Operations Manual

Design and Development of an Autonomous Underwater Vehicle

Team 23

AUVSI Robosub

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Abstract

The goal of Team 23 is to represent the FAMU/FSU College of Engineering in the 19th annual AUVSI Robosub competition, which occurs from July 25th to July 31st of 2016. This will be accomplished through the design, development, and extensive testing of a modular sub which meets all of the competition requirements provided by the AUVSI Robosub competition. The work process is described in the manual below as well as operation instructions for the submersible.

Team 23 was not the only team working on the Robosub this year, team 4 of the ECE teams also worked to reach the goal of reaching the competition this year. This manual will combine the progress of both teams into one central document to make it easier to follow all the information there is to know about the submersible.

Acknowledgements

We would like to thank the people who have helped us thus far and the ones who plan to help us in the future. This includes Kim Hinckley at the Morcom pool for letting us use FSU's dive pool for testing. Dr. Gupta and Dr. Shih for guidance and constructive criticism throughout the project and the course. Dr. Clark for pushing us to set high goals and achieve them. Dr. Harvey and Dr. Hooker for their support and suggestions and the ME and ECE department for funding our senior design project.

1. Functional Analysis

1.1 Electrical Function

The intended function of this project is to design an autonomous underwater vehicle, or AUV. In order to accomplish this several components needed to be addressed: the main electronics (the CPU), a waterproof electronics housing (hull), cameras and thrusters for navigation, and the mechanical components of subsystems to perform various tasks such as the marker dropper, gripper and torpedo firing mechanism. The major electronics hardware required to control the AUV is comprised of a main processing unit (MPU), microcontrollers, and motor drivers. Each subsystem has its own set of instructions and code which interacts with the MPU. Below is a signal diagram showing how the electronics communicate with one another in their subsystems. The legend on the upper left corner of Figure 1 organizes the components into their specific subsystems.

