FAMU-FSU College of Engineering
Department of Mechanical Engineering

Final Design Report
EEL4911C/EML4511C– ECE/ME Senior Design Project I

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Submitted in partial fulfillment of the requirements for
EML4511C – ME Senior Design Project I
EEL4911C – ECE Senior Design Project I
April 16, 2013

Executive Summary

The main objective of the FAMU-FSU 2012-2013 RoboSub Team is to participate in the AUVSI Foundation and ONR's 15th International RoboSub Competition. The competition is held in the TRANSDEC pool in San Diego, California and consists of a practice round, a first round, and a final round. Before the competition begins, each AUV (Autonomous Underwater Vehicle) will be inspected by the judges of the AUV competition to make sure that they do not pose a serious risk to TRANSDEC, other competitors, or the swimmers following the AUV. The judges will also be checking that the AUV is within the size, weight, and density restrictions that have been set forth. Once the AUV has been cleared by the judges they will then allow the AUV to compete in the competition.

The current design was conceived with the aim of developing a robust and flexible system. It achieves this through simplicity. The hull that will contain the electronics is a rectangular box with a lid affixed with bolts. The frame is both lightweight and functional as it uses a minimal number of parts and does not obstruct the lid, but still has enough mounting points for all necessary thrusters, sensors, and actuators. In addition, the new mechanical design will only incorporate five thrusters instead of six while still maintaining a similar level of control. These alterations combine to produce a lighter and more accessible design.

With regards to the electronics, we have greatly simplified the power system. The new design utilizes a separate battery for each major electronic subsystem, eliminating many issues with voltage regulation that were present in the previous design. Much of the hardware has been replaced: there is a new PC, and the Arduino Unos will be accompanied by an Arduino Mega which will control all AUV motions. The Arduino Mega controlling the thrusters will allow the AUV to maintain constant balance in conjunction with an inertial measurement unit (IMU).

This year’s design was designed with longevity in mind. A robust and well-documented vehicle will not only provide a better chance of being ready for the upcoming presentation, but will be more suitable for modification and improvement in future years.

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1 Introduction

As time has passed the Robosub senior design team has covered much ground in completing tasks to reach its final goal of having a working AUV for the AUVSI RoboSub Competition. Following the competition rules that are posted on the AUVSI website, the team has created plans for an AUV that will be able to operate and succeed within the competition guidelines. A new electronics housing and framing structure was designed and a detailed electronics system has been formulated to handle the communication of tasks among components. Vision software has been chosen, installed, and is currently being worked with to use it to its maximum potential. The electronics system and mechanical components are being supported by a sufficient power system. Several of the mechanical and electrical components have been tested and confirmed of their functionality. Risks involved in the project have been taken into consideration and much has been done to avoid possible pitfalls. Scheduling for the project requires much more work to be done in the spring semester in order to have a working product to compete with.

1.1 Acknowledgements

The 2012-2013 FAMU-FSU RoboSub team would like to acknowledge the following individuals for their continuing contributions to the project:

- Dr. Shih for providing funding via the Naval Engineering Education Center to complete this project.
- Dr. Jonathan Clark for advising the team on technical details, as well as advising on effective presentations and reviewing the team's written documents.
- Dr. Harvey for advising the team on technical details, as well as reviewing written documents for the team.
- FAMU- FSU COE Stride Lab for providing working and storage room in its lab.
- Dr. Frank for instruction on how to present effectively and create thorough written documents, and technical details.
- Ryan Kopinsky for information regarding components and software from last year.
- FSU Morcom Aquatic Center for providing their pool to be used for testing purposes.

1.2 Problem Statement

The current design team inherited a project that had some functionality but still needed significant modifications. The hull for the electronics served its purpose, but it was extremely complicated and time consuming to access. The frame on which the hull and the components were mounted proved to be unbalanced which affected the navigation of the robot in the water. The overall weight of the vehicle was also several pounds over the target weight. The functional software for the design was limited to a demonstration which made the vehicle submerge and move around in a predetermined manner. This code was effectively unusable for the current team, because it lacked the structural support for the artificial intelligence necessary for the competition. This year, the team aims to redesign many of the AUV's components and software for robustness and to address the programmatic requirements of the competition.

To address the issue of the hull, a new one will be designed, giving ease of access higher priority than in previous years. The main focus of the hull design will still be the waterproofing and pressure bearing aspects, but this will be designed around a different method of disassembly which prioritizes simplicity and minimal interaction with the mounted components. To have a more balanced, lightweight frame, the components will be relocated and the layout of the 80/20 aluminum that is being used will be changed. A new software design will be developed and implemented such that it provides the decision making, image processing, and motion control capabilities that are needed for the robot to compete successfully.

1.3 Operating Environment

The AUV will operate submerged in a saltwater pool at the TRANSDEC facility in San Diego. The TRANSDEC facility is a 300 ft by 200 ft by 38 ft deep pool containing 6 million gallons of chemically treated salt water which will be comparable to oceanic conditions. The temperature of the pool is isothermally maintained and should therefore should not adversely affect the performance of the AUV. The pool will be still and should have no waves disrupting the movement of the vehicle. The clarity of the water in the pool is anticipated to be excellent for camera and vision equipment. However, TRANSDEC is an outdoor facility, so adverse weather conditions may be a possibility during competition.

