan
1	Increase Product Expenses - Price estimates in the original proposal could possibly be lower than what the team actually pays	Low	Moderate	To make sure that this never occurs, the team makes budget talks a priority at every meeting

2	Unforeseen Expenses - As the team continues moving forward in the design and development of the AWQuSam, there may be devices or products that the team was initially unaware of, that are a necessity to the completion of this product	Moderate	High	If an engineer can identify a component that may be needed in the future early in the process, it becomes much less expensive to solve compared to the final stages of the design

3 Design of Major Components

3.1 Mechanical Housing

3.1.1 Hull

The prototype design for the AWQuSam uses a Riot Trickster Kayak. Some of the benefits of a kayak is that they are very durable, light weight, easily transported, cheap, and fairly streamlined. Purchasing a kayak makes the most economical sense for the purpose of the AWQuSam prototype. This route saves time, money, and labor cost. The kayak has been refitted to accommodate the needs of the AWQuSam. These accommodations include: (1) internal support for propulsion and electronic components; (2) structural support for sensors. The idea is that with this design, other kayaks could be retrofitted into an AWQuSam so special consideration is put into the versatility of the design.

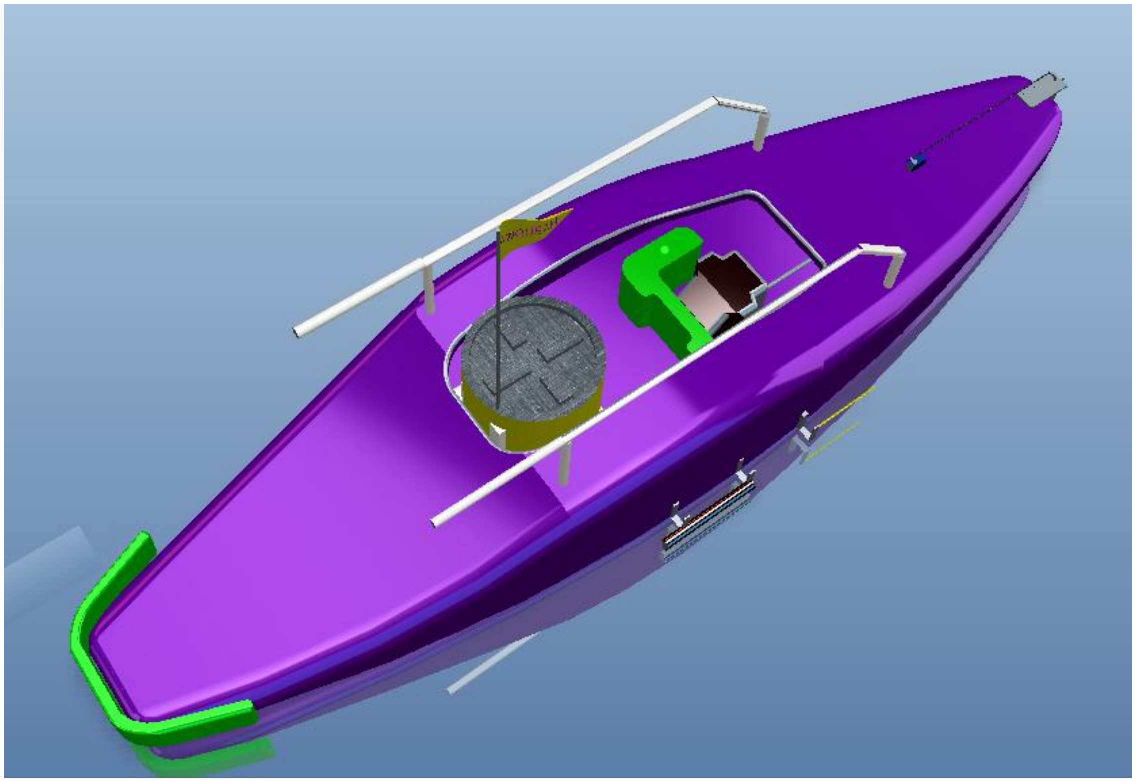


Figure 3.1.1.1: Hull Top View

The kayak hull encloses all the electronic and mechanical components but allows for easy access. It displaces more volume of water than the entire weight of the craft in order to achieve maximum buoyancy in order to cruise effectively in shallow waters. The design of the electronic box is water tight to avoid damaging electronic components if it capsizes or rains. It also light enough so that the craft is able to be carried by two using handles at each end of the hull. The dimensions of the Riot Kayak Trickster can be seen in the image below. The kayak itself weighs 33 lbs.

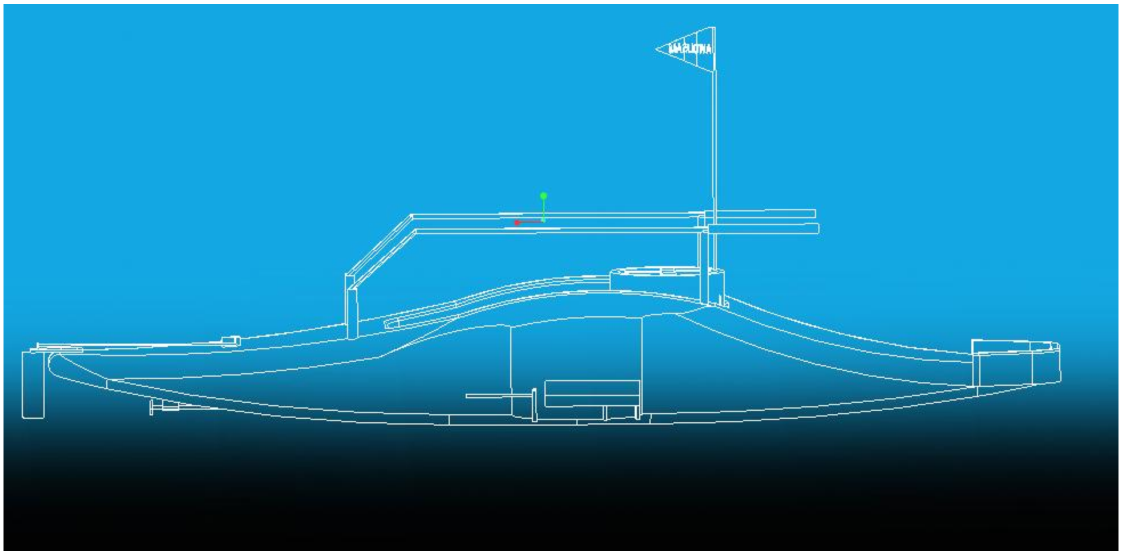


Figure 3.1.1.2: Wire Frame Side View. Vehicle is 93.55 inches long.

The kayak hull satisfies the posing environmental challenges. The AWQuSam does not suffer any degradation of performance when operated in and when stored in a salt fog atmosphere. It does not suffer damage from exposure to sunlight. The AWQuSam is able to operate in a hot, humid environment with a diurnal cycle peak of 100% humidity. The AWQuSam is fully operable at a continuous, ambient temperature of +55°C, and does not suffer neither damage nor degradation due to storage at a temperature of +70°C. The AWQuSAm is fully operable at a continuous ambient temperature of -5°C, and does not suffer neither damage nor degradation due to storage at a temperature of -20°C. The AWQuSam operates and remains functional during driving rain. The kayak protects all instrumentation from suffering any damage from waves up to 1 m. in height or collision.

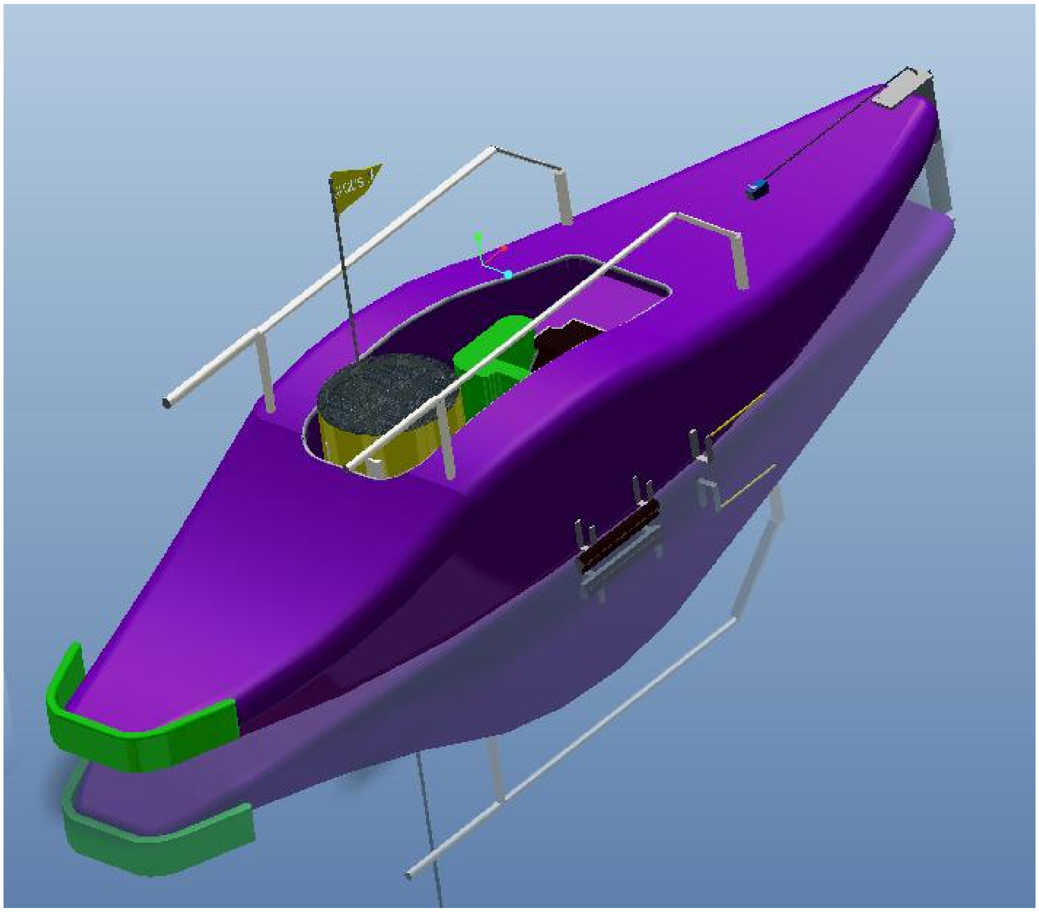


Figure 3.1.1.3: Hull Front View

The Riot Kayak Trickster is normally used in river rapids however it is no stranger to salt water. The kayak is normally used for tricks, so it was assumed that slides easily. Therefore two stabilizing keels were going to be implemented and used both as a structural elements as well as a hydrodynamic elements. After various test runs in calm and mildly choppy water it was clear that the keels weren't crucial. They could have been counterproductive by producing more drag, destabilizing, and possibly they could get stuck in a sand bar.

The Oceangraphy Department at Florida State University would like to gather data at the surface of the water and six inches below. The sensors are mounted on the side of the kayak with steel plates and bolts so that they can be fixed to varying positions. Each set of sensors (salinity and temperature) are on each side of the vehicle and initially fixed at those two required positions. A picture of the sensor placement can be seen below.

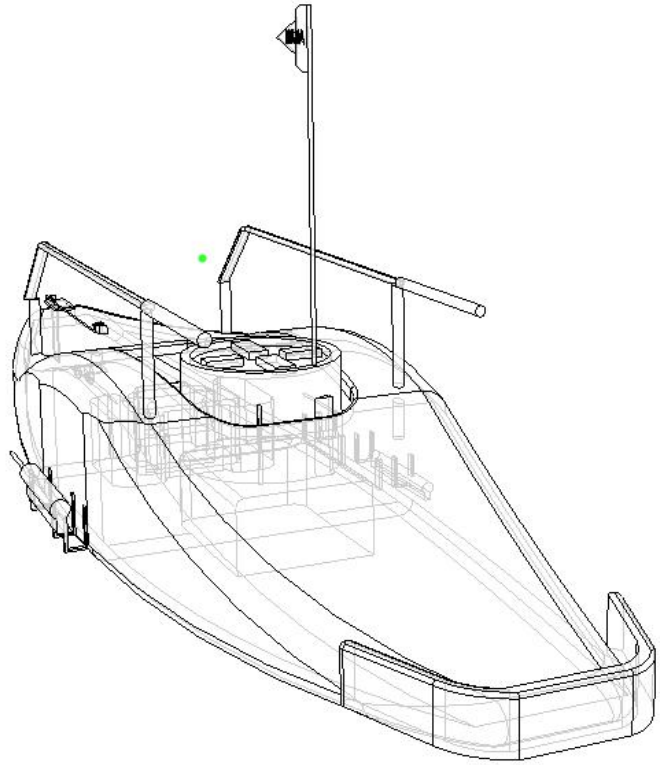


Figure 3.1.1.4: Sensor Placement View

The internal structure put in place in the main compartment of the hull holds the engine and the shaft in place. The engine and the shaft are placed in an angle coming out of the bottom of the back of the kayak as seen in this concept picture. The electronics box is fixed into the bottom of the hull by straps that holds it fix but also allows for easy dismounting.

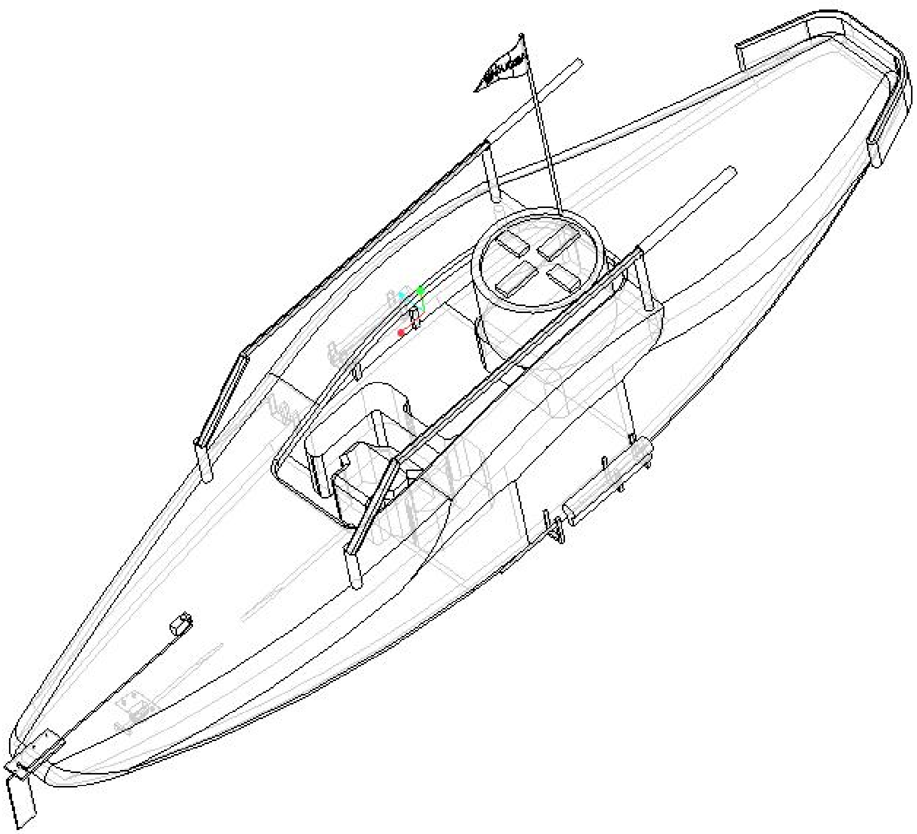


Figure 3.1.1.5: Hull Top View

Finally the hull of the AWQuSam is covered by a PVC structure frame that will support a waterproof tarp that will keep out the rain but allow for air to ventilate. It was decided that this was a better option than using a sleeve that covers the entire middle section. The fire-retardant cloth that fits snugly on the Riot Kayak Trickster was decided not to be used because it would allow for minimum ventilation. The top frame that allows the engine to exhaust and extract air easily. A picture of the frame can be seen in the image below.

