FAMU-FSU College of Engineering
Department of Mechanical Engineering

Operations/Maintenance Manual

EEL4911C/EML4511C– ECE/ME Senior Design Project I

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Introduction

Team 21 in the senior design class assigned the Autonomous Robosub Project. The goal was design and build an AUV to compete in the 2013 AUVSI RoboSub competition. The submersible had to be completely autonomous and able to complete several tasks in a time limit such as line following, passing through a gate, shooting torpedoes, picking up objects, homing in on a pinger, and buoy ramming.

Although the AUV is to be autonomous and not human controlled during competition, the proper maintenance, setup, and fitting of parts and components must be meticulous and specific. This manual is a guide to the various components of the AUV, their assembly, their operation, and necessary maintenance.

Table of Contents

1. Function Analysis and Flow Diagrams

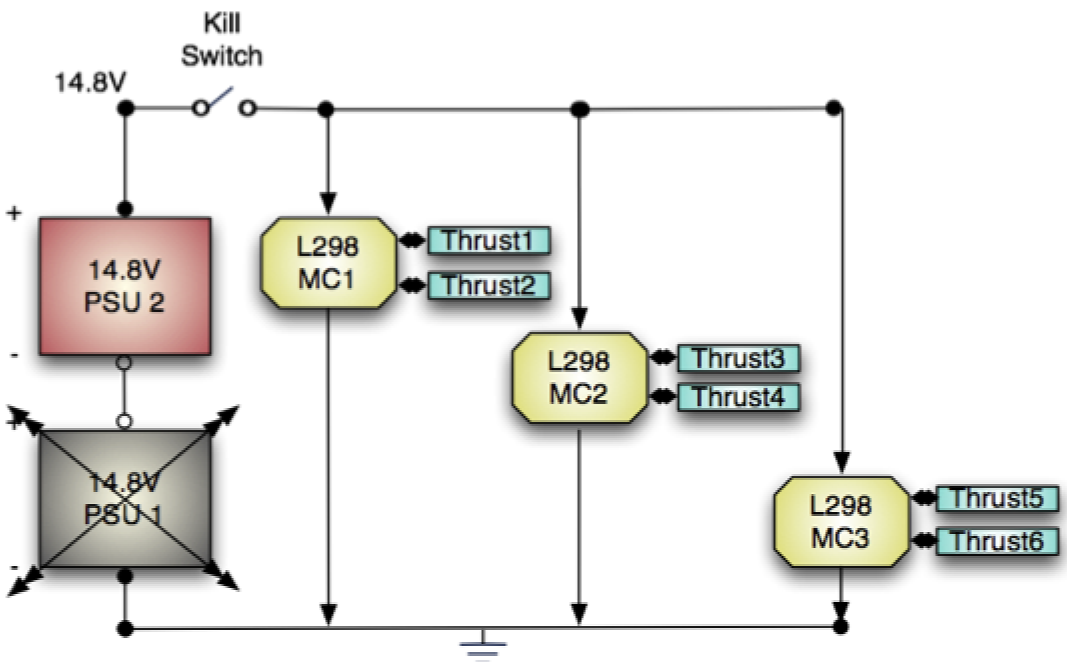

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Figure 1. Block diagram of power supply to thrusters. [PSU1 is a backup supply, not in use unless necessary]

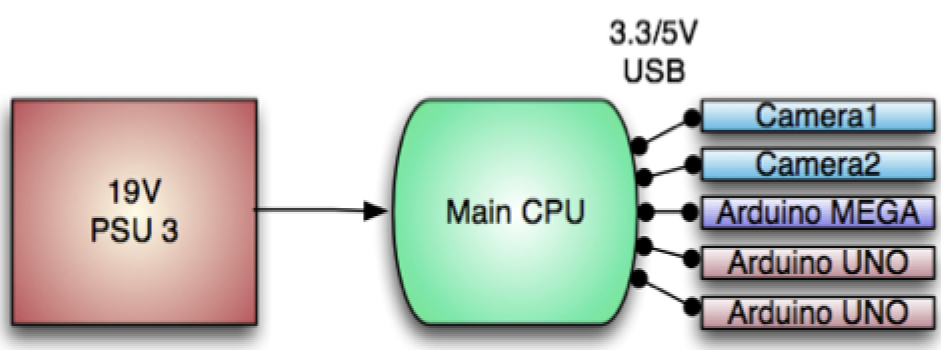

Figure 2. Block diagram of power supply to CPU and components

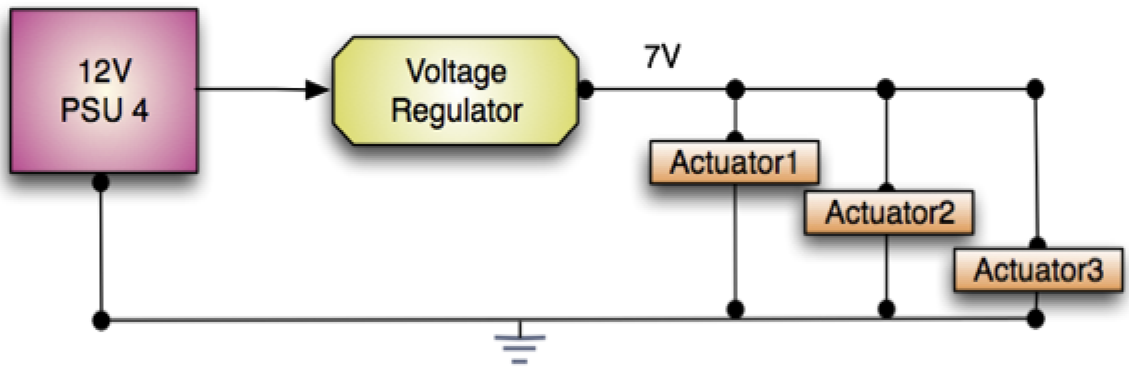

Figure 3. Block diagram of power supply to actuators

1.1 Electronics

The hardware required to control the AUV is comprised of a main control unit and many subsystems. Each subsystem is an entity within itself that is self-sustaining except for instruction from the main unit. Below is a basic block diagram illustrating how the electronics communicate with one another in their subsystems.