A hazardous environment will exist during transportation of the AUV to the TRANSDEC facility in San Diego in which it will have to be shipped in a 6 ft by 6 ft by 3 ft box. Testing of the AUV will take place at the Morcom Aquatics Center pool at the Florida State University. The Morcom pool is chlorinated fresh water, which is less dense than salt water. As a result, the AUV will be less buoyant during testing than it will be during the competition.

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

The intended use for the AUV is to compete in the annual RoboSub competition hosted by the Association for Unmanned Vehicle Systems Integration (AUVSI) and United States Office of Naval Research (ONR). The competition will consist of the AUV submerging, passing through a gate, following a obstacle course, dropping markers into specified containers, shooting torpedoes into specified targets, grab an object from the floor of the pool, carry it up and surface into a designated area then drop the object. These tasks are based on the information that is currently available and the only tasks that will be designed for at the current time. This is subject to change pending the release of the rules for the 2013 competition.

The AUV is autonomous, so the users will only be working to program and build the AUV before the competition, and it will operate by itself during the competition. The intended users of the AUV are the team members who built it, and possibly future team members who become involved with the project later. All users are expected to have an in-depth understanding of the required engineering principles to understand the design of the AUV.

In addition, the vehicle will be closely followed by AUVSI divers to ensure safety of the vehicle and the

TRANSDEC facility. As such, the AUV must incorporate certain features to ensure the safety of these divers. These safety features will be discussed in detail later in this report.

1.5 Assumptions and Limitations

The electronics housing will be made of 6064 aluminum in the shape of a box with a clear polycarbonate lid. The aluminum sides and base plate and the polycarbonate cover will allow for observation of the electronics housing without necessitating disassembly. The housing will be made watertight through the use of a groove cut into the polycarbonate cover and an O-ring placed inside that slips onto the aluminum plate walls. A total of 12 bolts will be drilled through the edge of the polycarbonate lid and edge of the box, firmly forming a tight seal around the perimeter of the lid.

There will be only one electronics housing for the AUV. The outer frame will be made from the 80/20 inch solid aluminum T-slots used in the previous RoboSub. The cameras, marker dropper, claw, torpedoes, compressed air tank, thrusters, batteries, and actuators will be used from the previous year's sub. These components will be bolted to the frame and water sealed properly.

For power distribution to the various electrical systems, off-the-shelf voltage regulators will be used and the electronics housing will be large enough to include all batteries required.

The primary size requirements are the following: the weight must be under 125 lbs or immediate disqualification will occur, the robot must be fully autonomous, and the robot must not exceed 6 feet by 3 feet by 3 feet. The AUV must be able to complete all challenges within a 15-minute time limit. Additional limitations apply in the form of time constraints imposed by the senior design course schedule and budget limitation due to limited funding sources.

1.6 Expected End Product and Other Deliverables

The end product of this project should be a completely autonomous unmanned submersible vehicle. It should be capable of submerging, entering through a gate, following a obstacle course via colored paths, dropping markers into specified containers, shoot torpedoes into specified targets, grab a specified object from the floor of the pool, carry it up and surface into a designated area then drop the object. This project's deliverable, the AUV, is a competition based product and is only being designed to complete these predetermined tasks.

Other expected products of the AUVSI RoboSub competition are a team website, a journal paper, and an introductory video of the team. The team website should consist of a layout of the team's work in building the AUV that is accessible to the public. The journal paper should be a technical paper explaining the operations of the team's AUV. The introductory video should be a short and riveting video to introduce the team and their competing AUV. The due date for the paper, video, and website is July 1, 2013 and the set competition date is July 22-28, 2013.

1.7 Safety Precautions

Proper safety precautions must be taken when designing and building any engineering project. The AUVSI competition rules set some safety standards for all competing AUV's. Each AUV must have an emergency kill switch that is easily accessible to the surrounding divers following the AUV. This is to ensure that the judges can power down the AUV at will. For the torpedo system, AUVSI requires that the torpedo launchers fire their payload at a low enough impact rate to not cause bruising on a person. Safety shrouds covering the blades on all the thrusters to ensure the blades cannot harm the divers following the AUV.

To ensure the safety of the components inside the electronics housing, several things were done. A rigid exterior frame and hull made of strong aluminum will withstand any minor force that the AUV could encounter. Along the lid of the housing, a watertight O-ring firmly creates a barrier stopping water from entering. Finally, separating each power system as a last precaution will allow only sectional damage if water does enter the housing.

1.8 Environmental Concerns

Environmental impact is concern that must be planned for and minimized in any scenario. The AUV will have standard, non-toxic aluminum for the hull and housing. The sealants used around the secant holes are also non-toxic to the environment. Proper care must be taken to properly dispose of the batteries used to power the AUV. During the duration of this team's involvement with the AUV these batteries will still be usable; however, in the future years senior design teams must properly dispose of the batteries. When the aluminum parts of the project are no longer needed, they need to be properly recycled at an appropriate facility.