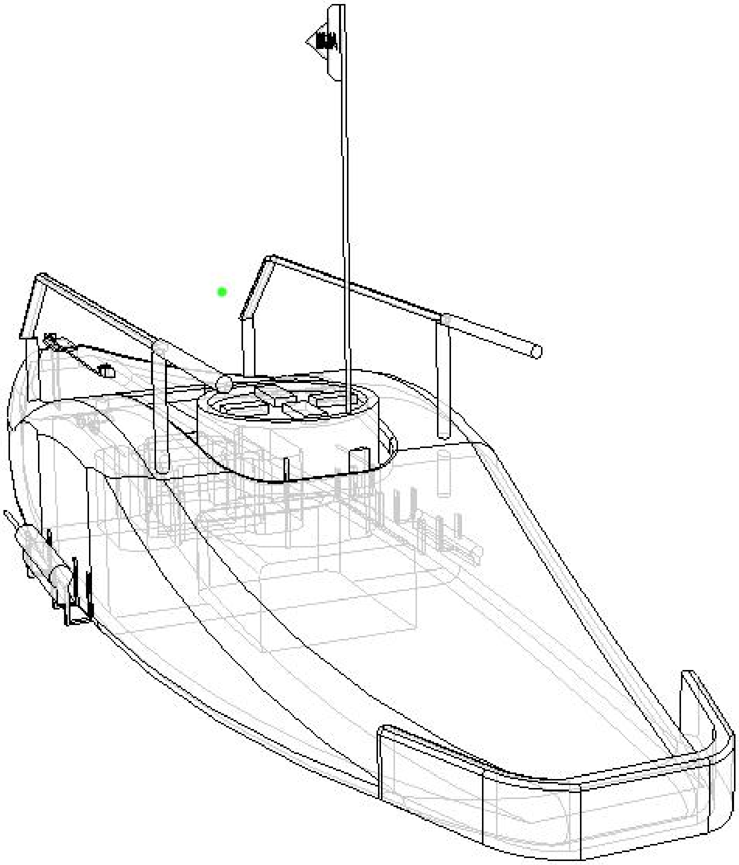


Figure 3.1.1.6: Hull with Top Covering

3.1.2 Electronic Housing

The electronics housing is a 5 gallon sealed paint bucket with a top that screws and seals in. It is placed safely inside the hull and encloses all electronic components. It is easily accessible when out of the water; however, when in operation all seals are water tight. The main challenge was to seal tight all electronic components during operation but prevent components from overheating.

The electronic housing can be seen in the images below. It will enclose the compass, GPS, mass storage card, battery, development board, communication system, in addition to all the wires. All wires are sealed in plastic tubing at the opening were they meet the electronics box, as shown in Figure3.1.2.2. The tubing will be sealed with all entrance/exit points (w/ box, kayak, etc) with RTV. The connections and assembly components can be seen in the images below.

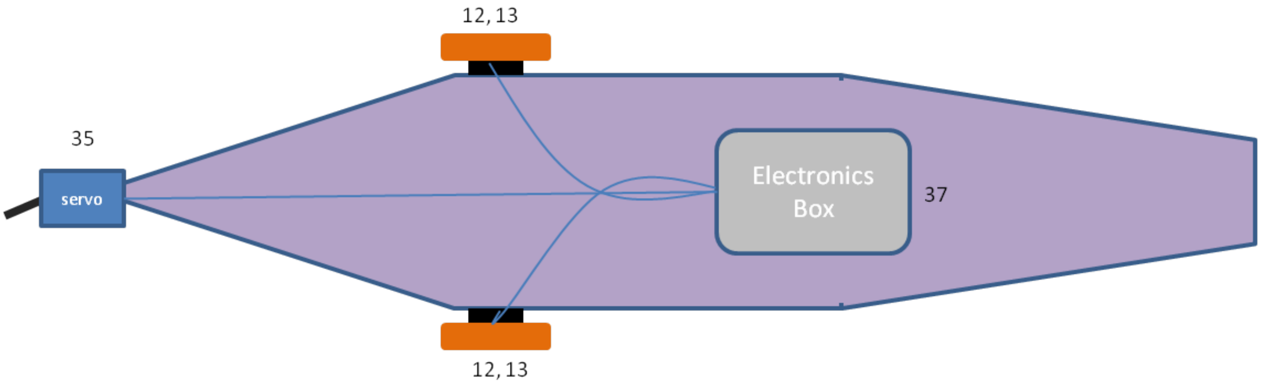


Figure 3.1.2.1: Wire Assembly

Figure 3.1.2.2: Wire Covers

The radio antenna comes out of the box housing. This is necessary for optimum signal transmission. The opening is water tight and the antenna is permanently fixed to the main box.

3.2 Propulsion System

The propulsion system for the AWQuSam consists on 3 major parts: (1) the engine; (2) the connecting shaft assembly; and (3) the propeller.

The engine we chose is the Honda GX35. It is a small 4 stroke gasoline engine similar to those in many household *weedwhackers*. The chart below shows the specs of the engine. It has a pull-cord for cranking, so the battery need not be connected to the engine. One of the most attractive characteristics of this engine is that it is lightweight- only 3.33 kg. Also it has a very low fuel consumption. At the given rate of fuel consumption a 12 hour mission will consume about 2-2.5 gallons of fuel. Two external fuel tanks of 1 gallon each are fitted to the PVC frame and connected to the smaller internal tank of the engine.The elevation [in addition to the slight tilt created by forward motion] will allow for the gas to flow naturally from the external tank to the engine tank. A hole in the engine tank will be drilled to make this connection. Similar to the diagram below.

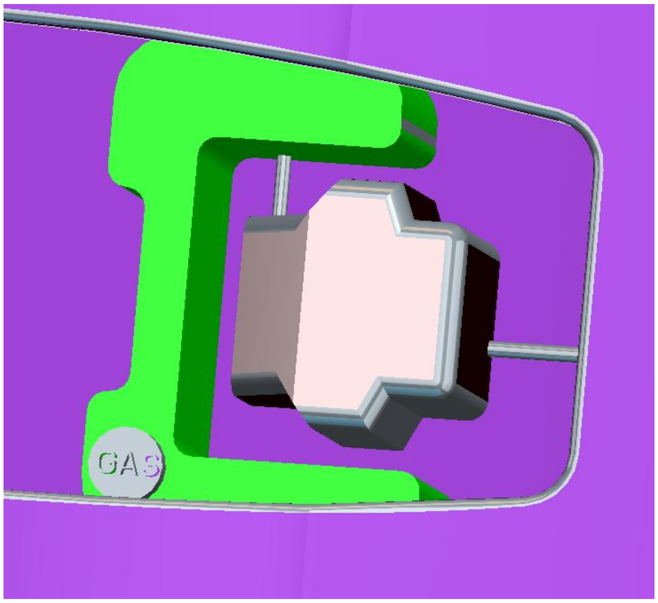
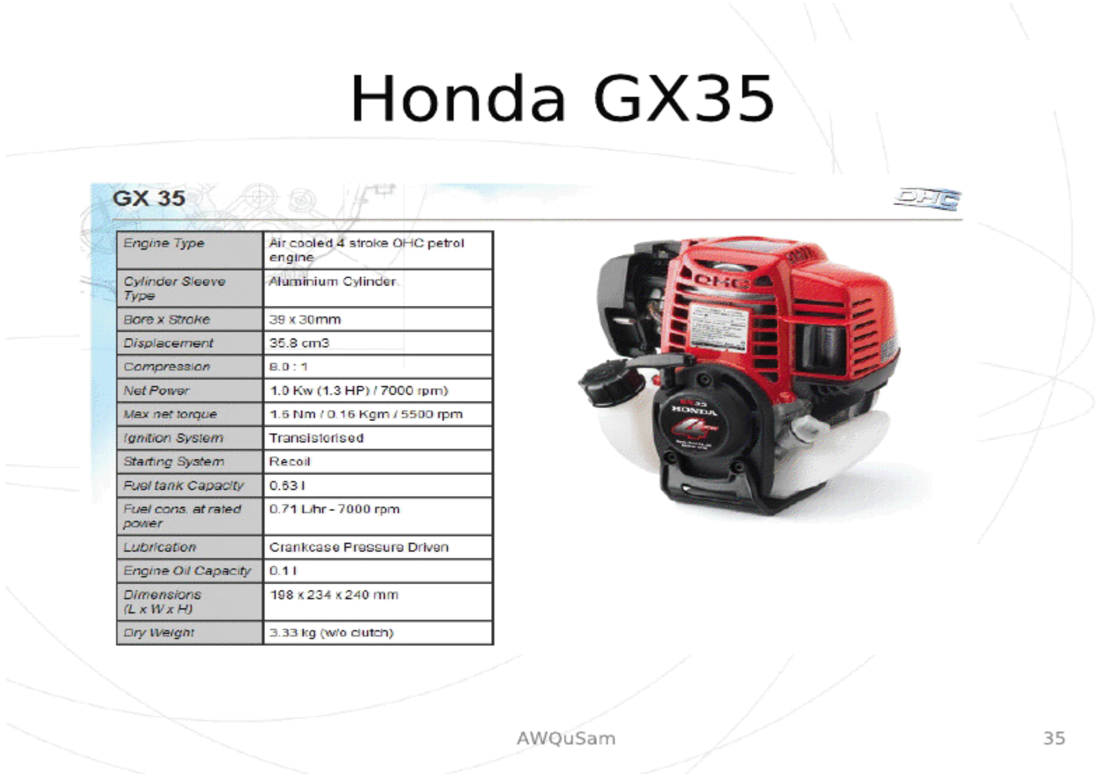


Figure 3.2.1: External Tank Connection

The engine has a high power to weight ratio and that is why a small internal combustion engine connected to a propeller was chosen over electric motors which would have had very heavy batteries to fulfill the 12 hour run. The engine is also more commonly used in weed whackers therefore they transfer torque well on long shafts.



Honda GX35

GX 35

Engine Type	Air cooled 4 stroke OHC petrol engine
Cylinder Sleeve Type	Aluminium Cylinder
Bore x Stroke	39 x 30mm
Displacement	35.8 cm3
Compression	8.0 : 1
Net Power	1.0 Kw (1.3 HP) / 7000 rpm)
Max net torque	1.6 Nm / 0.16 Kgm / 5500 rpm
Ignition System	Transistorised
Starting System	Recoil
Fuel tank Capacity	0.63 l
Fuel cons. at rated power	0.71 L/hr - 7000 rpm
Lubrication	Crankcase Pressure Driven
Engine Oil Capacity	0.1 l
Dimensions (L x W x H)	198 x 234 x 240 mm
Dry Weight	3.33 kg (w/o clutch)

AWQuSam 35

Figure 3.2.2: Honda GX35 Engine

The second part of the propulsion system is the connecting shaft assembly. It allows the motor to transmit its torque through the shaft to the outside of the boat underwater and then to the propeller.

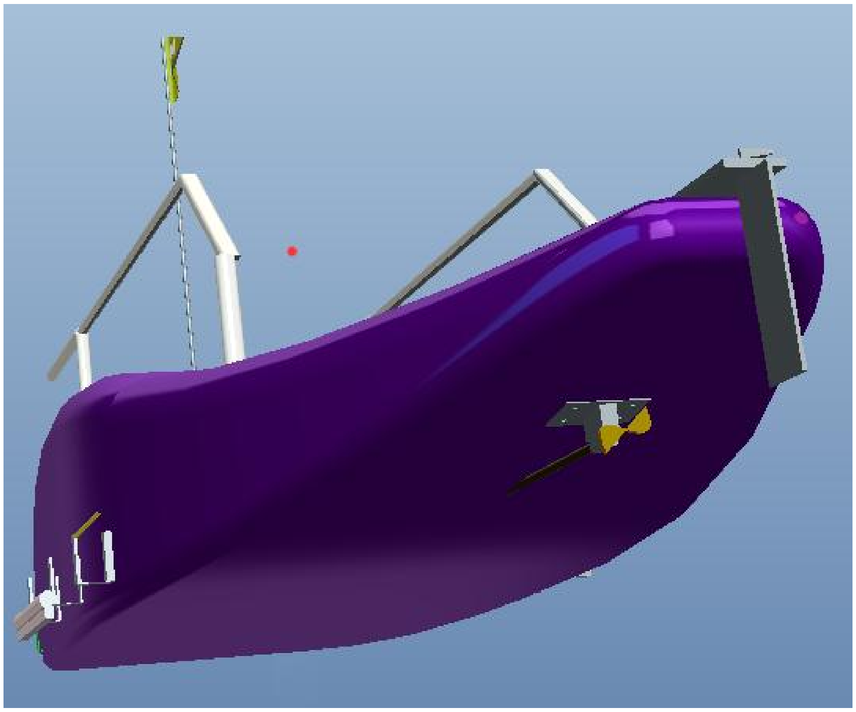


Figure 3.2.2: Shaft Assembly

The shaft assembly seen below consists of the aluminum strut which supports the shaft and attaches to the bottom of the boat. There is the the flexible dark metal shaft which transmits torque along its axis yet still allows for slight bends. It acts essentially like a universal joint. This dark metal shaft fits inside a very thin hollow Teflon tube (not shown below) to reduce friction and then that thin Teflon tube slides inside the hollow copper tube below. This configuration prevents water form draining in through the shaft hole in the boat. The rest of the hardware below, particularly in the bag, are nuts and bolts to attach the aluminum strut to the boat and to screw on the propeller at the end.

Figure 3.2.3: Connecting Shaft Assembly

The last component of the propulsion system is the propeller. The chosen prop initially was a Prather Racing Counterclockwise 3.10 inch diameter, 4.5 inch pitch and about 30-40 % mean area. Choosing the right prop to work best for a boat is no easy task. Dozens of variables have to be taken into account such as engine rpm range, engine horsepower, outputted torque, hull displacement, gearbox reduction if applicable, percentage of power loss due to bearings, speed length ratio, drag "C" value and more. After much research and analysis of a "*prop algorithm*" developed in the United Kingdom, the team found the appropriate prop size corresponding to the selected engine. A picture of the prop can be seen below.

Figure 3.2.4: Prather Racing Counterclockwise

This first prop worked fine but it didn't allow for the motor to spin at its full rpm. This is due to the size and the pitch of the prop. Consequently we decided to test two new propellers that were slightly smaller in size: 3 in. and 2.8 in. diameter.

3.3 Steering System

The steering for the AWQuSam is essential for its navigation. Its designed to keep the AWQuSam on track regardless of environmental conditions like currents or side winds. It is mechanically tough so that it does not suffer any damage from choppy waves. It allows the nozzle to turn 30-40 degrees from the normal axis.

The steering is done by having a waterproof high torque digital servo linked to a rudder. The servo is connected to the microcontroller board and corrects itself as a function of how far it deviates from the path. Pulse width modulated signals control the servo. The rudder is turned by the linkage arm that the servo controls. The linkage arm is connected to the shaft that goes through the rudder fixed.