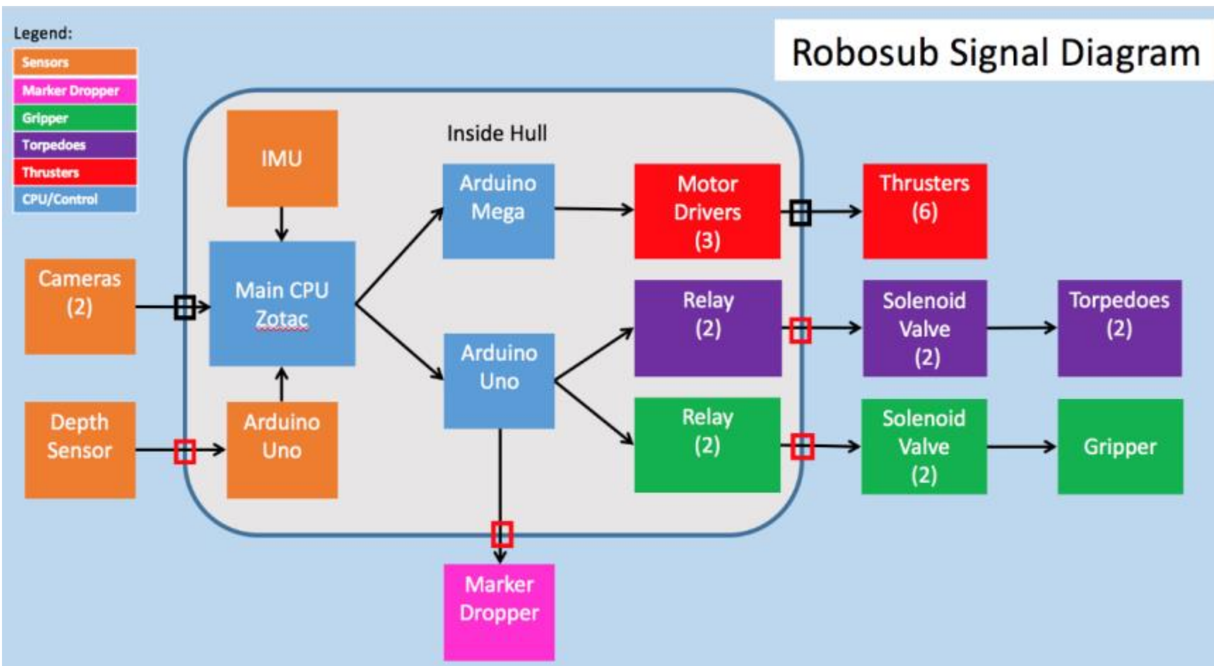


Figure 1: Signal Diagram

1.2 Mechanical Function

A well designed hull was one of the most crucial requirements for the entire project. A good balance between size and weight had to be found. The size is an important factor in that it must be large enough to hold all the electronics hardware but not but not have excess volume that caused too much buoyancy. The electronics housing is an important factor in the AUV since it will be housing all of the electronic hardware and will need to be watertight to prevent water shorting the electronics. A CAD of the hull can be seen in figure 2 below. The waterproofing will be done by using a weather strip as an o-ring around the inside of the hull. There are then six latches that put pressure on an acrylic lid. The pressure applied to the lid from the latches creates a watertight seal around the top. The housing is also important in that it is the main medium through which the heat generated by the electronics will be dissipated. If the heat dissipated is not enough, then the electronics could overheat, which could then cause small problems circuitry problems such as shorts. The final design that was chosen is shown above and is made of stainless steel. It is smaller and lighter than the previous years' hull but it solves the problem of the positive buoyancy. This hull was tested and not only passed the waterproof test, but also was designed to be slightly above neutral buoyancy so that the sub maintains its depth when the kill switch is presses and the thrusters turn off.

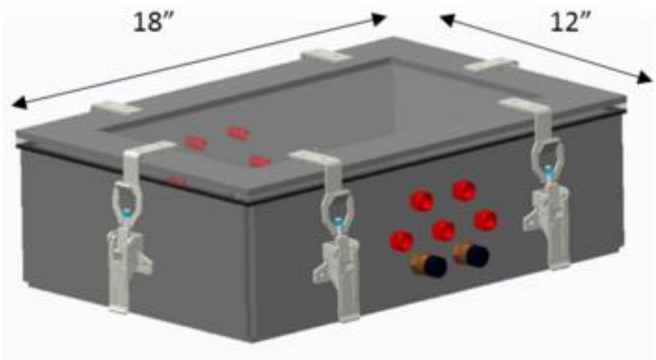


Figure 2: New Hull Design

2. Project Specifications

2.1 Electrical Specifications

Each controller, sensor, actuator, and thruster requires a specific voltage and current to function. To achieve this, a power system has to be designed to allow the AUV to operate for a sufficient time underwater. Table 1 shows some of the requirements needed for selected components of the AUV. The figures below also show the circuit that the battery will power.

Table 1: Battery Requirements

Components	Max Current (A)	Ave. Current (A)	Voltage Required (V)
Zotac PC Board	3.5	1.5	19.0
Arduino UNO	0.75	0.5	7.0 - 12.0
Arduino Mega	0.75	0.5	7.0 - 12.0
Motor Controllers	2.0	1.5	5.0
IMU	0.075	0.060	3.5 - 16.0
Thrusters	12.0	3.0	19.1
Depth Sensor	0.020	0.012	8.0 - 11.0

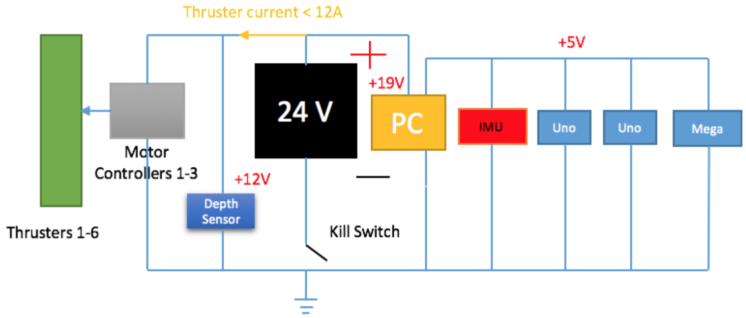


Figure 3: Battery Diagram

Figure 3 above shows the main power diagram for the AUV. The main components are all powered by a 24 V battery along with voltage regulators which cut down the power to the components that do not require as much.