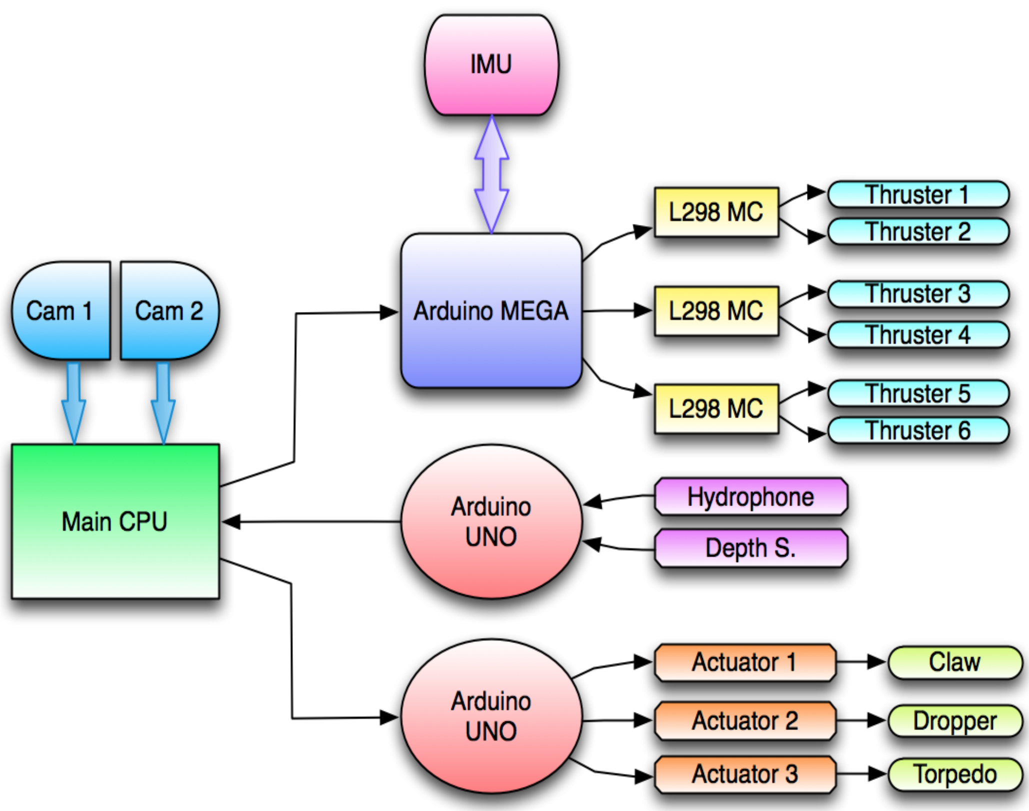

Figure 4. A simple block diagram of the proposed electronics system.

1.2 Electronics Housing (Hull)

The main design criterion behind the design of the electronics housing is the size. The size is an important factor in that it must be large enough to hold all the electronics hardware while having a minimal amount of free space, which will cause unwanted positive buoyancy. Limiting the size also decreases the amount of aluminum and in turn the total weight.

The electronics housing is an important factor in the AUV since it will be housing all of our electronic hardware and will need to be watertight to prevent water shorting the electronics. The waterproofing will be done by using an O-ring in a channel that will be cut using a CNC machine into the top part of the box. 1/4'' Bolts around an attached flange of the hull will cause sufficient force to prevent water leakage into the hull. 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, such as warping the boards, to large problems, such as completely destroying the board. The dissipation of the heat is the main design parameter that went into our choice of aluminum as the main body of the electronics housing.

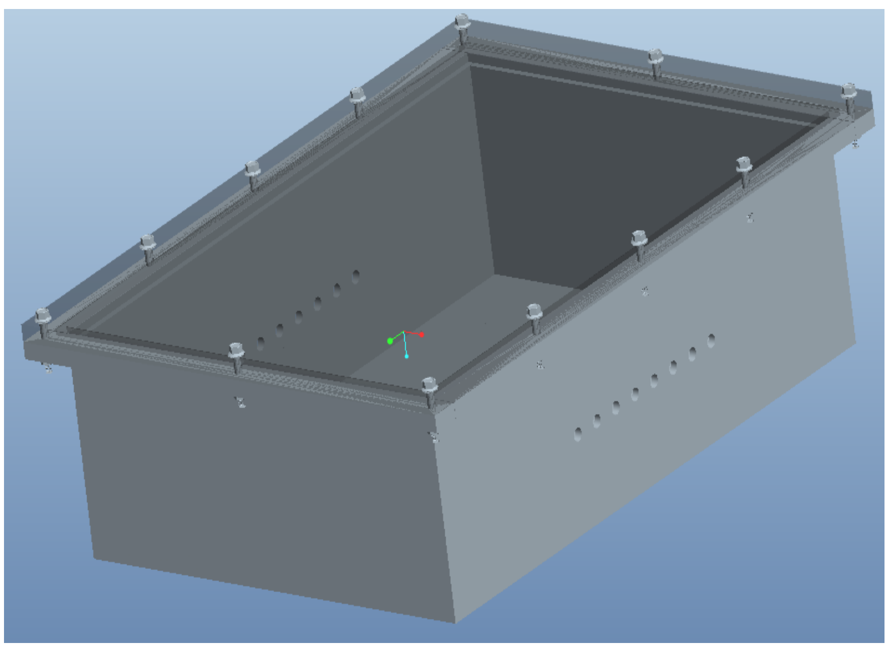

Figure 5. CAD model of Hull

1.3 Frame Structure

The frame structure will be composed of 80-20 aluminum bars. These bars have slots running the length of them allowing fasteners to be placed in them to screw down brackets and components. Arranging the components, such as the cameras, torpedoes, etc. , in a balanced manner will be crucial to the success of the robot. The external components will then be placed in key locations based on the center of mass of the hull and frame together. An image of the frame structure can be seen in Figure 9.