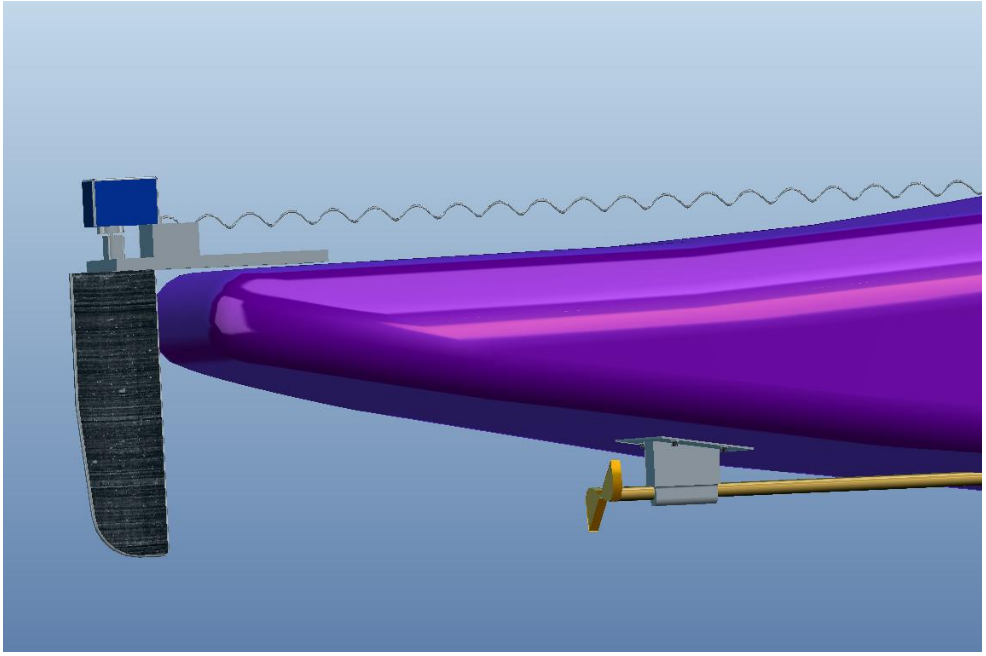


Figure 3.3.1: Steering Assembly

3.4 Navigation System

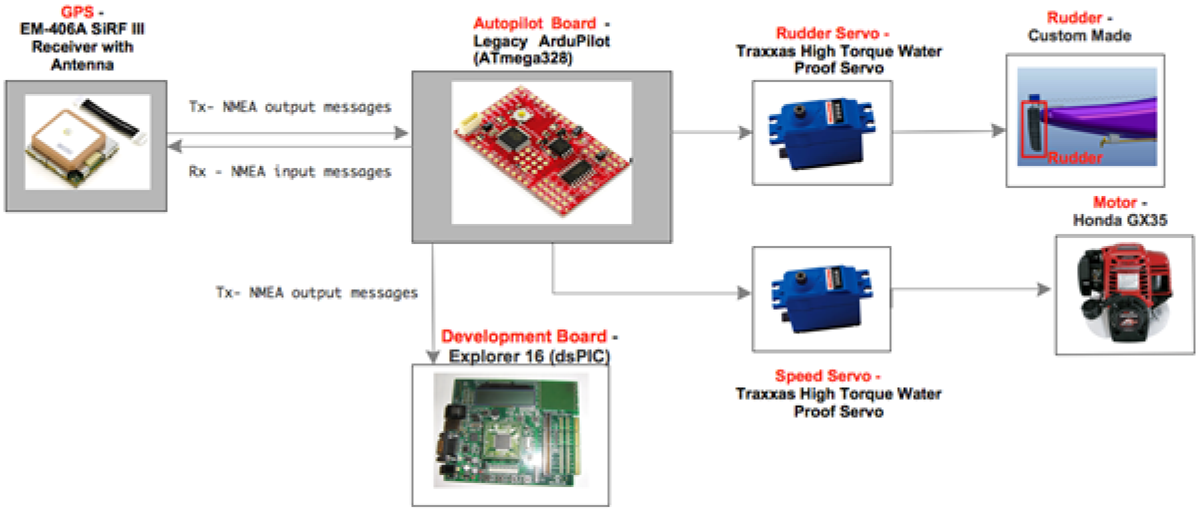


Figure 3.4.1 Top-level Architecture of Navigation System

As an autonomous vehicle, the AWQuSam must be able to maintain its path-planning strategies on-board during its mission. To satisfy this requirement, an on-board navigation system has been designed and implemented to undertake this task. This navigation system uses an Ardupilot module equipped with an ATMega328 microcontroller. The Ardupilot module is an off-the-shelf component with opensource software programming potential. The Ardupilot is provided with a minimum of two way point coordinates which are obtained by plotting a path via Google Earth. During the mission the Ardupilot receives 2 NMEA sentences from the GPS reciever, GPRMC and GPGGA, and parses the data for specific variables. The Ardupilot uses the its longitude postion, east or west, and it latitude postion, north or south, to calculate its waypoint bearing, and its distance from the current waypoint it is progressing towards. The waypoint bearing and the course of the AWQuSam at the moment are used as variables in a control loop feedback algorithim called the proportional-intergral-derivative, PID. The value from the PID determines the angle in which the rudder will turn. The rudder servo is set to update every time the Ardupilot receives a valid NMEA string. The speed servo is set to initialize the throttle once a valid satellite fix is obtained and turns the throttle off once the mission is complete. The Ardupilot will continue to update the rudder servo until it determines the mission is complete. The accuracy of the Ardupilot's path changes if the user decides to increase the waypoint distance variable. The waypoint distance represents the minimum distance between the AWQuSam and its current destination waypoint. As the AWQuSam progresses forward it is constantly updating its distance from its target waypoint. As soon as it determines that it has reached a distance equal to or less than the waypoint radius variable the AWQuSam will discard its current target waypoint value and progress to the next waypoint in the array.

For datalogging purposes, the autopilot will echo the GPS sentences to a receive pin on the Explorer 16 board. The autopilot will also transmit a command byte to the Explorer16 board to signify the end of the mission when the final waypoint has been reached.

GPS Smart Antenna Engine Board

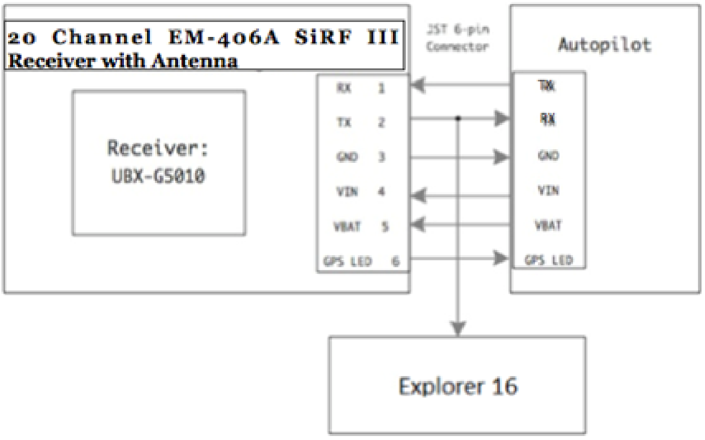


Figure 3.4.2 Interface between GPS Engine Board and Autopilot module

The 20 Channel EM-406A Sirf III Reciever with Antenna has an factory integrated receiver chip, the UBX-G5010. It uses the GPS protocol format, NMEA, to output messages. There are 7 NMEA message strings which the GPS outputs contyinously. The only message strings of importance for the navigation system are the Global Positioning Recommended Minimum Specific [GPS/Transit data] (GPRMC) and the Global Positioning System Fix Data (GPGGA). The GSAEB will communicate with the Autopilot module thru a Universal Asynchronous Receiver / Transmitter and Transistor-Transistor Logic (UART/TTL) interface via a 6-pin JST connector.

Table 3.4.1 Pin Layout for EM406-A

Pin No.	Pin Name	I/O	Description	
1	RX	I	Data Input (TTL level)	
2	TX	O	Data Output (TTL)	
3	GND	GND	Ground	
4	VIN	I	Supply Voltage	3.3V +/- 10%
5	VBAT	I	Backup Battery Supply Voltage	
6	GPS LED	O	LED Indicator	

Once the EM406-A is connected to the Autopilot, its initialization procedure will determine the baud speed, the GPS NMEA sentences to monitor (GPGGA and GPRMC) from the output stream, and setup variables to compare its generated checksum against checksum received in the data stream. The Autopilot module was designed to retrieve pertinent information from these two data streams, and use them in calculations.

GPS NMEA: $GPGGA (Global Positioning System Fix Data)

$GPGGA,hhmmss.ss,llll.ll,a,yyyyy.yy,a,x,xx,x.x,x.x,M,x.x,M,x.x,xxxx*hh

Table 3.4.2 GPS NMEA: $GPGGA Message Description

Name	**Example Data**	**Description**
Sentence Header	$GPGGA	Global Positioning System Fix Data
UTC of Position	hhmmss	Time Stamp
Latitude position	llll.ll	Degrees, decimal minutes
N or S	a	
Longitude	yyyyy.yy	Degrees, decimal minutes
E or W	a	
GPS Quality Indicator: - 0 = Invalid - 1 = GPS fix - 2 = DGPS fix	x	- 0 = Invalid - 1 = GPS fix - 2 = DGPS fix
Number of Satellites in Use	xx	
Horizontal Dilution of Precision (HDOP)	x.x	Relative accuracy of horizontal position
Altitude	x.x	Antenna altitude above mean-sea-level
Units of antenna altitude, meters	M	
Geoidal separation	x.x	
units of geoidal separation, meters	M	
Age of Differential GPS data (seconds)	x.x	Age in seconds since last update from diff. reference station
Diff. reference station ID#	xxxx	
Checksum	*hh	

GPS NMEA: $GPRMC (Recommended minimum specific GPS/Transit data)

$GPRMC,hhmmss.ss,A,llll.ll,a,yyyyy.yy,a,x.x,x.x,ddmmyy,x.x,a*hh

Table 3.4.3 GPS NMEA: $GPGGA Message Description

Name	**Example**	**Description**

	Data	
Sentence Header	$GPGGA	Global Positioning System Fix Data
UTC of Position	hhmmss	Time Stamp
Data Status	A	
Latitude position	llll.ll	Degrees, decimal minutes
N or S	a	
Longitude	yyyyy.yy	Degrees, decimal minutes
E or W	a	
Speed of Ground in Knots	x.x	
True Course	x.x	
UTC Date	ddmmyy	Date Stamp
Magnetic Variation Degrees	x.x	Easterly variation subtracts from true course
E or W	**a**	
Checksum	*hh	

The latitude and longitude coordinates extracted from the data stream will be used to calculate the true course between the current GPS coordinate and the current waypoint. It will also be used to calculate the distance between the current GPS coordinate and the current waypoint. The calculated information will be used to determine rudder control and navigation path during the mission.

Once the GPS is initialized, the Ardupilot will begin processing and performing calculations on the incoming data in order to set the rudder-servo and speed controller parameters periodically throughout the mission.

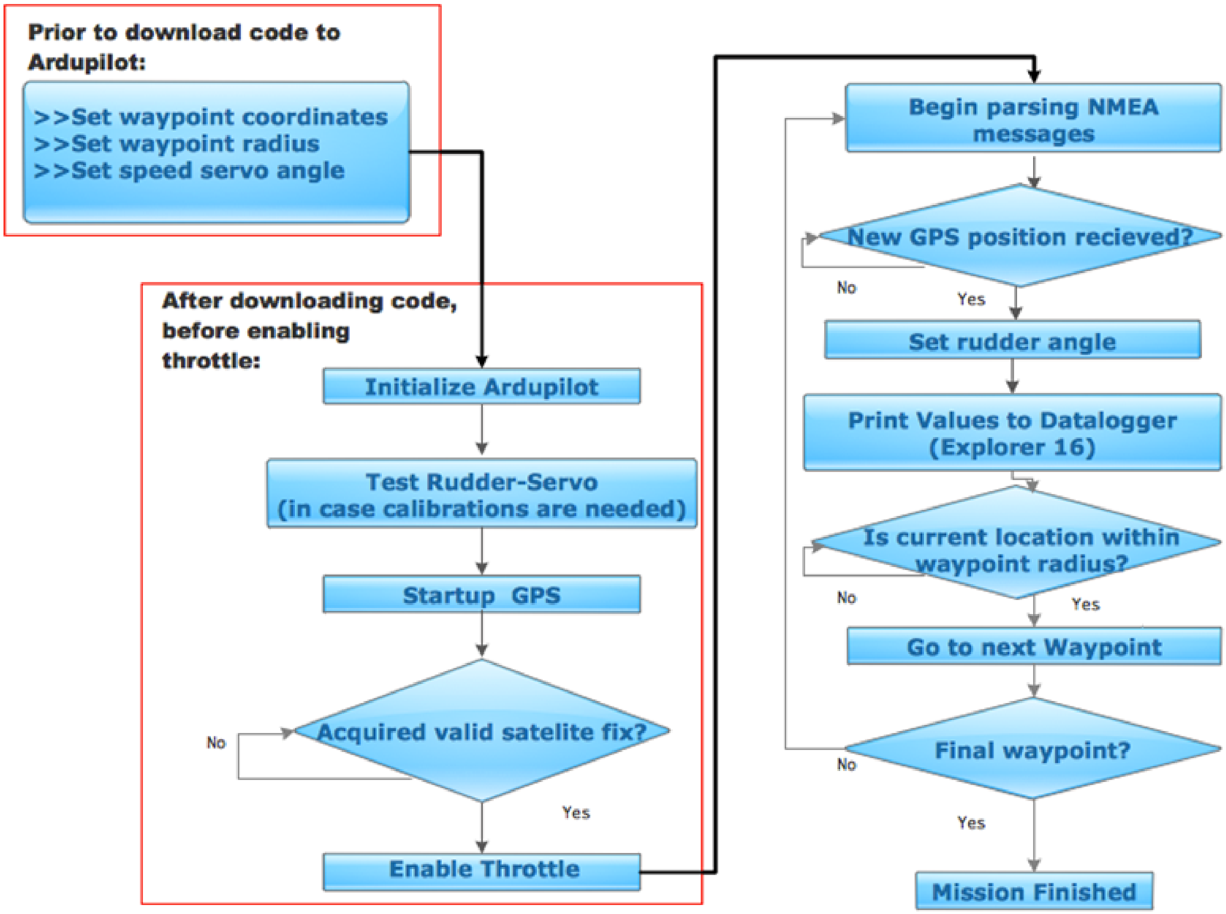
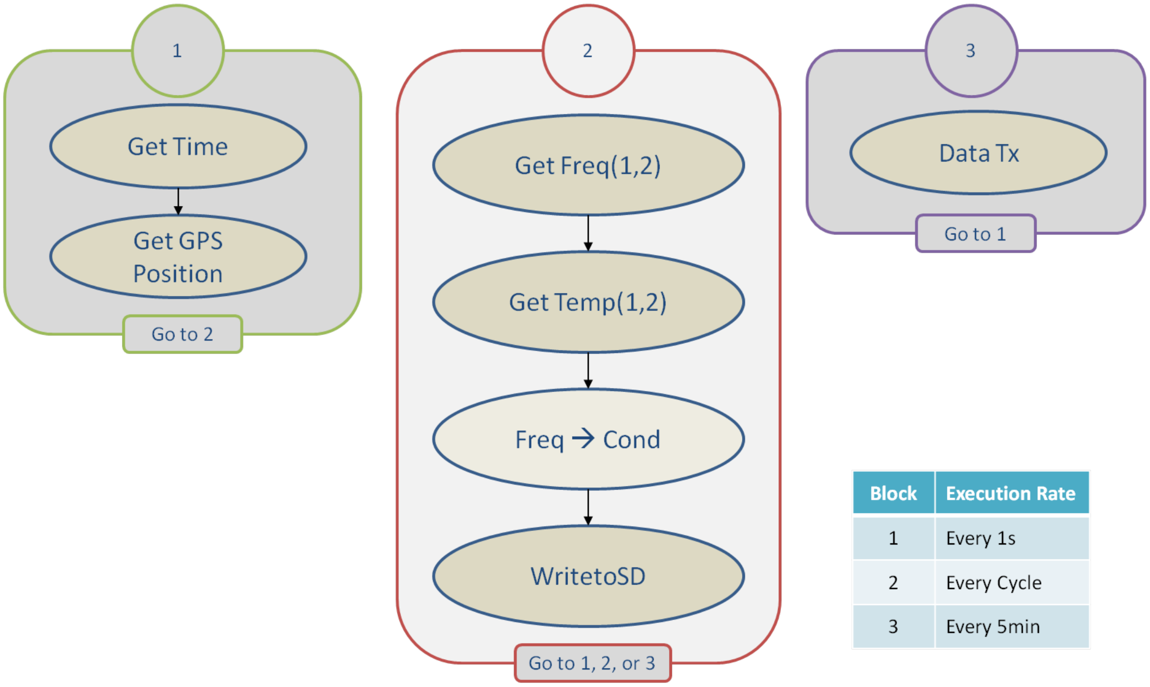


Figure 3.4.5 Navigation System Operation Flowchart

3.5 Data Acquisition System

The processing for the data acquisition subsystem has been implemented on the Explorer16 development board. This module interacts with both the data logging and data transmission systems. A software flow diagram describing this interaction is shown in Figure3.5.1, below. Block 1 will be executed each second in response to new data arriving from GPS. For a schematic overview of the connections with the Explorer16 Development board, see Figure3.5.2.