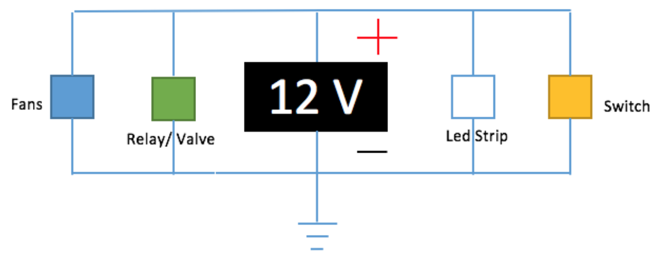


Figure 4: 12V Battery Circuit

The Figure above shows the secondary power diagram for the AUV. The functional purpose of this battery is to power the cooling fans along with the relays and air valves for the pneumatic system. This battery also serves aesthetic purposes such as powering the LEDs in the sub or lighting up the kill switch.

2.1.1 Main CPU

In order to integrate all of the subs functions to communicate with one another a main processing unit is need. The Zotac computer acts as the main processing unit for the AUV. As the MPU, the Zotac is essentially the sub's "brain" and is responsible for most of the high-level communication. The Zotac is where the image processing takes place which then communicates to other peripherals of the sub. The MPU interfaces with one Arduino Mega and two Arduino UNO microcontrollers. The Zotac makes use of its USB ports to establish bidirectional UART serial communication links with the microcontrollers. The information is sent to the Arduinos to control various hardware such as the thrusters, and depth sensor. The Zotac computer also utilizes two Logitech webcams connected via USB for vision information. The MPU receives power from an external 19V/ 4mA universal laptop battery. The Zotac also acts as a power source to the microcontrollers and IMU.

Figure 5: Zotac Mini Computer

2.1.2 Microcontrollers

Each serial device needs a "bridge" to communicate with the MPU. The Arduino UNO is a perfect solution to handle this communication. Two Arduino UNO's will be used in the AUV. Each Arduino will control a peripheral: actuators, hydrophones, etc. This will take the serial communication from each subsystem and allow control over USB from the MPU. This device was selected to be specifically used for motor control. It contains more pins to be used with all six thrusters. This allows thruster control to be sent to only one device instead of multiple Arduinos. It also allows for more processing power so that it can be directly attached to the IMU stabilizing unit. It is powered via USB and will be controlled through USB from the MPU as well.

2.1.3 IMU

The Inertial Measurement Unit, or IMU, is integral in maintaining the orientation of the AUV. It has nine degrees of freedom and outputs data in the x,y, and z planes. This particular IMU was a very cost effective model that was able to easily do the tasks needed with this project and communicate with the Zotac which adjusts the thrusters accordingly.

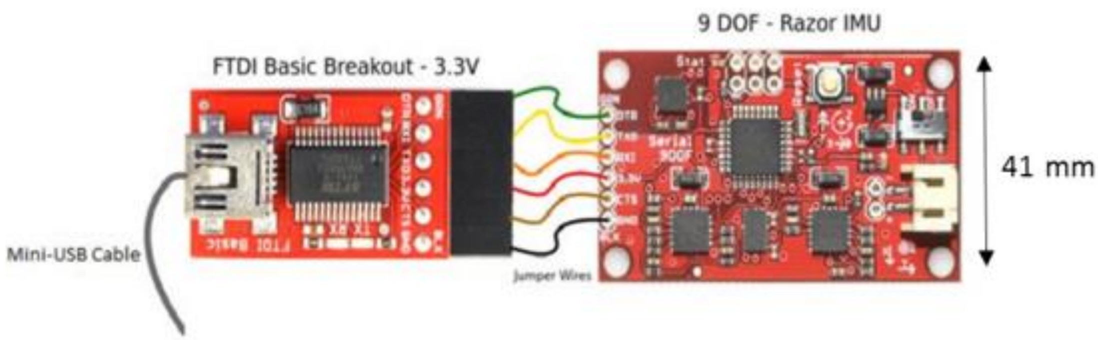


Figure 6: Sparkfun Razor IMU

2.1.4 Motor Controllers

There were three L298 H-Bridge motor controllers that were used in the AUV, both of which were very similar. This year the team purchases a new motor controller to replace the older model and make all of the controllers the same. The motor controller used is the CanaKit driver, with the following specifications:

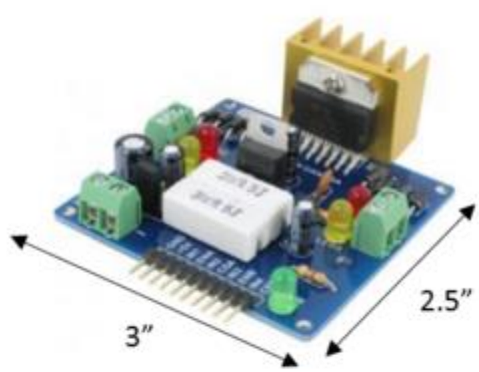


Figure 7: L298 H-Bridge motor controller

2.2 Mechanical Specifications

The hull without the frame weighs 75 lbs and displaces slightly over that to achieve a small degree of buoyancy when submerged. If needed buoyancy foam can be added to the bottom of the hull to achieve neutral buoyancy if it is too heavy. Furthermore weights can be added to the hull if it is too buoyant.

3. Product Assembly

There are a lot of connections that need to be made throughout the AUV in order for it to operate correctly. The signal diagram from figure 1 shows all the top level connections that need to be made, This section contains more detailed wiring diagrams as well as instructions for attaching the hardware to one another.

3.1 Mechanical Design

The mechanical design consists of the hull and frame assembly. The primary purpose of this design was to keep it simple and functional. The main idea behind the design of the hull was to achieve neutral buoyancy to put as l

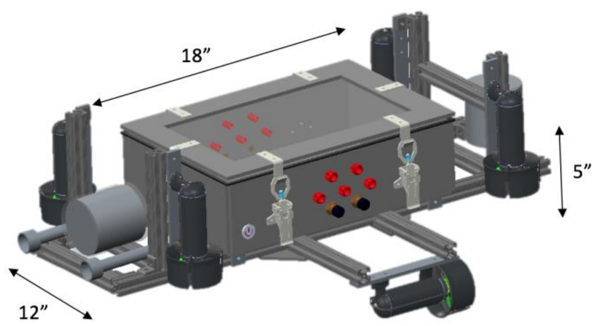


Figure 8: Hull Assembled on Frame

3.1.1 Gripper

The gripper mechanism must be able to grasp and continuously apply pressure to a variety of small objects throughout the course. The grip must constrain at least 3 degrees of freedom of the object throughout movement in all directions. The gripper must be controlled effectively by the microcontroller and interface with the cameras to ensure accuracy in securing a target.

Figure X shows the actuator the team has decided to go with for the gripping mechanism. This model runs off of compressed air. The camera would detect an object on the bottom of the pool and would activate an air compressor which would close the claw and keep it inside of its grip. This model will be improved upon this year by redesigning the physical gripper but keeping the same principles intact. The gripper for this AUV is mounted in the front.

Figure 9: Gripper Mechanism

3.1.2 Torpedo

The portion of this system that the team is focused on redesigning is the physical projectile. The problem of the floating torpedoes will invariably effect scoring during the competition. Upon investigation of an old torpedo It was found that the object is made out of either cast or machined ABS plastic that contains a metal rod in its center and a magnet to attach to the projectile system. The use of a metal rod gave structure and assisted in the attempt to correct buoyancy. With the knowledge that this had less than optimal buoyancy but the system is still designed for these to particular projectiles to fit into it the team chose to look at a manufacturing change. Figure 4 shows a remade CAD design made to mimic the previous design. The manufacturing methods that will be used to replicate this is 3D printing. Using 3D printed ABS rapid inexpensive prototyping is available to change buoyancy based on core size and infill. This will also allow the altering of core materials with ease to produce the ideal weight addition to the sub. Additionally the rapid prototyping will allow for slight shape changes to optimize trajectory in water.