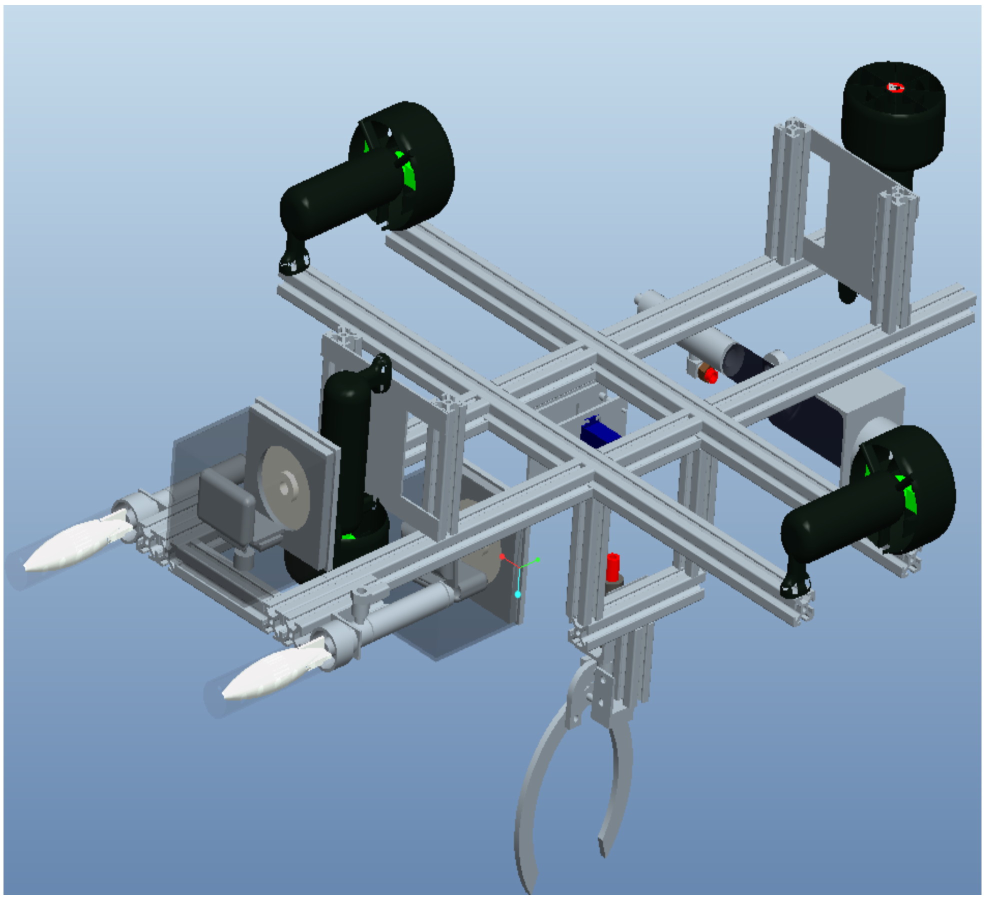

Figure 6. CAD model of framework and components

2. Product Specs and Performance

2.1 Power System

Each controller, sensor, actuator, and thruster requires a specific voltage and current to function. To achieve this, a power system has to be designed with the idea that it must be operated remotely; batteries will be required. Table 1 is a simple chart which shows some of the requirements needed for selected components of the AUV.

Component	*Maximum Current Consumption*	*Average Current Consumption*
Zotac PC Board (MPU)	3.5A	1.5A
Arduino(s)	.75A	.5A
IMU	.075A	.060A
Thrusters	12A	3A

Table 1 . Current consumption of electrical device

2.2 Main Processing Unit (MPU)

This unit is intended to handle all major communication between each peripheral device. Essentially this will handle data from all subsystems and manage communication between each of those subsystems. Also, this unit shall contain the implementation of the software system will provide the autonomous capabilities of the AUV. The selected device for this is the Zotac Intel Core i3-2330M ZBOXHD-ID82-U.

- CPU Intel Core i3-2330M Processor (2.2 GHz, dual-Core)
- Chipset Intel HM65 Express
- Memory:2 X 204- pin DDR3-1333 SODIMM Slots, Max Capacity of 16GB
- Hard Drive: Supports 1 X 2.5-Inch SATA 6.0 GB/s Hard Drive
- Ports: 4 X USB 2.0 Ports (1 front, 2 rear, 1 top); 2 X USB 3.0 Ports; 1 X Wi-Fi Antenna Connector; 1 X DVI Port; 1 X HDMI Port; 1x?Optical S/PDIF Out; 1 X RJ45 LAN Port; Audio I/O Jacks
- Carder Reader: 6-In-1 Card Reader, Supports MMC/ SD/ SDHC/ MS/ MS Pro/ xD
- LAN: Integrated Gigabit Ethernet Controller; 802.11n/g/b Wireless LAN; Bluetooth 3.0

Figure 7: Picture of Zotac MPU

2.3 Arduino UNO

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.

- Operating Voltage : 5V
- Input Voltage : 7-12V
- Digital I/O Pins : 14 (6 Provide PWM output)
- Analog Input Pins: 6
- DC Current per I/O pin: 40mA
- DC Current for 3.3V Pin: 50mA
- Flash Memory: 32KB
- SRAM: 2KB
- EEPROM: 1KB
- Clock Speed: 16MHz

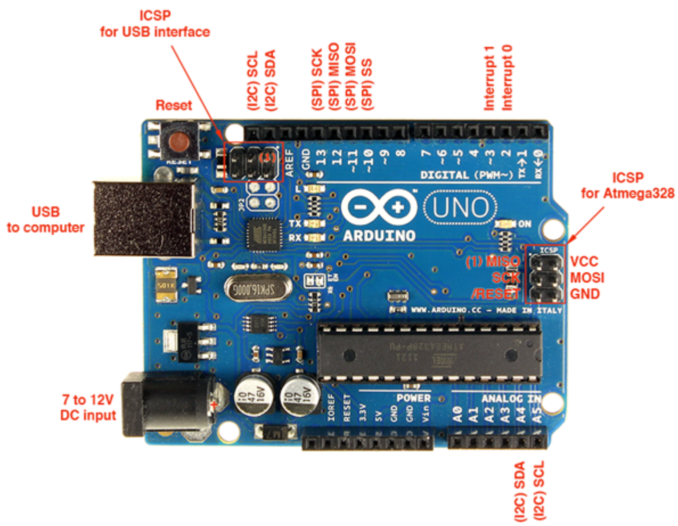

Figure 8. Arduino Uno Board

2.4 Arduino Mega

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.