Block	Execution Rate
1	Every 1s
2	Every Cycle
3	Every 5min

Figure3.5.1: Software Flow for dsPIC33FJ256GP710 microcontroller

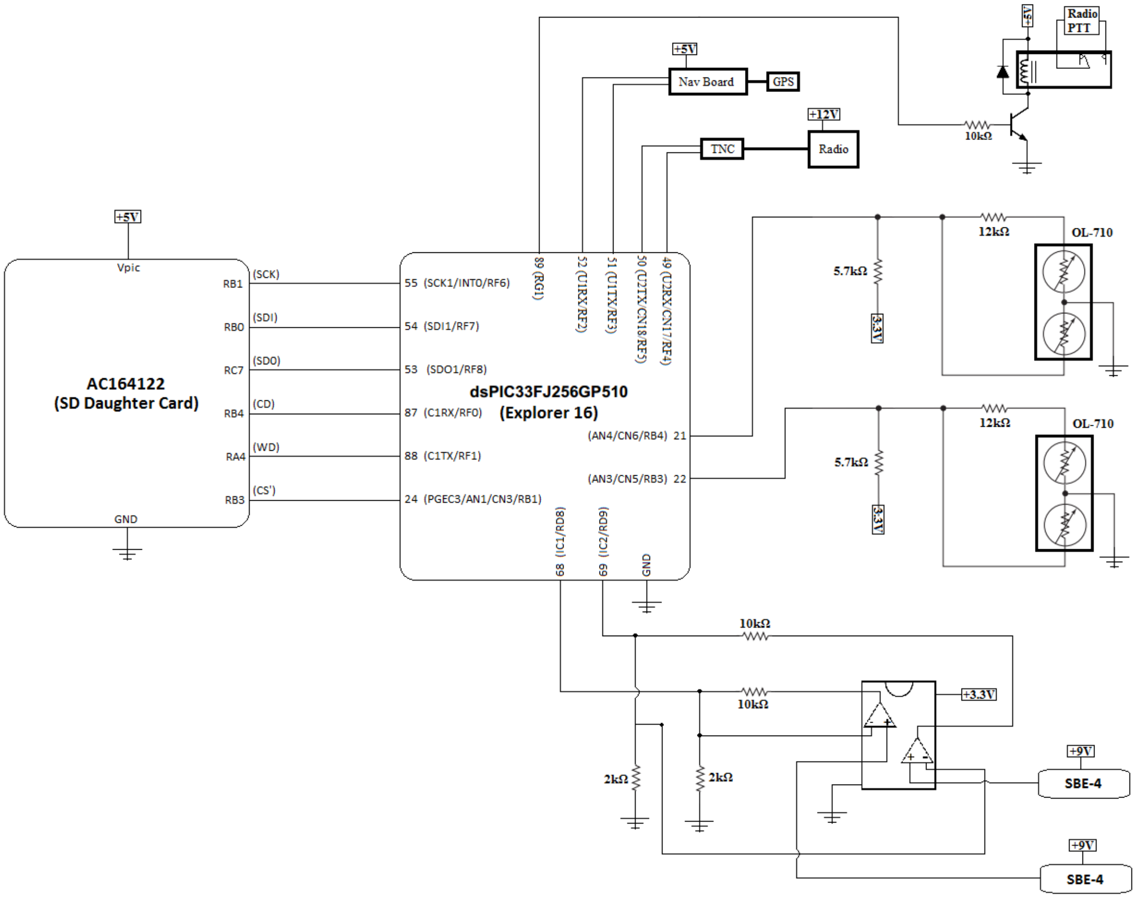


Figure3.5.2: Explorer16 System Schematic

3.5.1 Conductivity Acquisition

The SBE-4 conductivity sensor has a 3-pin connector, as shown in Figure3.5.1.1. The team utilized a RMG-3FS to pigtail cable (SBE PN: 17029) to facilitate placement of the sensor some distance away from the development board.

Figure3.5.1.1: RMG-3FS Connector on SBE-4

The sensors output a variable frequency square wave signal (from 2.5kHz to 7.5kHz) corresponding to the conductivity (from 0S/m to 7S/m). The square wave is a ± 0.5V waveform. The design will implement a microcontroller based frequency counter. Consequently, the waveform must be conditioned to have 0-3.3V TTL logic levels so the microcontroller can effectively count the rising edges of the waveform, as shown in Figure3.5.1.2.

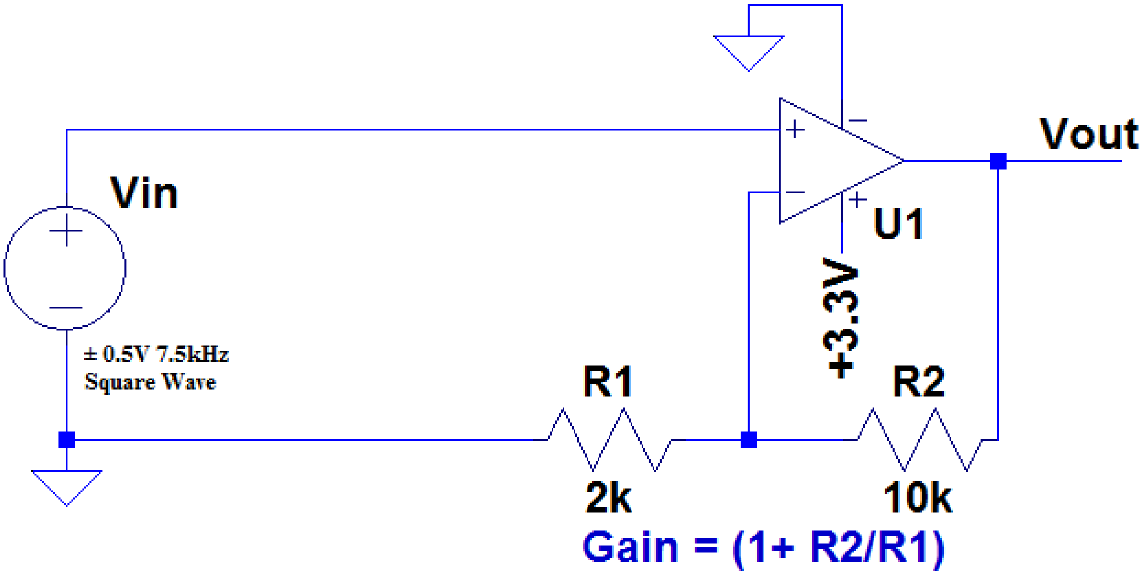


Figure3.5.1.2: Signal conditioning circuitry

V_{SS} of the operational amplifier was tied to ground. This trims the negative portion of the signal. Now, a 0-0.5V signal must be amplified to a level that can be analyzed by the

PIC processor. The gain of operational amplifier is given as:

$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_2}{R_1}$$

$$\frac{V_{out}}{V_{in}} = 1 + \frac{10k\Omega}{2k\Omega} = 6$$

Observe, also, that by using a 3.3V supply voltage for the positive rail of the op-amp, the 3.3V pins on the microprocessor are protected because the signal will never go above this value.

Figure3.5.1.3 shows the output waveform as well as the intermediary steps. Observe that the output waveform has the same frequency as the input, but now has TTL levels that can be processed by the microcontroller.

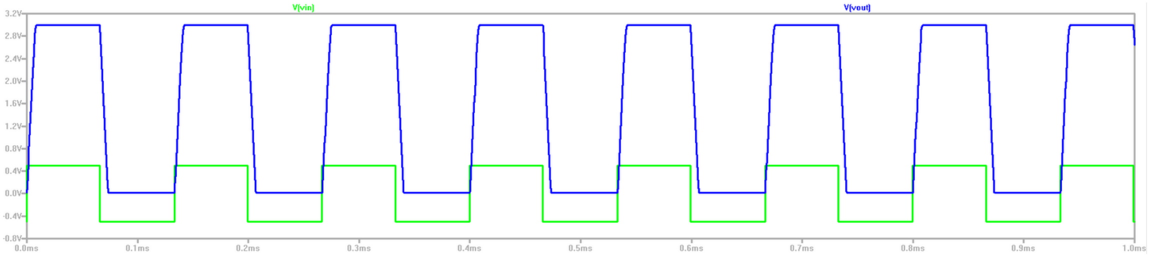


Figure3.5.1.3: Conditioned output of conductivity sensors

The design utilizes the input capture capability of the PIC microcontroller on the Explorer16 development board to determine the number of clock cycles between consecutive rising edges of the signal. From this information, the signal period is be determined, and subsequently the signal's frequency. The output of one sensor is tied to Input Capture1 (IC1, pin 68), and the other is tied to Input Capture2 (IC2, pin 69). Code for initializing the input capture and computing the frequency of a signal is provided in Appendix C.

The conductivity is then computed from this frequency and the water temperature before relaying this information to the data handling and data logging routines. The conductivity calculation is also based on a number of other constants, including the thermal coefficient of expansion, bulk compressibility, and calibration data provided by the manufacturer. This routine is also shown in Appendix C. See the attached calibration sheets (Appendix D) for details regarding this transformation.

3.5.2 Temperature Acquisition

Figure3.5.2.1 provides an overview of the design for measuring temperature.

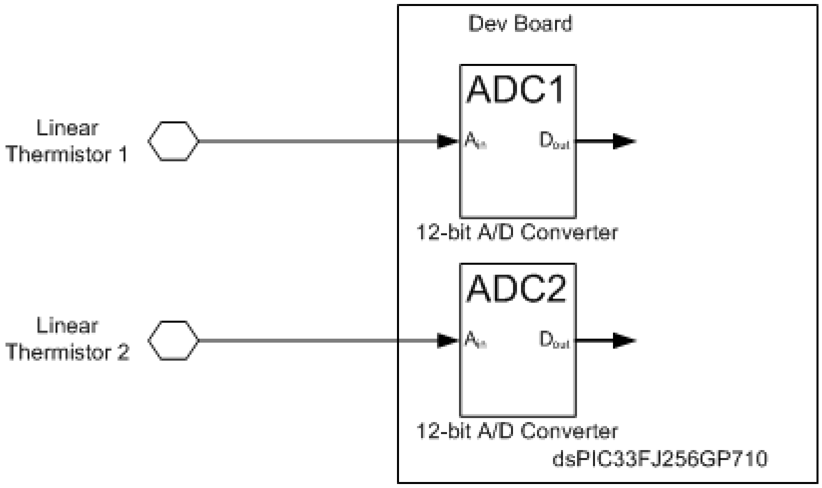


Figure3.5.2.1: Overview of Temperature Sensing Module

Because the relationship between a thermistor's voltage and the temperature is not innately linear, some design work has been performed. The OL-710 thermistor actually consists of two thermistors. When used with a particular resistor set, the output is linearized over a range of temperatures.

Each linear thermistor, as shown in Figure3.5.2.1, is actually represented by the circuit schematic shown in Figure3.5.2.2, below.

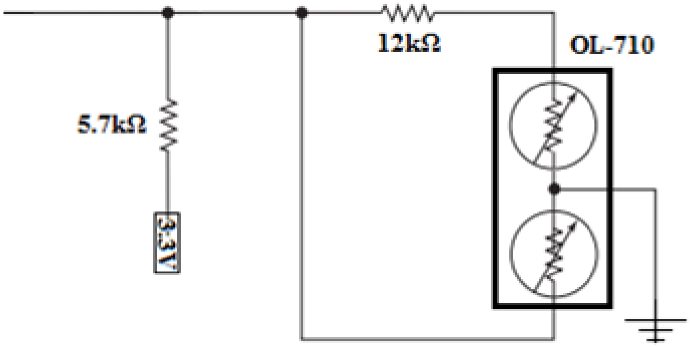


Figure3.5.2.2: Linear Thermistor Circuit Schematic

Resistor values of R_1=5700Ω and R_2=12kΩ can be selected to provide linear voltages across the range corresponding to -5ºC to 45ºC. With this resistor set, relationship between voltage and temperature is described as follows:

$$V_{out} = (-0.0056846 \cdot V_{in})T + 0.805858 \cdot V_{in}$$

The surface water temperature of the Apalachicola Bay is not known to fluctuate outside the range of 5ºC to 35ºC. The team will provide a system capable of accurately recording temperatures in the range of 0ºC to 40ºC. With a properly configured 12-bit analog to digital converter, this would allow for precision of 0.01ºC (indicated as an objective in the latest system specification).

Utilizing the equation above, with a 3.3V value for V_{in}, the A/D converter can expect voltages in the range of 1.9089642V to 2.6593314V corresponding to 40ºC and 0ºC, respectively. The A/D converter control register will be configured to use external reference voltages V_{ref+} and V_{ref-}. These voltages will be set to match this range of voltages. This allows the team to fully utilize the resolution of the analog to digital converter.

Unfortunately, due to time constraints, the actual design was implemented on a less desirable MCU (see Section 2.5, Technical Risk 3) with only a 10-bit ADC and no reference voltages. Consequently, temperature precision for the prototype is only 0.16ºC

This decision was made because file system functions (Section 3.6) required no modification for operating with this microcontroller. The engineer responsible for porting this functionality was not present the entire semester. Other engineers assumed his higher priority assignments in order to deliver a functional prototype, but time did not permit completing this delegated task. The customer indicated a greater desire for a functional proof-of-concept prototype that may not meet the objective temperature precision (but still meets the requirement of measuring temperature) than risk delaying the product delivery.

After passing through the analog to digital converter, a digital representation of the analog voltage was obtained. With this, the analog voltage can be computed. Based on the voltage, the temperature can then be determined. This temperature, in degrees Celsius (xx.yy), is converted to a string for the Data Transmission and Data Logging routines. This process is performed for both temperature sensors. Software for this subsystem is provided in Appendix C.

3.5.3 GPS Acquisition

All of the information to be acquired from GPS is available in the GPRMC sentence. The system consists of only one GPS unit that is connected to the navigation board. The navigation board will echo the sentences via its UART Tx to the Explorer16 development board. The Explorer16 has a software routine (provided in Appendix C) to parse the GPS strings and pick out the GPRMC sentence. From this sentence, the time, latitude, and longitude are retreived.

The Ardupilot navigation board is laid out in such a way that all data transmitted from the microcontroller's UART port is received by the GPS. The GPS firmware considers any string beginning with a $ character as a command string, so it delays and waits for the command. Because of this, the exact GPS sentence could not be echoed directly. Instead of beginning the sentence with a dollar sign, each sentence begins with a pound symbol (#). The software waits for this character, then checks each of the next characters until it receives the '#GPRMC' sequence. It then begins to store values until it reaches the new line (\n) character.

The navigation board will also send a command byte (!) to the Explorer16 signifying the end of the mission. Once the final waypoint has been reached and this command byte is received, the SD card will be closed to prevent loss of data and the AWQuSam will wait with Mission Complete displayed on the LCD display.

3.6 Data Logging System

The Explorer16 has only one expansion slot, and this slot had to be used by a prototyping board that brings all the pins of the MCU out. Consequently, the SD daughter card referenced in Section 2.2.5 was interfaced with the Explorer16, via the protoboard, according to the schematic shown in Figure 3.5.2.

File I/O capavilities were implemented using Microchip's memory disk drive file system library. For more information regarding the specific functions of this library, please refer to Application Note AN1045 by Microchip. The SD is first initialized and a file is created (data.log). A function was written to write time, latitude, longitude, conductivity(x2), and temperature(x2) to the SD card. This function is called each time new data is acquired from the sensors. Code for the routines described can be found in Appendix C.

Data is logged according to the routine outlined in Figure3.5.1. The human readable log has entries corresponding to the time, position, and data from each sensor. New sensor data is received multiple times per second. New GPS data (position and time) is received one time per second. Interpolation of intermediary position reports is not performed onboard the AWQuSam, but can easily be performed offline. Entries are logged as tab separated values for easy importing into a spreadsheet application or MATLAB routine for analysis. Figure3.6.1 offers an overview of a sample of data that may be logged.

t=0s	Time, Latitude, Longitude, Conductivity1, Conductivity2, Temperature1, Temperature2
	, , , Conductivity1, Conductivity2, Temperature1, Temperature2
	, , , Conductivity1, Conductivity2, Temperature1, Temperature2
	, , , Conductivity1, Conductivity2, Temperature1, Temperature2
	, , , Conductivity1, Conductivity2, Temperature1, Temperature2
	, , , Conductivity1, Conductivity2, Temperature1, Temperature2
	, , , Conductivity1, Conductivity2, Temperature1, Temperature2
	, , , Conductivity1, Conductivity2, Temperature1, Temperature2
t=1s	Time, Latitude, Longitude, Conductivity1, Conductivity2, Temperature1, Temperature2
	, , , Conductivity1, Conductivity2, Temperature1, Temperature2

.
.
.

Figure3.6.1: Overview of sample data to be written to SD card

3.7 Data Transmission System

Figure3.7.1 shows a block diagram of the data transmission system of the AWQuSam.