Figure 10: Torpedo Design

3.1.3 Marker Dropper

The design used for the marker dropper came from a design adopted from a previous FAMU-FSU RoboSub team. The decision to continue with this design came down to its simplicity and effectiveness. The mechanical subsystem is made out of aluminum 6061 and contains a parabolic track where two steel balls will be in place. The parabolic track is bound on both sides by aluminum walls in order to prevent the markers from accidentally falling off the device. There is a servomotor that is oriented vertically downward, located directly between each of the two markers. When the camera sees the desired object the servomotor will rotate right or left to a desired angle releasing one of the two balls. After the ball is released, after a given delay, the motor will rotate back to its starting position. When the cameras see the other desired object, the motor can rotate to the same angle in the opposite direction in order to allow the second steel ball to drop into the desired bin. The servomotor will be controlled by one of the microcontrollers. The wires from the microcontroller will run to one of the Seacon ports that will run the rest of the connection to the waterproof servo.

Figure 11: Marker Dropper

3.1.4 Thrusters

There are six SeaBotix BTD 150 thrusters on the AUV, 4 mounted vertically and 2 mounted horizontally providing backward/forward thrust as well as yaw control. These are controlled by three different motor controllers hooked up to an Arduino Mega. The connections between all these devices can be seen below.

4. Operation Instructions

4.1 Lab Testing

The Zotac can be powered by either the universal laptop battery or the wall adaptor. It is recommended to plug it into the wall in the lab when ding out of water testing. The Zotac's power button is on the front. You should see a blue ring of light on the computer when it comes on.

4.1.1 Torpedo/ Gripper Test

Open the Arduino IDE and open the file known as actuator_2013_04_18.ino. This file should be located in a folder known as "Torpedo" which is located inside of the desktop folder labeled "RoboSub 2015-2016". The code is well commented and the instructions are inside telling how to activate each air valve. This program uses the serial input of the Arduino to output pins to high.

4.1.2 Marker Dropper Test

Open the Arduino IDE and open the file known as marker_dropper.ino. This file should be located in a folder known as "Marker Dropper" which is located inside of the desktop folder labeled "RoboSub 2015-2016". The code is straightforward to use. There are two inputs to this code. One of the input tells the servo to rotate 45 degrees to the right and then return center while the other input tells the servo to rotate 45 degrees to the left and then return center This program uses the serial input of the Arduino to send the signal to the servo motor.

4.1.3 Control Test

Open the Arduino IDE and open the file known as final_sub_control.ino. This file should be located in a folder known as "final_sub_control" which is located inside of the desktop folder labeled "RoboSub 2015-2016". The code is well commented with a diagram and the instructions are inside telling what inputs control what thrusters. This program uses the serial input of the Arduino to output PWM signals to the motor controllers.

4.2 Water Testing

4.2.1 Sealing The AUV

Sealing the AUV is now a very simple task. All that is needed is the acrylic lid and metal top that contains the hook the latches attach to. Put the lid on the top of the AUV and then the metal top on top of this. Hook the latches to the designated areas and adjust them by screwing them either left or right so that they are not sitting loose when attached to the lid. Finally, push all six of the latches down. There should be a lot of resistance and this is how you know it is a solid seal. If the latches close too easily then they probably have not created a tight enough seal.

4.2.2 Wireless Control

In order for the sub to function it first needs to be set up using a computer. Since the Zotac does not contain a screen, it has to be wirelessly shared in order to control it. To do this all that is needed is a common network connection between the Zotac and a laptop. Then on the laptop the user can search for devices and the Zotac should appear and be labeled “robosub1314”. Once the user hits share screen, the desktop on the Zotac should appear in a new window on the laptop and the user can control it from their own device.

4.2.3 Running Code

There are a few steps for running the code to run the autonomous abilities of the AUV. Currently the ME Team has created subsystem code as well, but this is pending image processing from the ECE team to work autonomously. To activate the navigation code follow the following steps:

1. Open Terminal on the Zotac and open up three windows.

2. The first window is for the object tracking. Type cd Desktop/RoboSub14- 15/RS_C. To execute the program, input the command “./RoboSub_Control_v2”. This will turn the thrusters on and they will adjust speed in order to maintain a constant depth and start navigating to the first orange gate.