- Operating Voltage : 5V
- Input Voltage : 7-12V
- Digital I/O Pins : 54 (15 Provide PWM output)
- Analog Input Pins: 16
- DC Current per I/O pin: 40mA
- DC Current for 3.3V Pin: 50mA
- Flash Memory: 256KB
- SRAM: 8KB
- EEPROM: 4KB
- Clock Speed: 16MHz

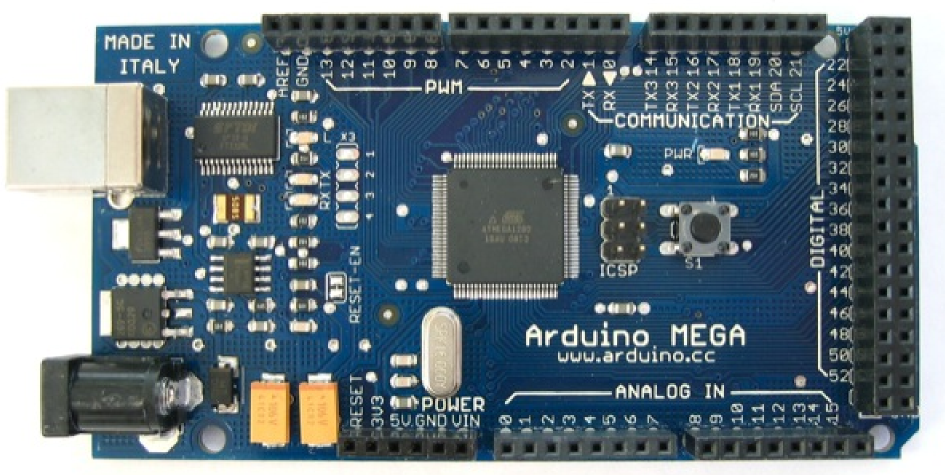

Figure 9. Arduino Mega Board

2.4.1 Inertial Measurement Unit

The IMU is used to stabilize the AUV when it is submerged in water. This is necessary so that the vehicle does not become unbalanced, which can cause many problems in designing and testing the movement system. Without such a system, the AUV not be able to move around stably. Here are the specifications for the chosen IMU:

- 9 Degrees of Freedom on a single, flat board:
    - ITG-3200 - Triple-axis digital-output gyroscope
    - ADXL345 - 13-bit resolution, +16g, triple-axis accelerometer
    - HMC5883L - triple-axis, digital magnetometer
- Outputs of all sensors processed by on-board ATmega328 and sent out via serial stream
- 3.5-16V Input

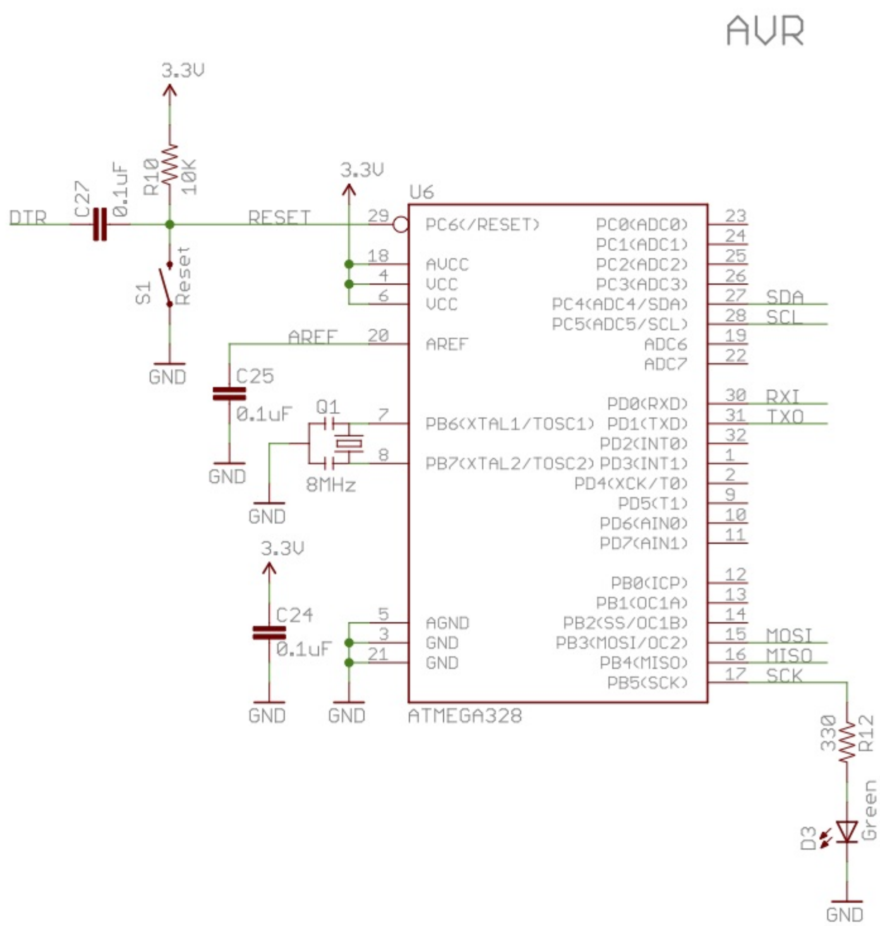

Figure 10. ATmega328 Schematic

2.4.2 Motor Controller- L298

To control each thruster an L298 dual H bridge driver is selected for interpreting the PWM signal from an Arduino. Essentially, each thruster is given a duty cycle range to accompany the necessary voltages the thruster requires to speed up and slow down. To control this, an Arduino will send PWM signals to the motor driver, where it will then take the voltage from the batteries and adjust the voltage output according to the duty cycle designated by the Arduino controllers. Two different motor controllers were used, one manufactured by Solarbotics, and another by Canakit. The Solarbotics motor driver is red while the Canakit is blue, however, they have similar specifications.

- Operate at input voltages of 6 to 26V
- 4A Total Drive Current (2A per channel)
- Requires 5V for board power
- Motor Direction indicator LEDs
- EMF Protection diodes