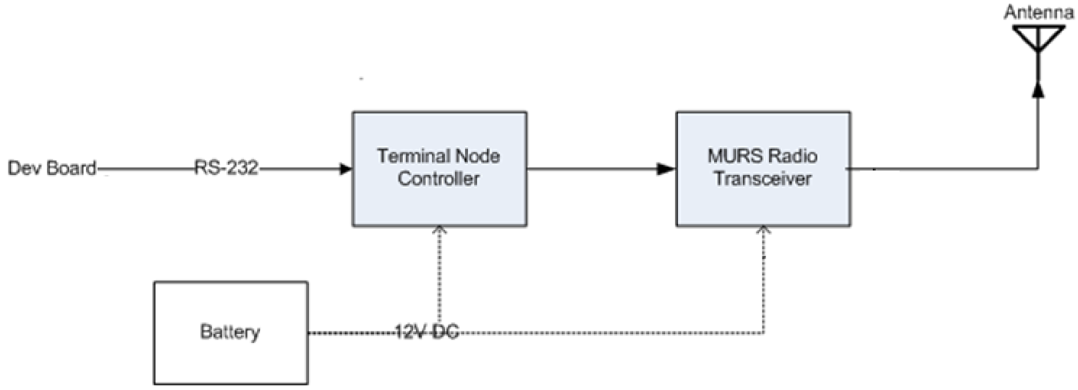
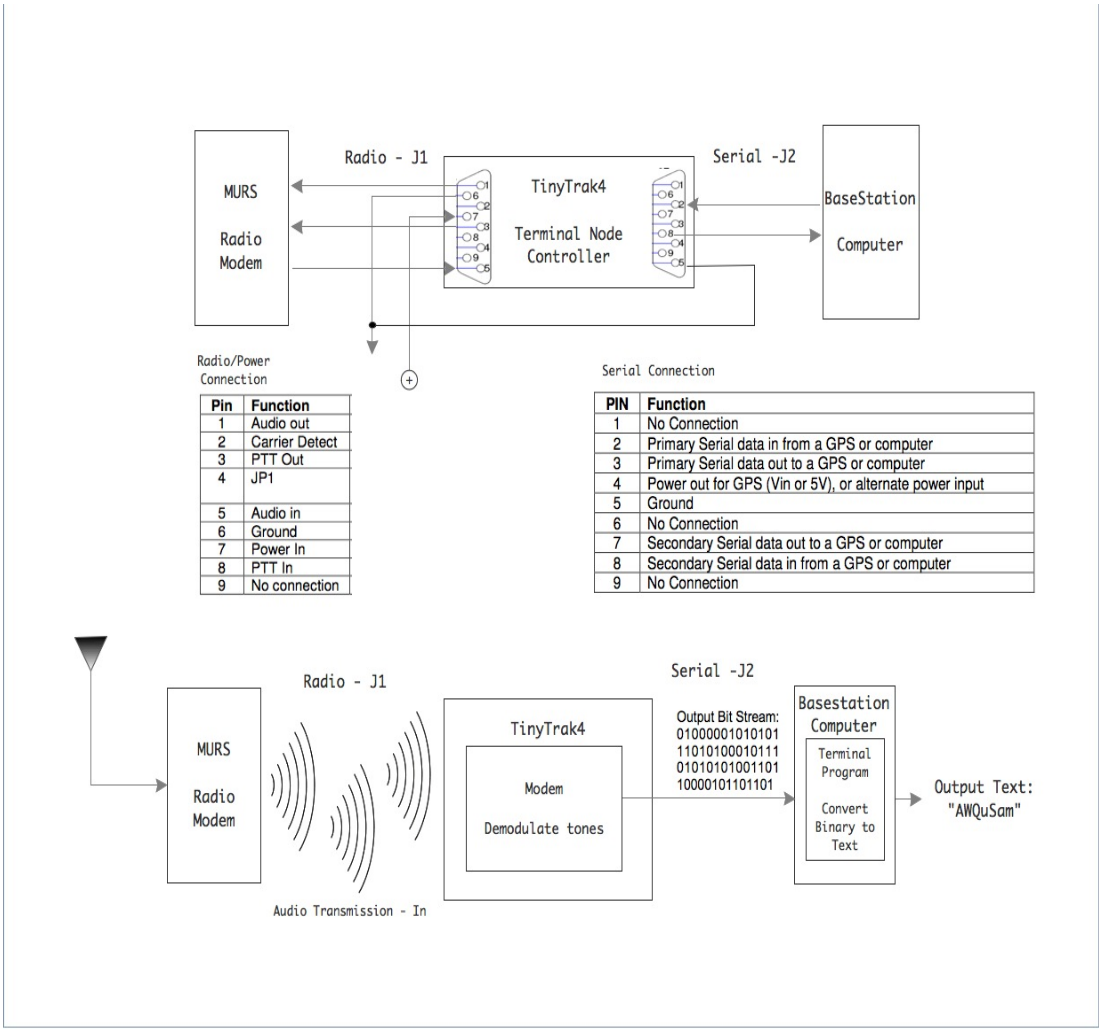


Figure3.7.1: Top-level block diagram of Data Transmission System



Radio/Power Connection

Pin	Function
1	Audio out
2	Carrier Detect
3	PTT Out
4	JP1
5	Audio in
6	Ground
7	Power In
8	PTT In
9	No connection

Serial Connection

PIN	Function
1	No Connection
2	Primary Serial data in from a GPS or computer
3	Primary Serial data out to a GPS or computer
4	Power out for GPS (Vin or 5V), or alternate power input
5	Ground
6	No Connection
7	Secondary Serial data out to a GPS or computer
8	Secondary Serial data in from a GPS or computer
9	No Connection

Figure3.7.2. TNC will receive serial bit stream from data handling routine

The MURS radio used in the design is the Dakota Alert MURS Base Station, model

M538-BS. This model was selected because it is a low-cost, effective transmission system. It is only capable of transmitting and receiving on the MURS frequencies, hence it is FCC approved for unlicensed use.

Figure3.7.3: M538-BS Dakota Alert MURS Radio

The antenna used on the AWQuSam is MURS45 by Firestik. This is a 5/8 wave antenna with gain of 6dB over isotropic. A 5/8 wave antenna was selected over a 1/4 wave antenna because they tend to propagate better in the horizontal plane.

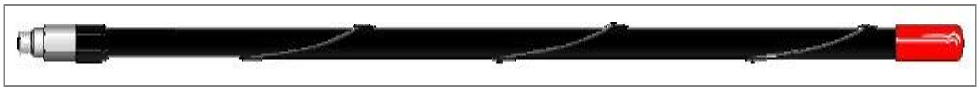


Figure3.7.4: Firestik MURS45 Antenna

The terminal node controller outputs an audio signal that represents the serial bitstream sent by the AWQuSam. This audio signal is passed to the M538-BS radio's microphone-in port. Figure3.7.4 illustrates the scenario. The speaker audio line is used at the base station receiver, and the mic audio line is used at the AWQuSam transmitter.

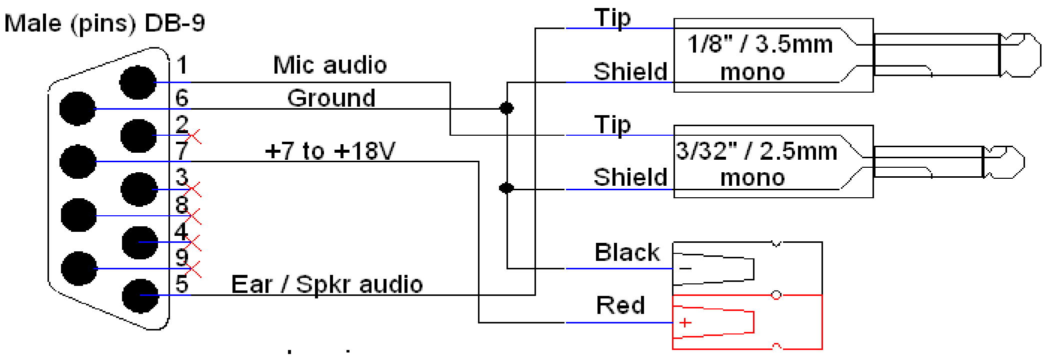


Figure3.7.5: Terminal Node Controller to M538-BS Interface

To interface with the terminal node controller, some modifications had to be made to the radio. The push-to-talk button must be pressed while a transmission is active. Grounding the radios PTT line activates this function. While transmitting data, the microcontroller activates a relay that pulls the PTT line of the radio down. Figure 3.7.6 highlights the internals of the M538-BS MURS radio with the push-to-talk pads indicated.

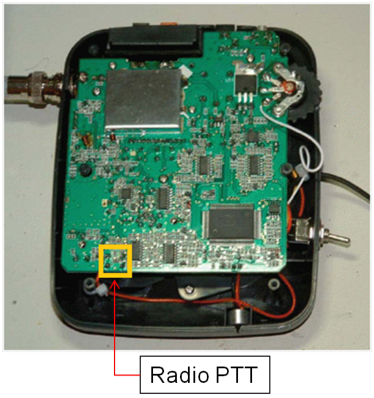


Figure3.7.6: M538-BS MURS Radio Open Box

The implementation required to simulate pressing of the push-to-talk button is represented in Figure 3.7.7, below.

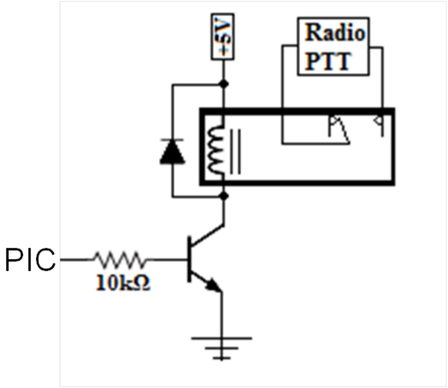


Figure3.7.7: Radio PTT Switch

Previous implementations of the design simply used the BJT as the switching element with no relay. This approach proved inconsistent, as more current is driven from the PTT high to low lines when the antenna is extended. As a result, the switch worked when the antenna was down but was unable to activate the push-to-talk button when the antenna was extended.

The relay approach is a mechanical switch, so it is more robust in that it functions regardless of load. However, because it is mechanical in nature, the relay is slower and consumes more power. Also, a diode is needed across the coil to protect the underlying circuitry from a voltage spike that occurs as a result of the switch closing.

The relay switches consistently and most efficiently with around 30mA through the coil. A pin on the microprocessor is not capable of driving that much current, so a BJT was required to amplify the current. The value of base resistor required was computed as follows:

$$i_b = \frac{i_c}{\beta} = \frac{30mA}{100} = .3mA$$

$$\frac{3.3V - 0.6V}{.3mA} \rightarrow 10k\Omega$$

3.8 Base Station Receiver

The Base Station Receiver functions in much the same way as the Data Transmission System (See Section 3.7) with data travelling in the opposite direction, as shown in Figure3.8.1.

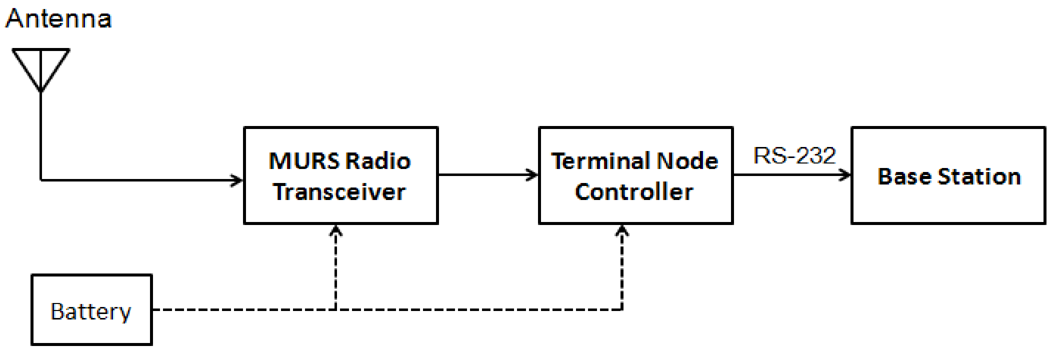


Figure3.8.1: Top-level Block Diagram of Base Station Receiver

To select a suitable radio transceiver, the team performed some quick calculations to determine the receive sensitivity required to achieve the desired transmission range (5km). From the Friis Transmission Equation:

$$P_r = P_t + G_t + G_r + 20\log\left(\frac{\lambda}{4\pi R}\right)$$

$$P_r = 27dBm + 6dBi + 6dBi + 20\log\left(\frac{1.96m}{4\pi 5000m}\right) = -51.12dBm$$

In the above equation, a transmission power of 2W was assumed over a maximum distance of 5km, with receive and transmit antenna gains of 6dB over isotropic. The wavelength, λ, based on a frequency in the 151-154MHz MURS band. It is apparent that the receiver must have a sensitivity of -45.12dBm to transmit over this range with these antennas.

The antenna used on the receiver is another model by Firestik, the MURS-BASE. It is also a 5/8 wave antenna with gain of 6dBi.

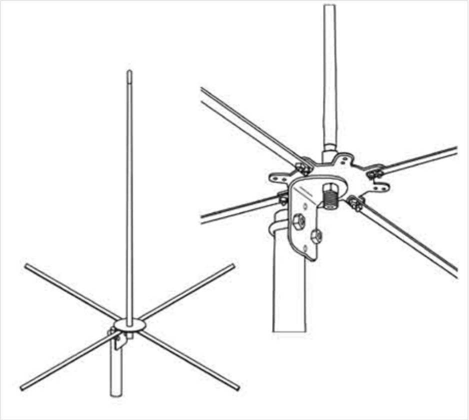


Figure3.8.2: MURS-BASE Antenna by Firestik

Refer to Figure3.7.5 for information regarding the interface between the terminal node controller and the MURS radio where the speaker audio line will be used at the base station receiver, and the mic audio line will be used at the AWQuSam transmitter.

The terminal node controller will demodulate the received audio signal into the serial bitstream that was transmitted by the AWQuSam. It performs error detection and correction before relaying the data to the TNC's output. This bit stream will be printed to a terminal on a PC furnished by the Florida State University Department of Oceanography.

3.9 Power System

The AWQuSam system is powered by a cluster of 12V batteries. Because of the duration of the mission, the battery's capacity must be no less than 28Ah. This already figures in a buffer of overhead, as it assumes almost continuous transmission from the MURS radio. The battery system consists of four 7Ah batteries. This battery arrangement weighs approximately twenty pounds. Figure3.9.1 illustrates the breakdown of the power system. The Explorer16 is powered by a 9V input, as recommended for thermal reasons. Internal voltage regulators on the Explorer16 are used to provide +5V and +3.3V to the board components. These internal regulators are also used to power some of the external components.

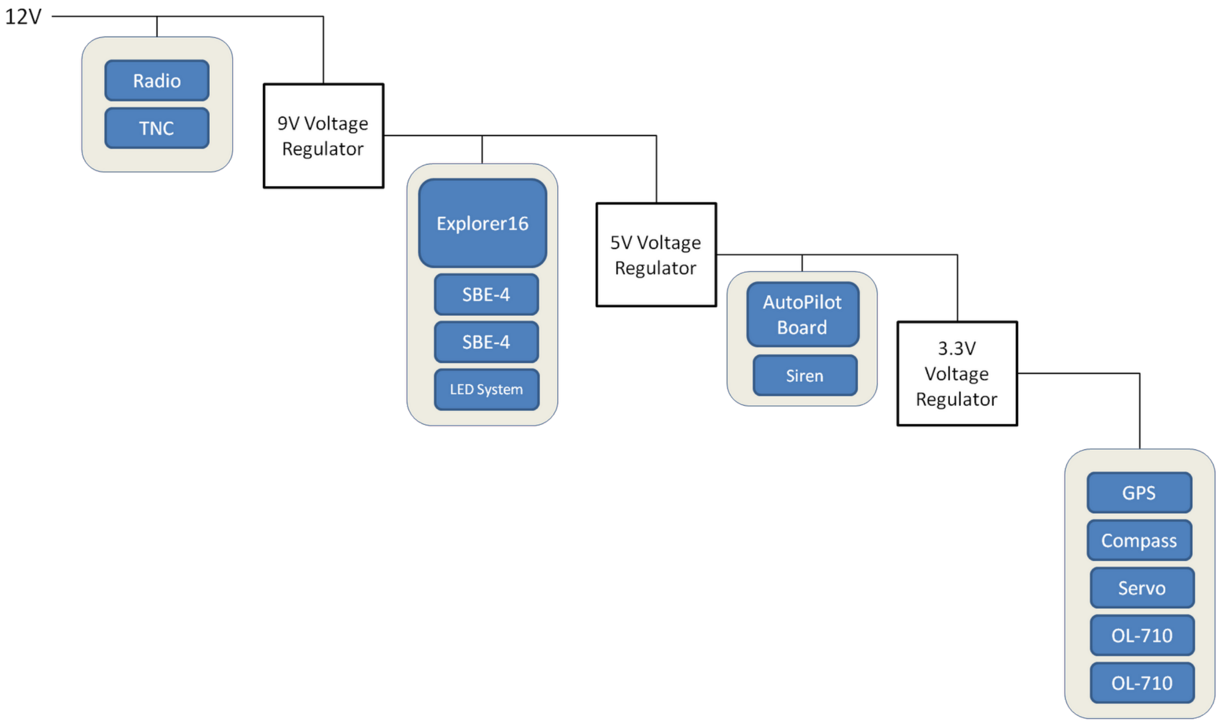


Figure3.9.1: Power System Architecture

Each voltage regulator is a simple 780x type 3-terminal device. Using the configuration shown in Figure3.9.2 below, each regulator will provide a stable regulated voltage across a range of loads.