3. The next tab is for the thruster control. Then enter “./ColorDetection”. This should open up two new windows, one for the front facing camera and the other for the bottom facing camera. To test if the code is working hold an orange object, the camera is currently said to identify this color, and see if the camera identifies it.

4. The last tab is for the IMU. Type the command cd Desktop/RoboSub14-15/IMU/C++. This should pull up the IMU program in the terminal. To execute the program the user has to type “./example”. The program should now be running and the user should see the different sets of axis updating based off of the current orientation of the IMU.

5. Troubleshooting

5.1 Water Leak

If water leaks into the sealed hull the electronics can be permanently damaged and cause the sub to stop working during competition. To prevent this, proper testing must be performed before placing electronics in the hull. Furthermore absorbent material can be placed on the bottom/sides of the hull to prevent small leaks from puddling up near electronics.

5.2 Overheating

Because the hull is small and air tight conduction of heat produced by electrical components can cause the electrical components to overheat and fail. To prevent this fans are placed in the hull to aid in convective heat transfer. Furthermore a heat sink can be added to use the outside water to facilitate heat transfer.

5.3 Connection Issues

Due to the amount of subsystems on the hull there are many electrical connections both outside and inside the hull. These electrical connections can be broken or malfunction through normal movement or user error and cause the AUV to stop working. To prevent these electrical disconnections more secure connections can be made by soldering and using clamps on the wires. Also connections could be tested using a multimeter to ensure proper connections.

6. Regular Maintenance

6.1 Mechanical Maintenance

The moving components in the mechanical system require some form of lubrication, this includes the solenoid valves, gripping mechanism, and latches. All seals on the hull that separate the hull internals from the water must be checked prior to and immediately following any aquatic operation. If leakage is noticed extra sealant should be applied to the problem area and retested. The Hull lid should be inspected for cracks and the waterproof rubber spacer between the lid and the hull edge should be inspected for tears prior to any pool testing.

6.2 Electrical Maintenance

The electrical components for the most part should last for many years to come. The major components, such as the Zotac and Arduinos, should not need to be replaced unless during testing one of them gets shorted. The same goes for the four relays as well as the voltage regulators. The only maintenance that should need to be done should be checking to make sure all the connections are still solid and all of the solder joints are still intact. The batteries to power the AUV will also need to be charged.

7. Spare Parts

Table 2: Parts List

Part	Cost	Quantity	Distributor	Part Number
Stainless steel			McMaster-Carr	
Rubber Seal	$20.00	1	Steelerubber	70-1192-52
Acrylic Lid	$16.83	1	McMaster-Carr	8574K28
Toggle Latches	$20.93	6	J.W. Winco INC	110ENGL
Latch Catch Plate	$2.98	6	Protex	03-1692SS
Cable Penetrators	$4.00	12	BlueRobotics	PENETRATOR-10-25-A-R2
34" Aluminum Bar	$9.77	2	8020.net	1010
8" Aluminum Bar	$3.79	12	8020.net	1010
5 hole 90° bracket	$6.30	4	8020.net	4151
2 hole 90° bracket	$2.90	20	8020.net	4119
¼-20 x .500" Button Head	$0.30	62	8020.net	3690
¼ - 20 T-Nut	$0.61	62	8020.net	3675
2 Hole T-Nut	$0.95	4	8020.net	3356
3 Hole T-Nut	$1.55	4	8020.net	3358
Kill Switch	$22.88	1	Oznium	

8. Recommended Approach/Conclusion

8.1 Thruster Modifications

Currently the sub has 5 degrees of freedom and is only missing translation in the sideways direction. By placing and additional thruster pointing sideways the sub can navigate easier and allow it to complete tasks more efficiently. Furthermore the thrusters on the sub are several years old and are in need of replacement in the near future. The thrusters are about $700 therefore new thrusters should be investigated such as the blureobotics thrusters which are recommended by competition officials.

8.2 Camera Modifications

Much like the thrusters the cameras are beginning to age and will eventually need to be replaced. The current camera housing is fairly large and could accommodate several different types of cameras. If a more compact camera is chosen a new camera housing could be made that is smaller and produces less buoyancy force.