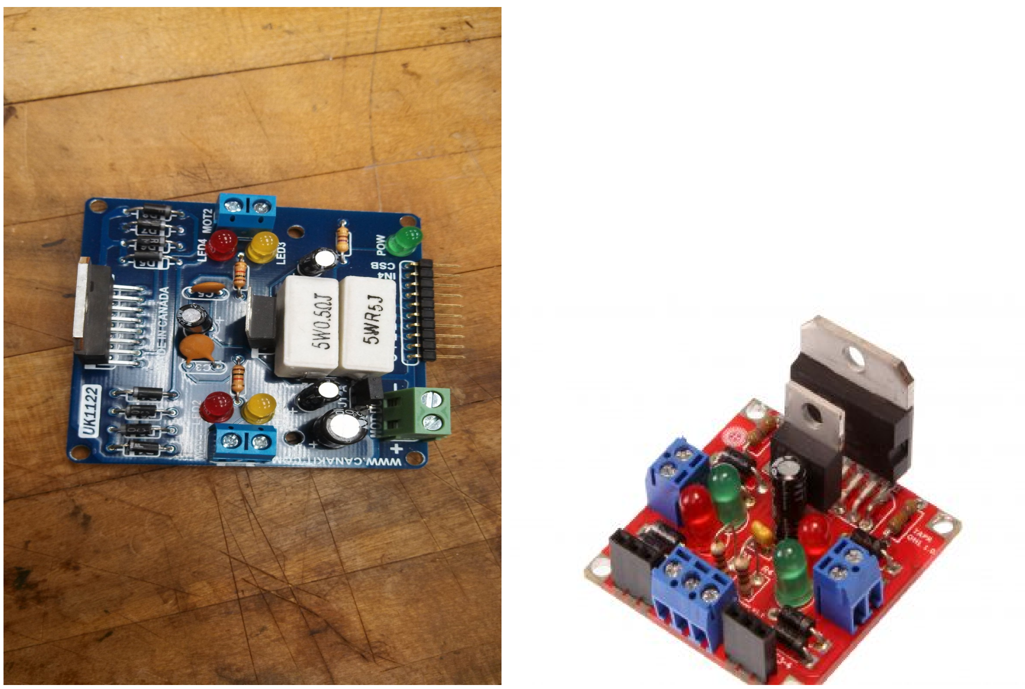

Figure 11: Picture of the two different motor controllers being used, the Canakit to the left and the Solarbotics to the right.

2.5 Batteries

2.5.1 Thruster Power

Several batteries were used to power the AUV's several systems. A 14.8V Li-ion battery will be used to power the 6 seabotix thrusters being used.

Figure 12: Picture of Li-ion battery

2.5.2 MPU Power

The Main Processing Unit is powered by a 16/19V Switchable laptop battery. This system also powers many of the subsystems such as the 5V needed by the arduino systems.

- Capacity: 4000mAh (made by 8 pcs 2.0Ah 18650 Li-Ion inside)
- Running time: 2- 3 hrs depended on laptop model
- Battery Chemistry: Lithium Ion(Li-ion)
- Input: DC16.8V/1.5A
- Output: 16V and 19V DC switch selectable according to your battery.
- Max. Discharging: 3A
- Dimension: 155x100x23 mm
- Weight: 2.8 lbs (1270g)

2.5.3 Actuator & Future Power

The third battery is used for powering the actuators, however it outputs a regulated 12V which is a standard voltage for many voltage regulators. This battery was selected in case any future components required power or if we ran out of possible output ports for the arduino's from the MPU power source.

- Capacity: 77 Watts hours(14.8V 5.2 Ah, 2600mAh 18650x8 cells inside)
- Running time: Dependent on load
- Battery Chemistry: Lithium Ion(Li-ion)
- Output: 12V/13.2V Switchable
- Max. Discharging: 4A
- Dimension: 127x80x43 mm
- Weight: 1.0 LB (670 gram)

2.6 Logitech C615 webcams

The vision system uses last year's Logitech C615 webcams. The choice of camera is of some importance, as they must be supported by the primary camera drivers available on Ubuntu, the AUV's operating system. OpenCV is used to implement the vision processing system. OpenCV is an image processing library used throughout scientific literature and by several other teams in the AUVSI competition. Last year's senior design team also used OpenCV, and this year's team aims to build upon their design. The built-in functionality included with OpenCV will greatly ease the task of detecting and tracking objects throughout the course.

- Full HD 1080p video capture (up to 1920 x 1080 pixels) with recommended system
- HD video calling (1280 x 720 pixels) with recommended system
- Logitech Fluid Crystal™ Technology
- Autofocus
- Photos: Up to 8 megapixels (software enhanced)
- Built-in mics with automatic noise reduction
- Hi-Speed USB 2.0 certified (recommended)

Figure 13: Logitech c615 webcam

2.7 Mechanical Subsystems

2.7.1 Air Release Actuators

The pneumatic actuators are used for controlling the claw grabber and the torpedos. Each actuator requires a 12V input to actuate. The 12V signal will be controlled by an Arduino, but the voltage input will be taken from the 12V battery designated for the electronics. The voltage is regulated using a Canakit motor driver outputting a PWM signal with 100% duty. Four actuators will be used, two each controlling a torpedo launcher and two controlling the opening and closing of the claw mechanism.

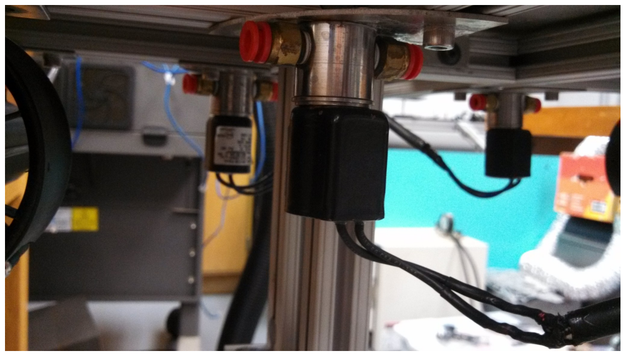

Figure 14: Picture of attached actuator

2.7.2 Torpedo Launchers

Two torpedo launchers are mounted on the front of the submersible and fire two 3D printed torpedoes. They are custom built using an air pressure launcher made by Bimba, a piston launcher with a magnet to hold the torpedoes against the piston, and a plastic tube to hold the torpedoes in place until firing. The compressed air released through the control valve will cause the air cylinder pistons to extend (approximately 2.5"). The two torpedo launchers are identical and have been developed to shoot the torpedos through needed targets in the competition. They are located on opposite sides of the vehicle for symmetry and stability. The torpedo firing velocity is calibrated such that it will not cause injury to humans.

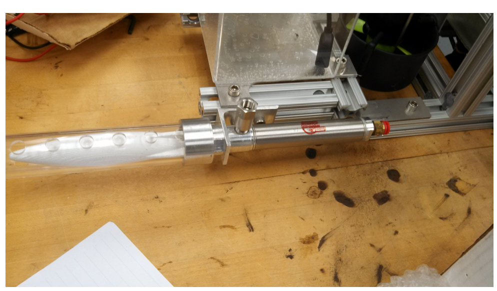

Figure 15: Picture of Torpedo Launcher and Torpedo

2.7.3 Air Tank with Regulator

A 750 mL air tank is used to supply the air pressure to actuate the claw and torpedo launchers. A regulator is used in combination with the air tank to reduce the air pressure from an initial 850 psi to a desired operational level of 100 psi. A multi directional separator hose connects the regulator to the separate components. The hose used for all the air travel is rated at 250 psi The air tank is detachable and can be refilled at a local scuba shop when empty.