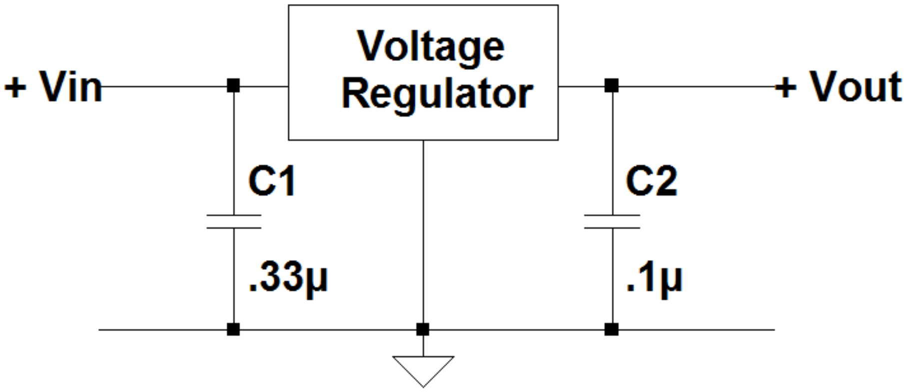


Figure3.9.2: Schematic for each voltage regulator

Coaxial barrel plugs were made to connect to existing jacks on the radio and Explorer16 board. The MURS radio barrel jack is of size M with outside diameter of 5.5mm and inside diameter of 2.1mm. The Explorer16 barrel jack is size N with outside diameter of 5.5mm and inside diameter of 2.5mm.

3.11 Safety System

The AWQuSam needs to be safe for the public and the environment. Apalachicola Bay is a busy area frequented by swimmers, fishermen, yachts, and boats in addition to animal life. In order for the vehicle to legally operate autonomously it needs to prove it is safe.

Safety specifications include that the vehicle needs to be easily detectable by all spectators. This means that it has to be visible from afar. It needs to be brightly colored. It needs to be detected even if it is not on any one's line of sight. It also includes a mechanism to prevent from damaging or physically hurting any one or anything it comes in contact with.

The safety system of the AWQuSam includes an LED system. This LED night time lighting system will serve as indication lights when operating at night. The LED lighting system has its own power suminstered by one 9V battery. The kayak shall also be painted neon orange to make it easily visualized although that is not done to the prototype..

The AWQuSam includes a loud siren from a car alarm system with the ability of being turned off and on. This will provide unknown spectators with an indication that the AWQuSam is nearby. See image of siren on Figure 3.1.2.3.

A foam bumper is placed in the front of the vehicle to cushion any collisions and prevent the AWQuSam from damaging any of the boats around in case of a collision and protect all unknown spectators from a dangerous collision with the vehicle. The design of the bumper can be seen in Figure 3.1.1.3.

3.12 Cooling System

Two major components of the AWQuSam produce heat and need to be cooled. These are the engine and the electronics box. Both will be cooled using the air draft provided by the movement.

To enhance the cooling system freeze packets were going to be placed around the electronic box (not inside) providing low temperatures for the duration of the mission. However due to the small amount of heat produced by the electronics it was decided to best avoid the packets for they would provide more mass inside the vehicle.

Instead a copper pipe in a coil will go in and out of the electronics box. Air flows in and out the copper pipe through one of the ends of the pipe. The inlet end is facing the front of the kayak so that the dynamic pressure of the air causes the air inside the pipe to circulate and transfer out the heat produced inside the box.

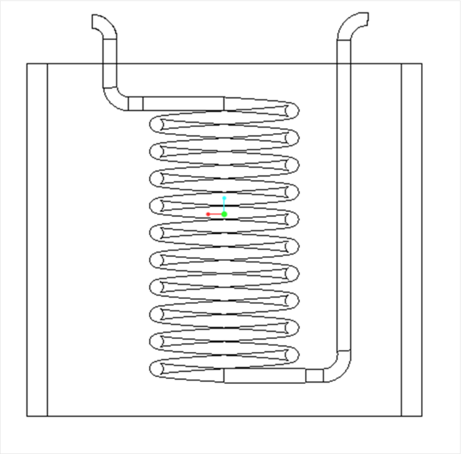


Figure3.12.1: Schematic for cooling system

4 Test Procedure

4.1 Test Equipment

Table4.1: Module Test Equipment

Find Number	Component	Manufacturer	Description	Qty
1	Test Computer	(Any)	Windows computer used to facilitate module and system testing	1
2	USB A->B Cable	Microchip	Cable for interfacing Test Computer to Explorer16	1
3	RJ11 Cable	Microchip	Cable for interfacing ICD3 to Explorer16	1
4	Explorer16 Development Board	Microchip	Used to implement data acquisition and interface with data logging / data transmission subsystems	1
5	9V Wall Mount Power Supply	Microchip	Provides power to Explorer16 Development Board	1
6	dsPIC PIM (dsPIC33FJ256GP 710)	Microchip	Plug in programming module to perform tasks of Explorer16	1
7	Function Generator	(Any)	Simulates SBE-4 Conductivity Sensor	1

8	DC Power Supply	(Any)	DC Power Supply to provide external power to a number of modules	1
9	SD PICtail Daughter Card	Microchip	Interfaces with Explorer16 to facilitate data logging	1
10	Prototype PICtail Daughter Card	Microchip	Interfaces with Explorer16 to breakout all pins of PIM	1
11	SD Card	(Any)	SD card to which data will be written	1
12	SBE-4 Conductivity Sensor	Seabird	Outputs variable frequency signal to be analyzed by Explorer16	2
13	OL-710 Temperature Sensor	Omega	Linear thermistor set to be analyzed by Explorer16	2
14	In-Circuit Debugger	Microchip	Hardware debugger (ICD3) for programming Explorer16	1
15	MPLAB IDE	Microchip	Software, to run on Test computer, for developing on Explorer16	1
16	RS-232 DB-9	Byonics	Cable used for interfacing Test computer with TinyTrak4	2
17	TinyTrak4	Byonics	Terminal Node Controller for modulating and demodulating packets	2
18	MURS Radio	Dakota Alert	Radio Transceivers utilized in Data Transmission subsystem	2
19	MURS45 Antenna	Firestik	A ⅝ wave antenna to increase range of Data Transmission subsystem	2
20	TinyTrak4 - Alpha Config	Byonics	Computer programmer for TinyTrak4	1
21	Engine GX35	Honda	Air cooled 4 stroke petrol engine	1
22	Strut	PMB	Supports shaft in assembly	1
23	Shaft	PMB	Dark metal bendable shaft transmits torque	1
24	Teflon tube	PMB	Reduces friction and prevents water from draining in	1

25	Copper tube	PMB	Hollow copper tube fixes shaft	1
26	Bag of nuts and bolts	PMB	Attach the aluminum strut to the boat and screws propeller at end	-
27	Propeller	Prather	Racing counterclockwise prop, 3.10 in. diameter, 4.5 in. pitch	1
28	Kayak	Riot	Flat bottom kayak makes AWQuSam main hull	1
29	Voltage Regulators	-	Set of voltage regulators (see power system schematic)	-
30	SRM-24 12V Battery	Interstate	Battery used to power the AWQuSam	1
31	D2523T GPS Module	ADH Tech	GPS Module used for navigation system and for logging position	1
32	¼ inch thick 12x24 in. plexy glass sheet	-	Material would be cut in three pieces: one rudder and two keels	1
33	Assembly components for keels and rudder	-	Safely fixes both keels and rudder to kayak	-
34	EZ Pass Black Velcro	3M	Fixes electronics box to the bottom of the kayak	1
35	TRX2075-Digital Waterproof Steering Servo	Traxxas	Main component of the steering system. Moves the rudder.	1
36	Electronics box	TBD	Contains all electronics.	1
37	Autopilot	Sparkfun	UDB4 UAV Development Board for navigation system	1
38	In-Circuit Debugger	Microchip	PICkit 3 In-Circuit Debugger for interfacing with UDB4	1
39	Accelerometer	Sparkfun	MMA7361 3-axis Accelerometer	1
40	Gyro	Sparkfun	IDG500 2-axis gyro and ISZ500 1-axis gyro	1
41	Speed Servo	TBD	Optional component for controlling the speed of the motor	1

4.2 Test Configurations

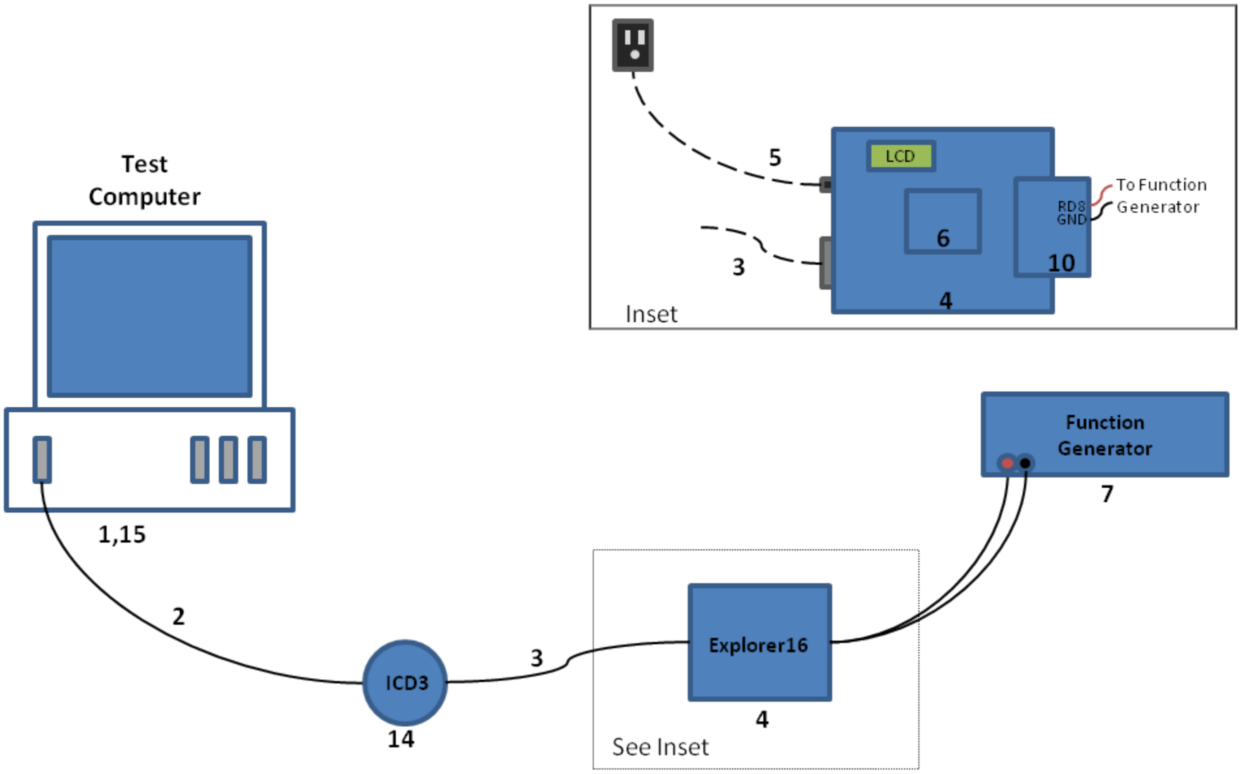


Figure 4.2.1: Test Configuration #1 for Data Acquisition, Conductivity Sensor Subsystem

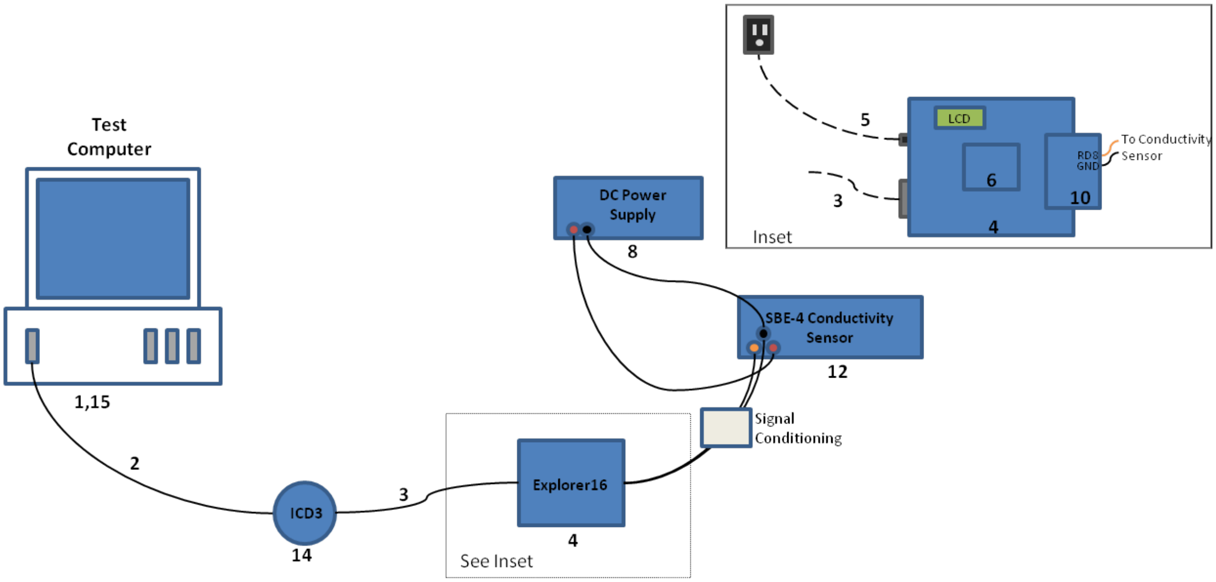


Figure 4.2.2: Test Configuration #2 for Data Acquisition, Conductivity Sensor Subsystem