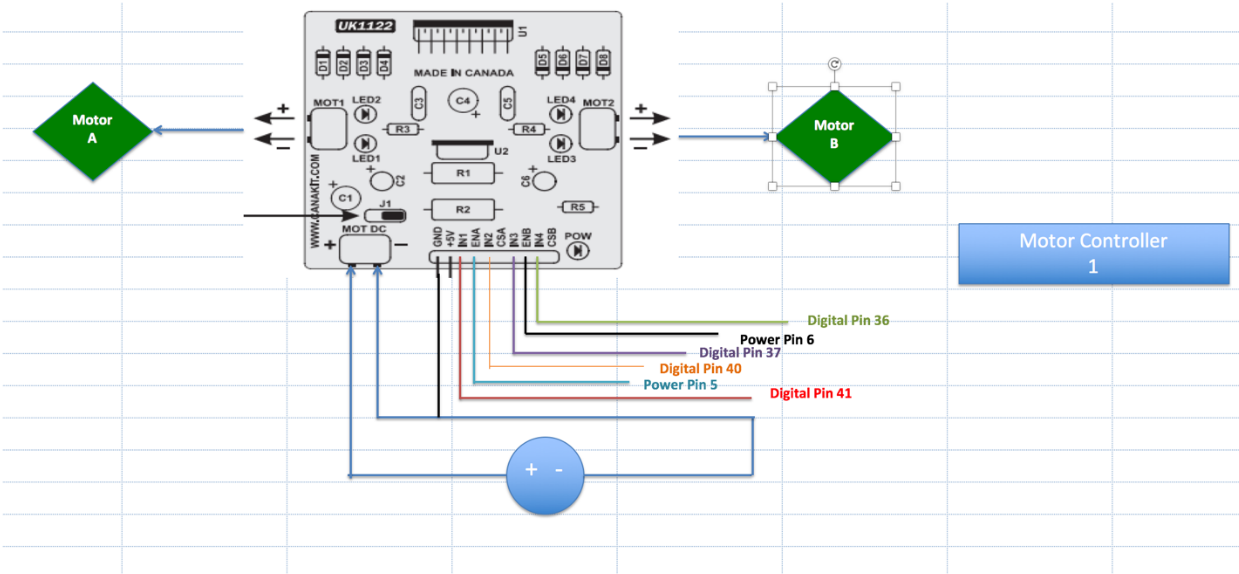
8.3 Waterproofing Air Tank

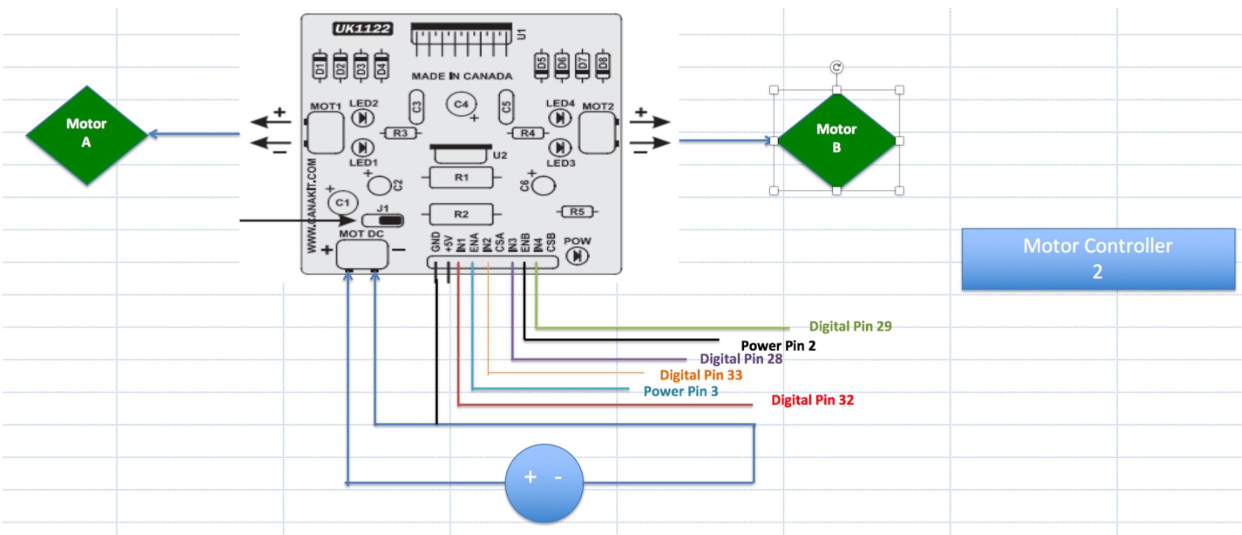
The air tank that it currently being used is not made for underwater use and will eventually rust. A waterproof casing could easily be made to prevent this rusting and corrosion. Another solution would be to find a small enough tank that is waterproof. Finally the more complex option would be to place the tank inside the hull and drill a hole that a pipe could fit to. This may not work due to the little available space in the hull.