Figure 16: Air tank with regulator

2.7.4 Marker Dropper

The marker dropper subsystem was inherited from FAMU-FSU 2010 Robosub team. An aluminum housing with an attached servo motor will be able to move a servo arm pushing the markers (miniature stainless steel balls) out when signaled. The servo motor is connected directly to the Arduino Uno.

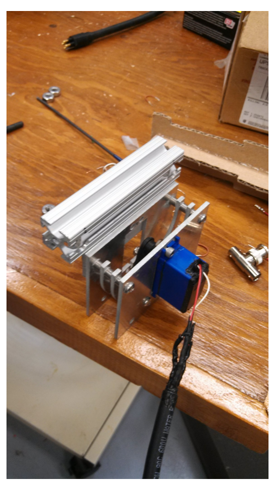

Figure 17: Picture of marker dropper

2.7.5 Claw Mechanism

The claw mechanism is a custom built component inherited from last year's team. The claw is powered by an air actuator which is fed into a tri-junction air tubing. A 12V signal triggered by the Arduino causes a valve to open and air to force the claw to close. To release the claw, a signal is sent to the exhaust actuator which is connected to the tri-junction connector, releasing the built-up air. The claw itself will protrude from underneath the AUV about 16'', giving plenty of clearance space between the object and AUV.

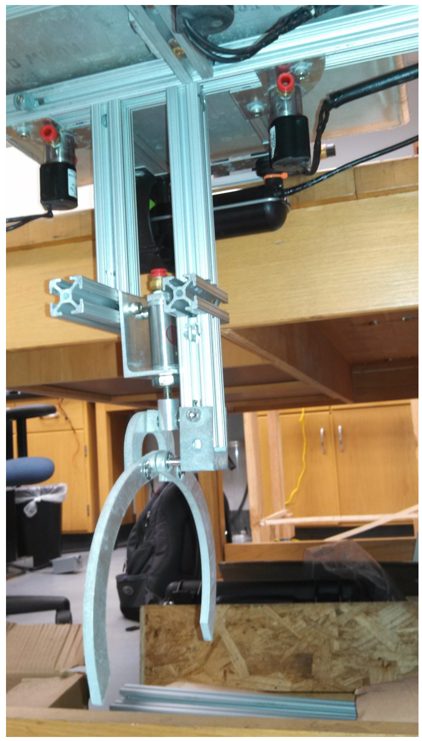

Figure 18: Picture of Claw actuator

2.8 Sensor Subsystems

2.8.1 Hydrophones

Four SQ26 Seismic and Towed Array Hydrophones are used to complete the task of following a pinger. These hydrophones are low cost , have good sensitivity, and are very stable.

- Voltage sensitivity: -193.5 +/- 1.0 dBV @20deg C
- Frequency response: flat from 1Hz to 28,000Hz
- Mass: 16 grams
- Water blocked leads
- Operating depths: down to 2,000 meters

Figure 19: Picture of Hydrophones

2.8.2 Depth Sensor

The depth sensor utilized on the AUV is IMCL Submersible Level Transmitter - Ceramic Sensor. It is a ceramic, piezo-resistive hydrostatic level measurement device. The variant used is the 4-wire version, featuring two supply pins and two output pins. There are three versions of 4-wire variant with different input and outputs. A table detailing these inputs and outputs is below.

Supply	2-30V DC	2-12V DC	3-12V DC
Output	Passive mV/V	2mV/V	10mV/V

Table 2: Depth Sensor Specs

It has yet to be determined which input and outputs are used by the team's depth sensor. In the case of the passive response, a table is provided in the product documentation detailing the outputs at various pressures.

2.8.3 Thrusters

The AUV uses Seabotix SBT150 with the electronics removed and Seabotix BTD150 thrusters for propulsion. Both types of thruster are capable of delivering almost 3 lbs of thrust apiece. With the electronics removed, there is no difference between the two and they perform the same given the PWM signals from the motor controllers. The thrusters have been shown by the team to be safe for operation in air up to half their maximum current rating.

The maximum current draw of the Seabotix thrusters is 4.25A. As such, it is essential to ensure that the current draw of the thrusters does not exceed the current rating of the motor controllers. Students at Washington State University and the University of Idaho have characterized the thrust-to-voltage relationships of the thrusters complete with the current draw. These relationships have been included in the appendix. Since the thrusters may behave differently than predicted, care should be taken to operate at a PWM voltage lower than what would draw the maximum current the motor controller can handle.

Figure 20: Picture of Seabotix thruster

3. Steps for Operation and Shutdown

The AUV was created in order to perform a specific set of tasks autonomously purely for competition, so it’s operation is fairly simple. After loading the intended code on the main computer, fastening the lid down properly, and ensuring all wiring is safely connected the AUV is ready to be put in the water. Once put at the start of the competition course the kill switch should be flipped. The AUV will then perform all of its preprogrammed tasks using the visuals it is constantly receiving from the camera. No human interaction is required until the desire of stopping the AUV is wanted. The kill switch is then flipped and the AUV will no longer actively move. It can then be safely removed from water and reused when needed. It is advised to rinse the sub with fresh water after a test in chlorinated water or salt water to prevent the corrosion of external components

4. Required Assembly

The AUV will come with all of the major components already attached to the frame. The frame comes pre-assembled with equal balancing of equipment for balance. th It is possible for the user to change the location of these major components with the use of hex wrench. Proper wiring of the electrical controllers, batteries, and computer is next. Finally sealing the lid down on the hull of the sub is required. To do this all the user should need is the 3/16" allen wrench, included in the set for the ¼" thread bolts, and the 5/32(4mm) allen wrench, included for the 8020 t-slot connectors. Once the user has ensured that all components are tightly attached to the frame they can move on to the next step, attaching and wiring the "brain" for the AUV.

4.1 Attaching SEACONs and connecting cables

The first step is to connect the wiring of outside components to electronic controllers inside via SEACONs. SEACONs are the wet-dry connections for the AUV and are used to connect the outside components with the inner electronics, and are the same connectors that the Navy uses. The SEACONs can be attached using the adjustable wrench, make sure that the SEACONs are placed in the proper order for different components require different SEACON plugs. The order can be seen in the figure below. Ensure that the SEACONs are tightly secured to the wall of the AUV so that water cannot leak inside.