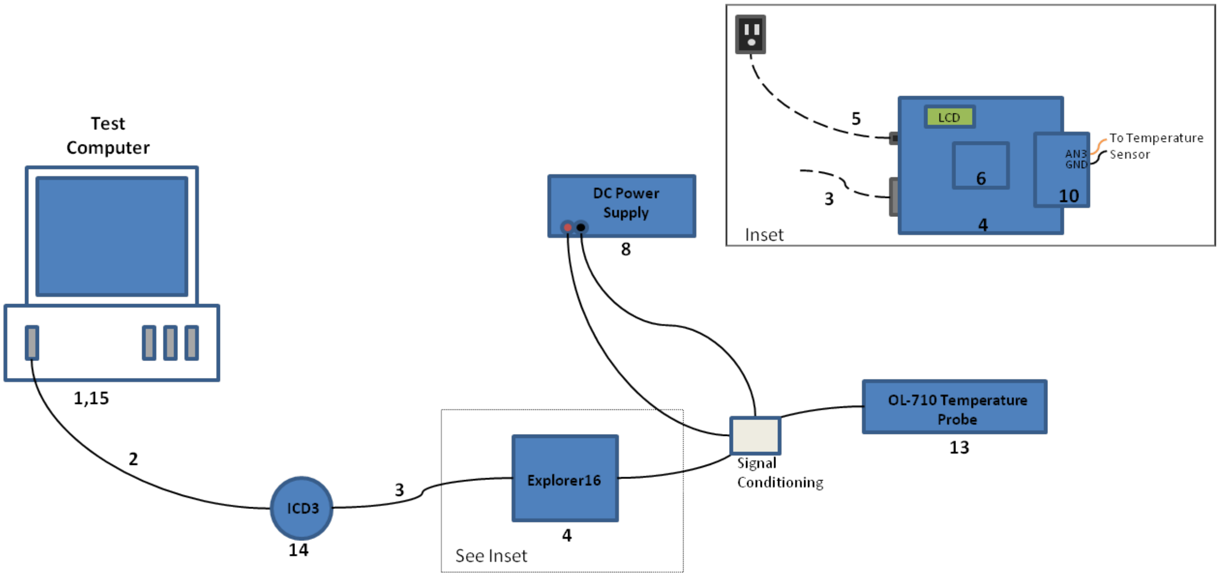


Figure 4.2.4: Test Configuration for Data Acquisition, Temperature Sensor

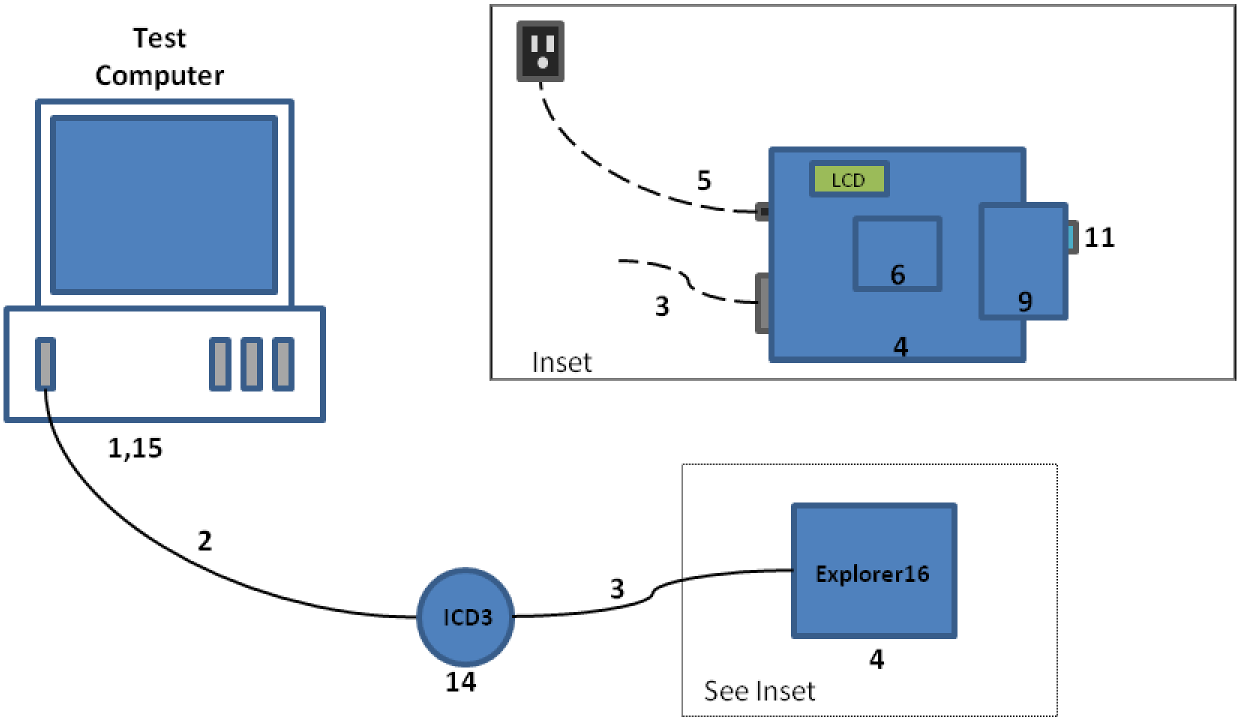


Figure4.2.4: Test Configuration for SD Data Logging Module

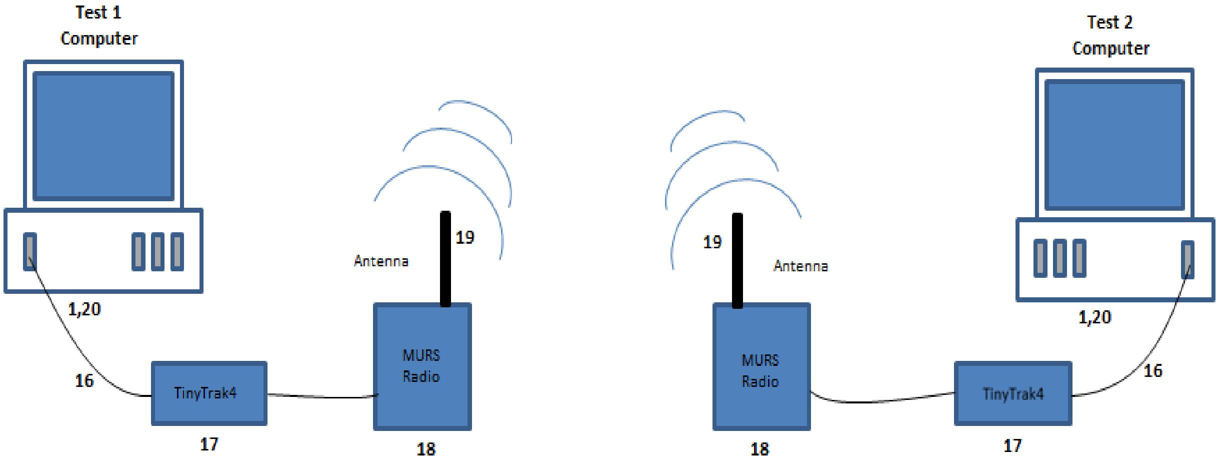


Figure 4.2.5: Test Configuration for Data Transmission

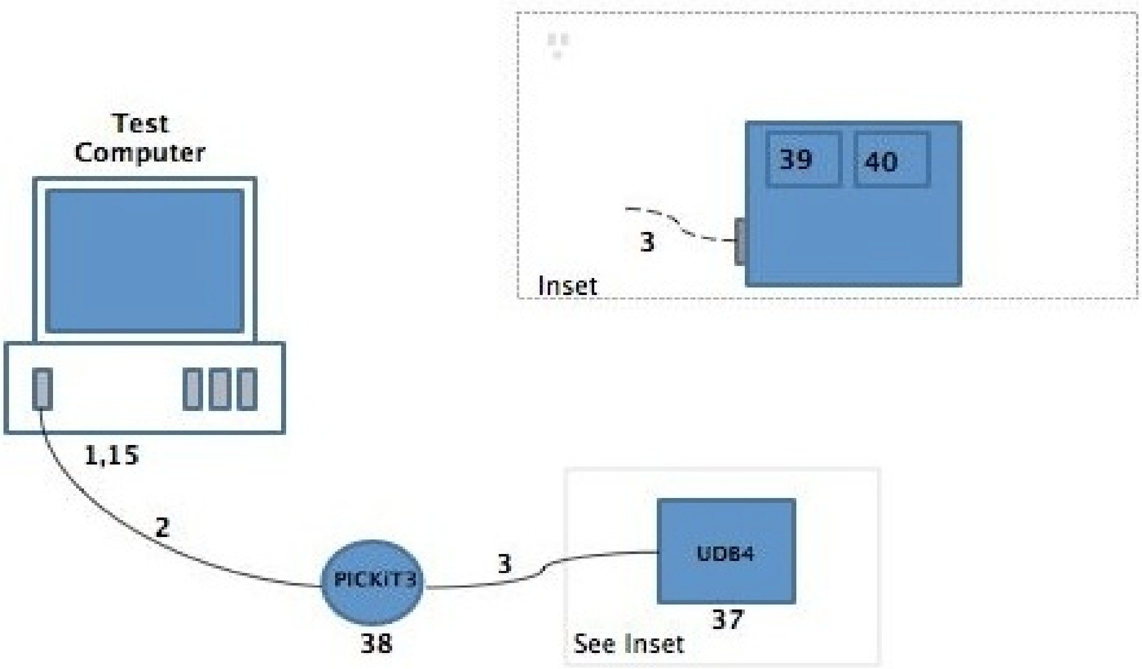


Figure 4.2.6: Test Configuration for Navigation system: UDB4

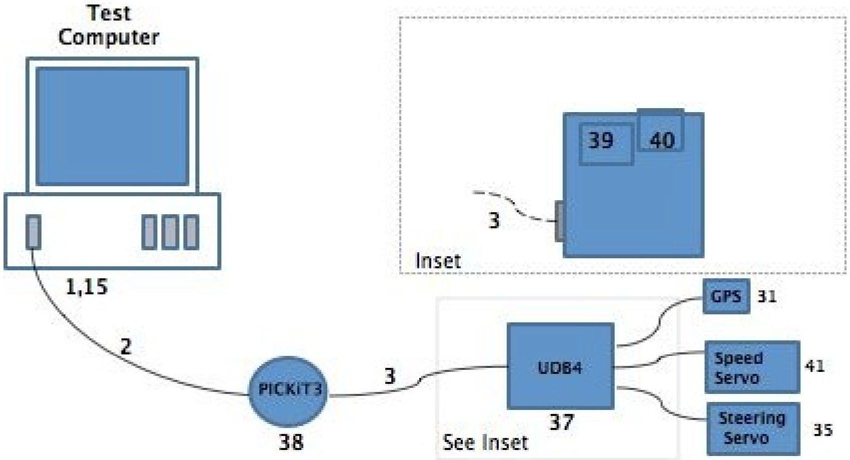


Figure 4.2.7: Test Configuration for Navigation System: UDB4, GPS, Speed and Steering Servo

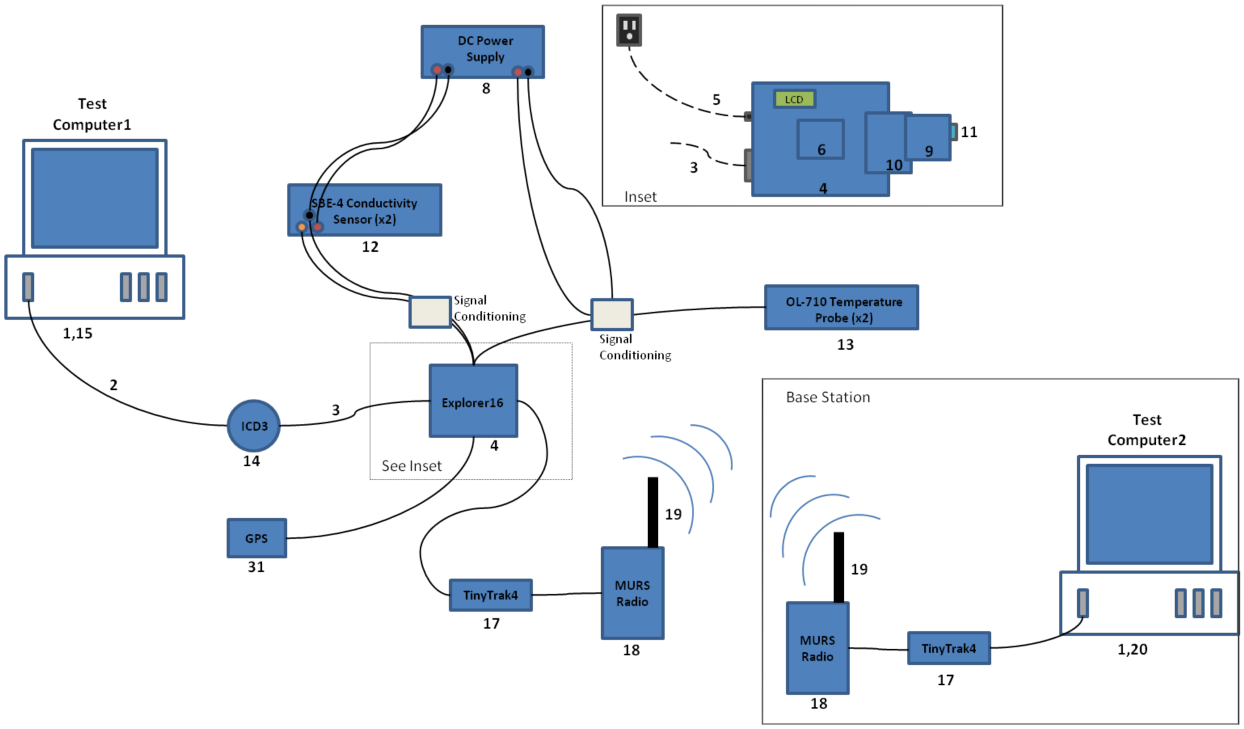


Figure4.2.8: Test Configuration for integrating Data Acquisition, Data Logging, Data Transmission

4.3 Test Plan for Major Components

4.3.1 Data Acquisition, Conductivity Sensor

Step #	Step Description	Expected Results	P/F N/A	Comments

1	Place the system in the configuration shown in Figure4.2.1		N/A	
2	Configure Function Generator to output a 3.3V square wave signal with frequency between 2.5kHz and 7.5kHz		N/A	
3	Execute Frequency Count test code block from MPLAB		N/A	
4	Verify the correct frequency is displayed on the LCD.	The microcontroller should determine the frequency of the signal using the input capture feature. The signal's frequency should be displayed on the Explorer16's LCD display	P	See Appendix B
5	Replace the Function Generator with the SBE-4 Conductivity Sensor (Refer to Figure4.2.2).		N/A	
6	Configure DC Power Supply to provide 12VDC to SBE-4.		N/A	
7	Immerse SBE-4 in a solution with known conductivity between 0 and 7 S/m.		N/A	
8	Verify output of signal conditioning is a 3.3V square wave signal.	Output of the SBE-4 conductivity sensor should be scaled to provide a 3.3V square wave signal to be analyzed by Explorer16.	P	
9	Execute Frequency Count test code block and Freq > Cond test code block.		N/A	

10	Verify LCD displays the appropriate frequency corresponding to the conductivity of the solution in which the sensor is immersed.	The function should determine the frequency of the signal and then convert this frequency to conductivity. The conductivity displayed on the LCD should match the known conductivity of the solution.	P	See Appendix B

4.3.2 Data Acquisition, Temperature Sensor

Step #	Step Description	Expected Results	P/F N/A	Comments
1	Place the system in the configuration shown in Figure4.2.3		N/A	
2	Apply 3.3V stimulus to OL-710 temperature probe		N/A	
3	Execute Get Temperature test code block from MPLAB		N/A	
4	Verify the correct temperature is displayed on the LCD.	The microcontroller should determine the voltage corresponding to the thermistor's temperature using the analog-to-digital converter feature. The temperature should then be computed and displayed on the Explorer16's LCD display	P	
5	Verify the temperature is correctly computed throughout the temperature range from 0ºC to 40ºC.	The 12-bit A/D converter should be configured to expect input voltages corresponding to temperatures 0ºC to 40ºC.	P	

6	Verify that temperatures in this range are displayed on the screen with a precision of .01ºC (or better)	The temperature computed should respond to variations of .01ºC. The computed temperature should resolve to .01ºC.		See Appendix B

4.3.3 SD Data Logging

Step #	Step Description	Expected Results	P/F N/A	Comments
1	Place the system in the configuration shown in Figure 4.2.4		N/A	
2	Execute Write To SD test code		N/A	
3	Remove SD Card and insert in test computer		N/A	
4	Verify data was accurately written to the SD Card.	The data should be written to the SD Card via the SPI1 serial interface of the microcontroller. The data written should be identical to the data sent over the serial interface.	P	See Appendix B

4.3.4 Data Transmission

Step #	Step Description	Expected Results	P/F N/A	Comments
1	Place the system in the configuration shown in Figure 4.2.5		N/A	
2	Create character string in terminal on Test Computer one		N/A	

3	Send string from terminal to TNC to begin data transmission across MURS radio		N/A	
4	Receive string from TNC on terminal of Test Computer two.		N/A	
5	Verify that data received on Test Computer two is identical to data sent from Test Computer one.	The data received should be identical to the data sent without any errors.	P	
6	Increase data size to match typical output sent from AWQuSam and verify that the data received is identical.	The data received should be identical to the data sent without any errors.	P	
7	Increase the distance between the MURS Radios to be 5km.		N/A	
8	Verify data is received at the base station receiver.	The data received should be identical to the data sent without any errors.	P	See Appendix B

4.3.5 Hull and Thrust Test

Step #	Step Description	Expected Results	P/F N/A	Comments
1	Measure the weight of the kayak.		N/A	Weight: 33lbs
2	Place kayak in body of water to estimate buoyancy and ensure there are no leaks.	Kayak floats smoothly on choppy waters.	P	

3	Attach kayak to rope and rope to an analog force sensor. Measure the speed of the kayak (with a GPS) as a function of the thrust experienced by the kayak. Thrust is applied a boat powered by a gas engine.	AWQuSam is able to move at speeds of at least 6 knots.	P	At 15 lbs of thrust kayak moves at 7 mph.
4	Repeat Step 3 but adding 45 lbs extra in water weight to act as placebo masses for other components of the boat.	AWQuSam is able to move at speeds of or more than 5 knots.	P	At 18 lbs of thrust kayak moves at 6.4 mph/

4.3.6 Propulsion System

Step #	Step Description	Expected Results	P/F N/A	Comments
1	Assemble propulsion system according to diagram in Figures 3.2.1 and 3.2.3		N/A	
2	Test the normal operations of the Honda GX35 engine with 2.5 gallons of fuel.	The engine runs smoothly for 12 hours without stopping	P	Engine runs smoothly as long as there is a constant supply of gasoline. Max operating time was 3 and half hours during testing. It is expected that if nothing unforeseen happens it will run for 12 hours.
3	Test engine in water AWQuSam. Measure variable speeds using placebo masses for other components	AWQuSam is able to move at speeds of or more than 5 knots.	P	GPS shows the maximum speed the vehicle travel is closer to 6 knots but variable to customers desire.