9. Appendix

Table 3: Spec Sheets

Component	Spec Sheet
Zotac-ZBOX CI321 nano PC	https://www.zotac.com/us/product/mini_pcs/ci321-nano
Arduino Uno	https://www.arduino.cc/en/Main/ArduinoBoardUno
Mega	https://www.arduino.cc/en/Main/ArduinoBoardMega2560
IMU	https://www.sparkfun.com/products/10736 and https://www.sparkfun.com/products/9873
Motor Controllers	https://www.sparkfun.com/products/9670
Seabotics motor	
Gripper	https://trimantec.com/wp-content/uploads/2015/06/catalog-for-HFY.pdf
Marker Dropper Servo	


Motor A
Motor B
Motor Controller 1
Digital Pin 36
Power Pin 6
Digital Pin 37
Digital Pin 40
Power Pin 5
Digital Pin 41
+ -


Motor A
Motor B
Motor Controller 2
Digital Pin 29
Power Pin 2
Digital Pin 28
Digital Pin 33
Power Pin 3
Digital Pin 32
+ -

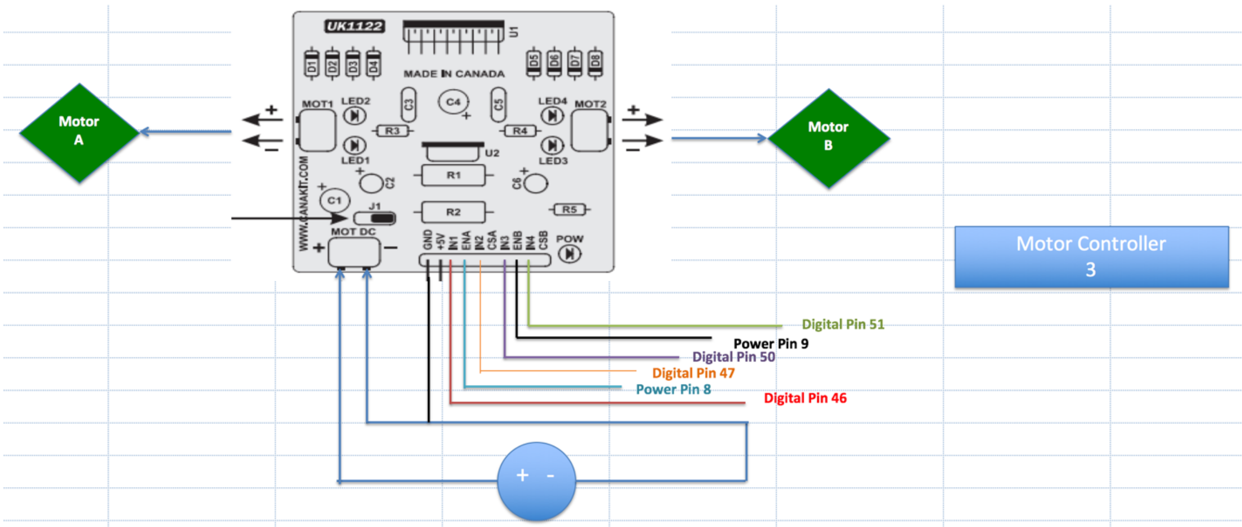


Figure 12: Motor Controller Wiring