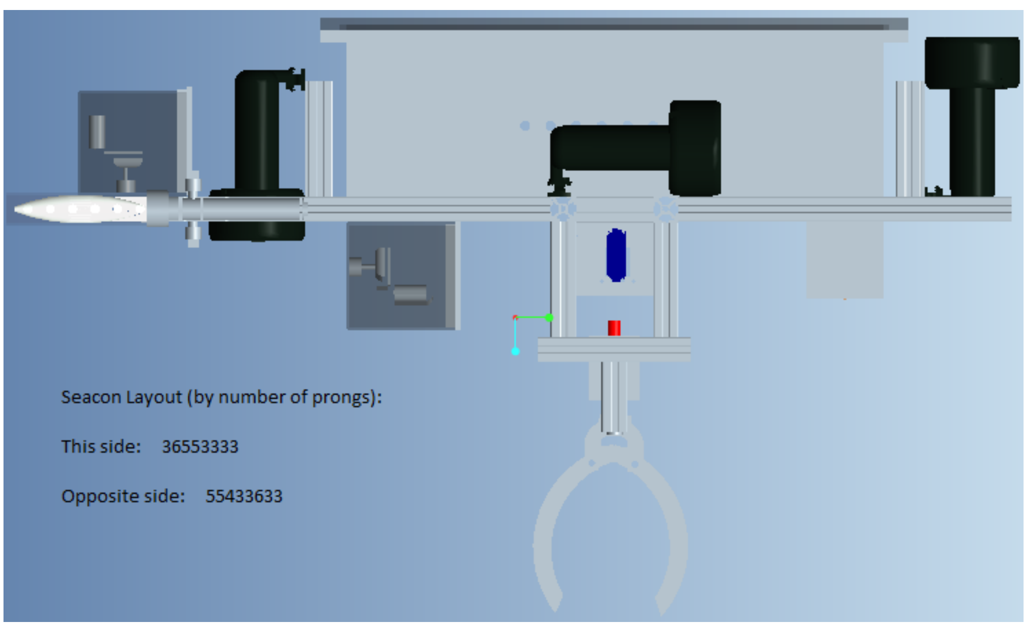

Figure 21: Seacon layout Diagram

4.2 Attachment of air tubes from tank to actuators and to components.

Once the SEACONs are attached it is then advised that the air hose be attached. be sure to attach the air hose properly, as described to ensure safe use of the compressed air. The air lines connect from the exit of the quad- junction to three of the four solenoid valves. Two lead directly to the solenoid valves of the left and right torpedo, the other leads to a tri-junction. One path of the tri-junction routes the air to the inlet of the single-acting air cylinder of the grasp/release mechanism, which allows the claw to open. The other tri-junction route leads to the inlet of the exit solenoid valve, which when actuated releases the air in the hose to the claw allowing it to close again.

4.3 Wiring of electronics

The AUV propulsion control system consists of the Arduino Mega, 3 Motor Controllers, and an IMU. Once the components are gathered, the user will need to use the wiring diagram illustrated below. Soldering will be necessary to ensure that the connections are permanent and will not be disrupted during operation.

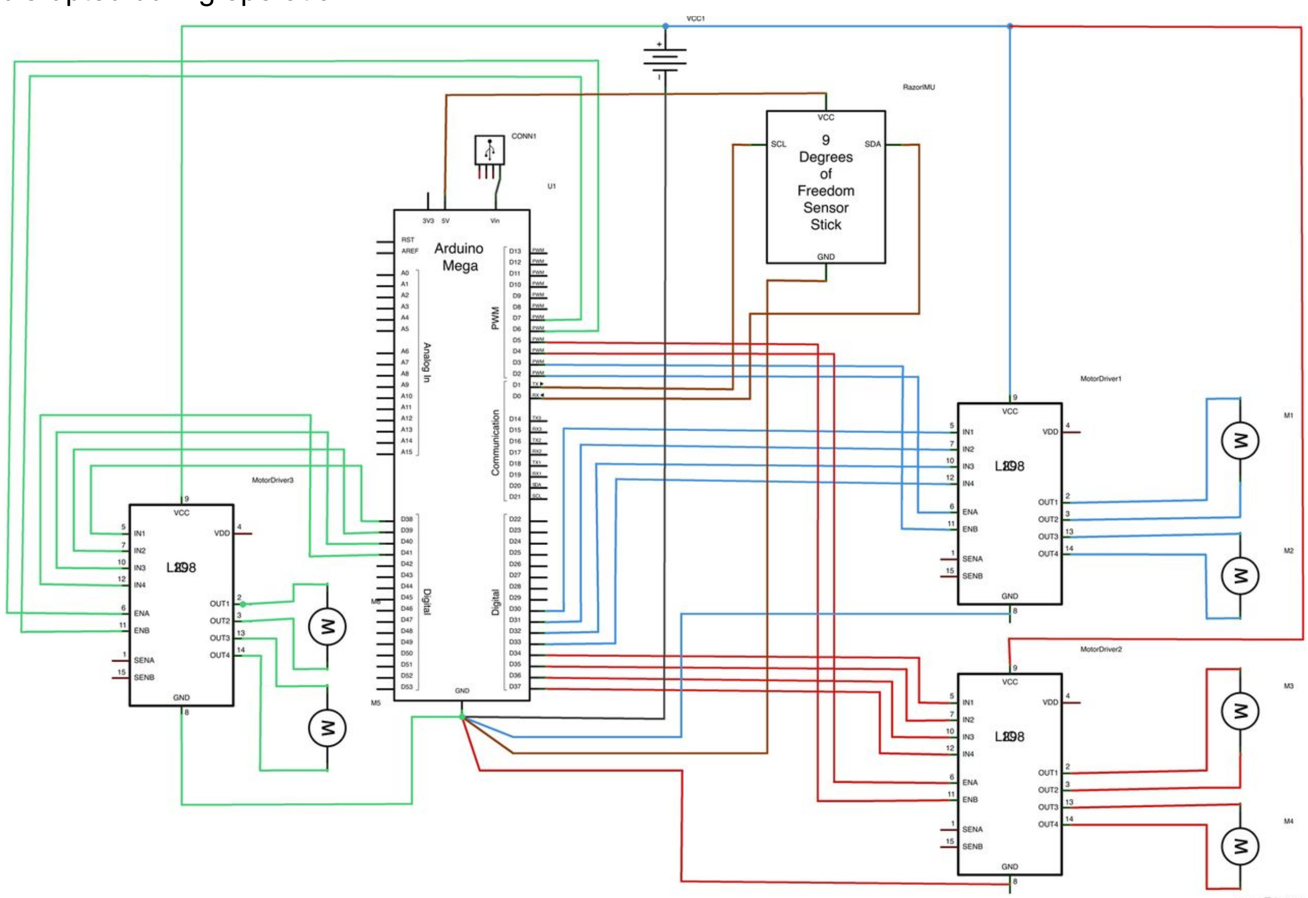

Figure 22: Wiring Diagram of Controllers

4.4 Sealing the Hull

After proper placement of the electronics and all other necessities inside the electronics housing, the next step is to tighten down the lid using bolts and nuts. The bolts are ¼" thread and can be tightened using a ¼" wrench, but the nuts are oversized nuts and require a ½" wrench. ¼" washers also rest between the bolt and the lid better distribute force. When tightening the bolts ensure that the O-ring attached to the lid if firmly pressed. However, too much tightening can fracture the lid, so caution is required. Tightening the corner bolts and then proceeding to tighten the in-between bolts is the preferred method of bolt tightening.