4	Measure the temperature of the engine after an hour run	Honda engine remains relatively cooled by draft	P	Motor temperature reaches steady state and never exceeds operating temperature.

4.3.7 Steering System

Step #	Step Description	Expected Results	P/F N/A	Comments
1	Assemble steering system according to diagram in Figure 3.3.1		N/A	
2	Test response of the servo motor on command in calm waters.	Servo motor is able to provide enough torque to move the rudder.	P	The vehicle handles like a champ.
3	Test effectiveness of system to steer the craft appropriately.	Steering will require some accommodations to achieve effective steering.	P	No accommodations were required from Step 2.
4	Calibrate angle of the servo with steering intensity.	System will require some trial and error to achieve optimum steering		NOT DONE YET
5	Test vehicle performance to run on a 360 degree turn.	Step will show us system turning radius and will require more trial and error to achieve an appropiate turning radius of 5 meters maximum.	P	Vehicle is able to turn at about 3 m. radius.
6	Run the AWQuSam by remote control in rougher waters.	Mechanism proofs to be tough enough to handle itself in currents and waves.	P	Vehicle handles mild choppy waters well however it is best advised to stay away from heavy storms.

4.3.8 Mechanical Housing Stability, Bouyancy, and Safety features

Step #	Step Description	Expected Results	P/F N/A	Comments

1	Assemble hull structure and housing according to diagram in Figure 3.1.1.1, 3.1.1.3, 3.1.1.4, 3.1.1.5, 3.1.1.6, 3.1.2.1, 3.1.2.2, and 3.1.2.3		N/A	
2	Test the water tightness of the cover.	Cover successfully prevents water from entering the vehicle. Note that perfect tightness is impossible.	N/A	NOT APPLICABLE ANY MORE. New PVC frame makes the cover anti rain but allows for air ventilation.
3	Test attachment and that all components in the hull are fixed in position. This will be done simply by group members. Wave simulation will be involved.	All componets of the system remain in place safely attached. Bolts and screws don't loosen.	P	Vehicle can be turned upside down, shaken, and rocked and all components are held in place.
4	Place vehicle in water to determine the stability and bouyancy of the system.	Trial and error will be involved to achieve optimum balance and stability of the system. This step will also allow us to determine sensor (and other components) placement.	P	Vehicle performed really well even from the first test run. It has a 6 in draft which is perfect for sensor placing. There were some issues with leaks that were fixed gradually with sealant.
5	Run the vehicle remotely control and maximum speed.	Step will allow us to determine the exact placement for sensors (at surface and 6 inches below surface).	P	Vehicle runs smoothly. Without weight in the front the nose is lifted up in the air. However electronics and batteries add enough weight to level it out.
6	Test spring-keel mechanism.	Step will allow us to determine the size of spring required to bring keels back into position after coming in contact with an obstacle.	N/A	NOT APPLICABLE ANY MORE
7	Run the vehicle on shallow waters.	Step will allow us to identify the effectiveness of the stabilizing keels to rotate back when they come in contact with obstacles or ground. Trial and error will allow us to determine the appropriate type of spring that push keels back.	P	The vehicle was run in shallow waters and through weeds and it didn't get stuck or the weeds didn't restrict the kayak or the prop. It did move slower.

8	Test effectiveness of LED navigation lights.	AWQuSam will be easily identifiable from a distance of no less than 50 meters.	P	Highly visible from 30 m.
9	Test effectiveness of siren.	AWQuSam will be detected from a distance of no less than 50 meters.	P	Extremely annoying.
10	Test effectiveness of bumber. The test will involve various runs of the AWQuSam in collision with fixed surfaces and the impact will be analyzed by the group members.	Bumper proofs to be effective enough that it won't damage any other vehicle or hurt any unknown spectators.		NOT DONE YET

4.3.9 Cooling System

Step #	Step Description	Expected Results	P/F N/A	Comments
1	Measure the temperature dissipated by the electronics inside the electronics box.	TBD	N/A	NOT DONE YET
2	Test the amount of time the cooling system will take to bring down the temperature inside the box by 10%.	TBD	N/A	NOT DONE YET
3	Test the effectiveness of the cooling system in maintaining the temperature of the electronics below thresh hold. Note that in this test operating conditions must be met (i.e. air draft and motion)	Packets are able to maintain the electronics at a safe temperature for the duration of the mission.		NOT DONE YET

4.3.10 Navigation System

Step #	Step Description	Expected Results	P/F N/A	Comments

1	Place the system in the configuration shown in Figure 4.2.6 and power board	Board MUX light should be on	P	
2	Configure EM406-A GPS to output update at a 1 Hz rate.	Whille viewing data transmitted to the Ardupilot in a serial window, 1 NMEA sentences should arrive every second	P	
3	Configure D2523T GPS to output GPGGA and GPRMC satellite data at a set update rate	Only two sentences should be seen in the serial window.	P	
4	Configure pulse width modulation ports on Ardupilot	Servo test should cause servos to update from their minimum to maximum positions 3 times.	P	
5	While GPS is updating data, travel a planned route with significant waypoints		P	
6	Verify GPS outputs GPGGA and GPRMC string	GPS should output only two GPS strings each beginning with the appropriate string header (i.e. $GPGGA, $GPRMC)	P	
7	Verify the GPS points which were recieved	The GPS coordinates obtained should match or vary slightly from known coordinates along traveled path	P	

8	Verify UDB4’s ability to change speed output on speed servo when commanded	(Optional: For future expansion) Speed servo should increase or decrease speed on command	P	
9	Verify UDB4’s ability to change direction of steering servo on command	Steering servo should rotate clockwise and counter-clockwise on command	P	

4.4 System and Integration Test Plan

4.4.1 Data Acquisition, Data Logging

Step #	Step Description	Expected Results	P/F N/A	Comments
1	Place the system in the configuration shown in Figure4.2.8		N/A	
2	Configure Function Generator to output two 3.3V square wave signals, each with varying frequency between 2.5kHz and 7.5kHz		N/A	

3	In MPLAB, configure Explorer16 (in loop) to: 1. Call *GPS* test code 2. Call *Frequency Count* test code for each input 3. Call *Get Temperature* test code for each probe 4. Call Freq > Cond routine (optional) 5. Write all acquired values to SD card		N/A	
4	Verify all values are written to SD Card	The microcontroller should accurately determine the frequency of each signal using input capture. The microcontroller should determine the temperature of the probes using A/D Converter. Time (hh:mm:ss), Position (Lat+Lon), Conductivity (x2) and Temperature (x2) should be written to the SD card	P	See Appendix B
5	Verify the frequency and temperature are logged at a rate of no less than 8 samples per second	The microcontroller should measure and record data from each sensor at a rate of at least 8 samples per second.		

4.4.2 Data Acquisition - Data Transmission

6	In MPLAB, configure Explorer16 to repeat step 4 and add: 6. Write acquired data to TNC serial output		N/A	

7	Configure receiver terminal to monitor serial port (commX) to which TNC is connected		N/A	
8	Verify data received at receiver terminal matches data output by Explorer16	Bit stream written to the receiver terminal should match the bitstream written to the TNC serial output of the Explorer16.	P	See Appendix B

4.4.3 Power System Integration

Step #	Step Description	Expected Results	P/F N/A	Comments
1	Place the system in the configuration shown in Figure 3.10.1 where the 12V input is from a DC power supply (FN 8)		N/A	
2	Verify all components receive power and are functional	The 12V supply should be distributed and regulated to supply power (per specification) to each component of the system	P	
3	Replace DC power supply with 12V battery (FN 30)		N/A	
4	Verify all components receive power and are functional	The 12V battery supply should be distributed and regulated to supply power (per specification) to each component of the subsystem	P	
5	Verify the system remains powered for 12 continuous hours of operation	The 12V battery should have sufficient capacity to provide power to the system for 12 hours of continued operation	P	See Appendix B

4.4.4 Electronic Housing Integration

Step #	Step Description	Expected Results	P/F N/A	Comments
6	Recharge battery		N/A	
7	Place the system in the configuration shown in Figure 3.10.1 where the 12V input is from a 12V battery (FN 30)		N/A	
8	Place electronic components within electronic housing and place outside for 12 hours (typical hot,humid diurnal solar cycle)		N/A	
9	Following this test, verify the AWQuSam still operates functionally	The cooling system of the electronic housing should be sufficient to provide a safe operating temperature for the AWQuSam's electronic components.	P	
10	Recharge battery		N/A	
11	With electronic components still within electronic housing (and cables in operational configuration), verify all cable interfaces with housing are properly sealed. Expose housing to driving rain (or simulated rainfall)		N/A	
12	Verify there is no water intrusion into the electronic housing	The electronic housing should be resistant to water intrusion as a result of driving rainfall. No water should enter the electronic housing through cable interfaces with the housing. All components should remain fully functional during and after operation in driving rainfall.		

4.5 Summary of Test Plan Status

See Appendix C

5 Schedule

See Appendix A

6 Budget Estimate

Item	**P/N**	**Manufacturer**	**Distributor**	**Qty**	**Projected Cost**	**Actual Cost**
PIC Development Board w/ Programmer	DV164037	Microchip	Microchip	1	$225	$225.00
SD Daughter Card	AC164122	Microchip	Microchip	1	$28.50	$28.50
Conductivity Sensor	SBE-4	Seabird	In House (FSU Oceanography)	2	-	-
Temperature Sensor	OL-710	Omega	Omega	2	$200	$173.00
Compass Module	SEN-07915	Honeywell	Sparkfun	1	$34.95	$34.95
GPS	GPS-09566	ADH Technology Co. Ltd	Sparkfun	1	$79.95	$79.95
microSD 16GB Memory Card	COM-08163	A-Data	Sparkfun	1	$9.95	$9.95
USB to Serial Converter	USB-232-1	CommFront	CommFront	1	$30	$26.40
MURS Radio Modem	RV-M3-M	Raveon	Raveon	2	$260	$113.00
TNC	TinyTrak4	Byonics	Byonics	2	-	$202.00
Base Station Antenna	MURS-BASE	Firestik	TBD	1	$39.99	$62.05
4x4 Keypad	TBD	Grayhill	TBD	1	$20	-

Wiring and Accessories					$200	
Battery	SRM-24	Interstate Batteries	Amazon	2	113.95	
Servo Motor	High Torque Water Proof Servo	Traxxas	TBD	1	83.76	
Honda GX35 35cc Engine	#HEGX35NTT3	Honda	Bailey’s	1	399.99	$299.38
GX35 - Clutch	Clutch	Honda	Small Engine Warehouse	1	38.97	$80.95
Prather 280 BC Metal Prop	PRAB280	-	FunRcBoats	1	-	$21.99
Kayak	-	-	CraigsList	1	98.00	$140.00
Shaft	SF2	Surface Drive Hardware	PMB Model Boats	1	$52.15	$52.15
Engine Coupling	HF192A	Surface Drive Hardware	PMB Model Boats	1	$22.11	$22.11
Hoses	Discharge and Suction Hoses with couplings	TBD	TBD	1	40.00	
Mounting Hardware	Sealants and Bolts	TBD	TBD	N/A	40.00	
SubTotal:					$2017.27	
Total Proposed Expenditures:					$2000.83	$1509.33

Table5.1: Product Prototyping Budget

7 Conclusion

Design and development of the Autonomous Water Quality Sampler progressed as expected. The final design of the major subsystems are included in this review. Navigation, data acquisition, data logging, propulsion, and steering are all critical subsystems of the design. These subsystems have been completed and tested. They have been integrated with one another and fitted to the mechanical hull, as designed. The project’s future may include form factor optimization and integration of different types of sensors. AWQuSam Engineering’s primary business objective is to meet the customer’s requirements by providing quality service and designing with integrity. The quality of the team’s service is a direct consequence of the team’s commitment to continual excellence.

8 References

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Operations Manual

A1 System Power Up

1. Ensure desired GPS waypoints are entered into AWQuSam. See Section A4
2. Insert SD Card
3. Crank Motor
4. Place Power Switch in “ON” position
5. Vehicle will begin moving when GPS is acquired. Keep away from propeller!

A2 System Shutdown

When retreiving AWQuSam, first disengage engine by pressing Motor Shutoff button.

When the final waypoint is reached, “Mission Complete” should be displayed on LCD. If so, it is safe to place Power Switch in “OFF” position.

If retrieving AWQuSam before final waypoint is reached, Press and hold S3 button on Explorer16 until “Mission Complete” message appears on LCD display.

Once “Mission Complete” message appears, it is safe to place Power Switch in “OFF” position. SD Card can be safely removed.

Important: If SD Card is removed before “Mission Complete” is displayed, data may become corrupted or lost. SD Card may require formatting before it will function properly.

A3 Data Structure

Data on SD Card and data transmitted in real time is formatted as follows:

```
        Time          Latitude       Longitude      Cond1 Cond2 Temp1 Temp2
```

where Cond refers to conductivity and Temp refers to temperature

An example log entry is shown below.

```
        152712.148    2955.4348N    08424.8626W 4.741   4.728   22.54   22.20
```

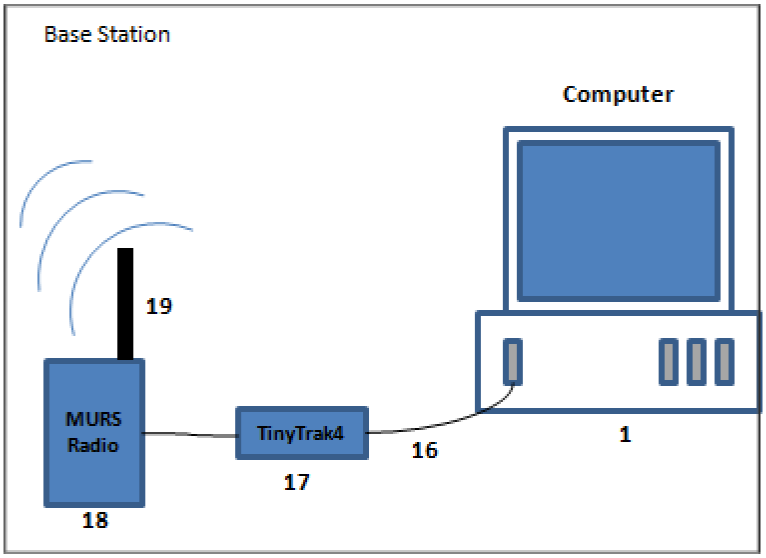
The first column represents a time of 15:27:12 (and 148ms) UTC. Latitude and longitude reports columns are to be intepreted as follows: The two digits immediately to the left of the decimal point are whole minutes, to the right are decimals of minutes, and the remaining digits to the left of the whole minutes are whole degrees. For example, the second column of the above log entry represents 29 degrees and 55.4348 minutes. Similarly, the third column is 84 degrees and 24.8626 minutes.

The fourth column is the conductivity measured on the left side of theAWQuSam. The temperature corresponding to this measurement is shown in the fifth column. Similarly, the sixth and eighth columns represent data acquired from the right side of the AWQuSam.

A4 Configure Waypoints

A5 Base Station Setup

Place components in the configuration shown in Figure A5.1



FigureA5.1: Base Station Configuration

On the test computer, install a RS-232 terminal (such as Termite: http://www.compuphase.com/software_termite.htm)

Configuration terminal application to monitor the appropriate COM port with 19200 baud.

Data will be displayed as it is transmitted by the AWQuSam.

A6 Routine Maintenance

Appendix A. Project Schedule

Appendix B: Test Results

Appendix C: Project Code

Appendix D: Calibration Sheets