5. Problems and Troubleshooting

With such a complex system there are a plethora of problems that can occur. The biggest problem that can occur is that the lid is not properly sealed and water is able to get into the electronics hull. Testing the watertightness of the hull can be done by submerging it underwater without electrical components inside, leaks can be spotted without damaging equipment. If the problem of a component coming loose from the frame occurs, the simple solution of bolting it back on is required.

Much of the troubleshooting with the AUV will come in the form of debugging coding. To ensure proper commands to respond to the AUV's dynamically changing location and needed action is a labor intensive effort. Continual testing, measuring, and calibrating the desired speed and decision making commands is the only way to solve this problem.

6. Regular Maintenance

Maintenance of the AUV is minor. After practice or competition trials the AUV should be rinsed and dried off to ensure no harmful chemicals or rust from the pools will damage the exterior. The air tank will need to be refilled after several uses and can be easily done so at a scuba shop. After a fair amount of usage time, all batteries will need to be recharged for a few hours. Most or all of the controllers and motors will be running at around 50-75% max rating, so there is little fear in overheating and burning out components.

7. Future replacement and repair notes

Replacement parts for the AUV can be ordered online from the listing of components in the previous sections. If the sealant on a camera box breaks down, more sealant is available and repair requires scraping off the old and applying new sealant. If the water tight casing for the wiring breaks down, a small can of plastic layering is available to apply a new layer.

8. Future spare parts that may be needed

Future spare parts that may be needed for testing and competition are few. More electrical wiring may be needed if some wires break or the electronic arrangement is redone. More air hose tubing would be required if a new layout for the pneumatic system is wanted. An underwater pinger system would be necessary to test the hydrophones and pinger following commands. Other competition test equipment such as underwater shapes, rings, boxes, buoys, and paths would be greatly helpful in mimicking competition conditions.

Appendix

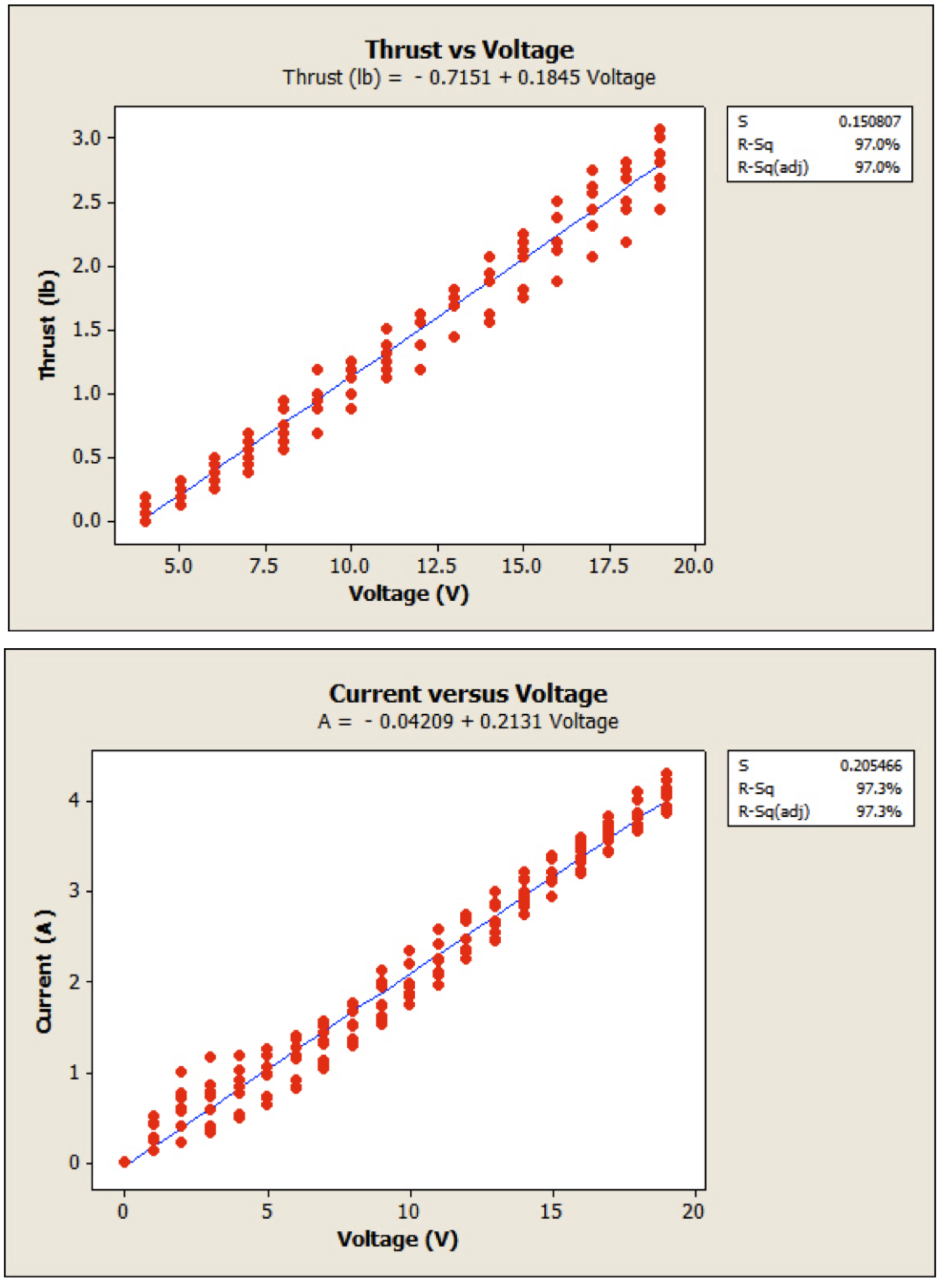

Figure 23: Thrust vs. voltage and current vs. voltage plots for the Seabotix thrusters