2 System Design

The following section will discuss the various subsystems and components of this year's design and how they will work together to achieve project goals. The chosen design emphasizes robustness, flexibility, and simplicity and seeks to eliminate issues with the previous model with a nearly complete redesign of all systems. Major changes from last year's design include an entirely new hull and frame with an unobstructed lid for easy access, individual power networks for each electrical subsystem, and a more integrated control system. These changes allow the new design to achieve all design goals while reducing weight and complexity.

2.1 Overview of the System

The primary criterion of the mechanical design was the development of a reliable housing for electronics as well as mounting points for all other components that are needed to accomplish the tasks that will be set for the competition. Figure 1 shows the CAD drawing of the the AUV design. The main components were available from last year's built robosub. These includes the thrusters, torpedo launchers, claw attachment, marker dropper, cameras and their waterproof cases, the actuators used to control the claw and torpedoes, and the 80/20 aluminum that makes up the body of the frame. The electronics hull is a completely new design compared to last year's team and improves on many faults that design had. These issues will be discussed in later sections.

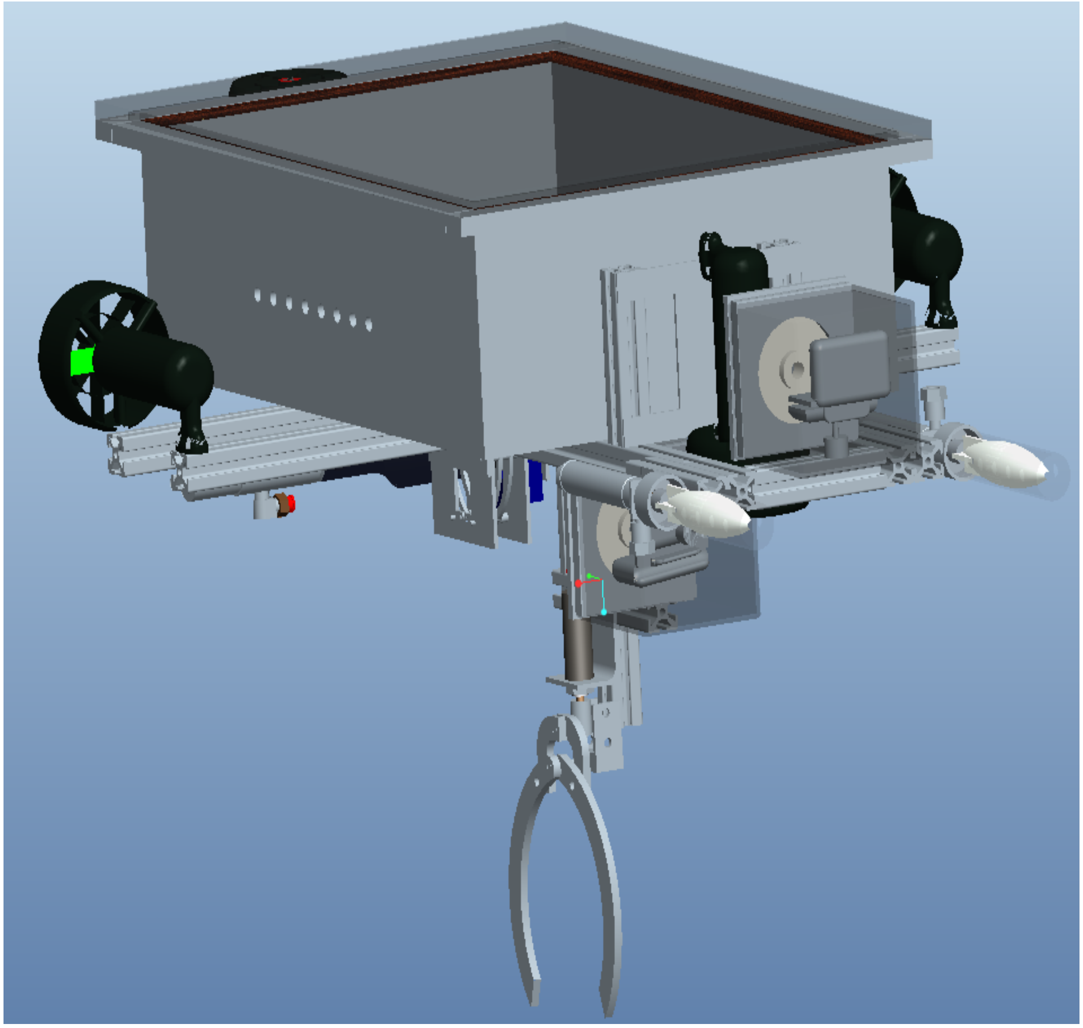


Figure 1. CAD model of final design

The main parts of the electrical subsystem are the top level controller, vision system, and the electronics hardware. The computer vision makes use of an open source vision software called OpenCV. This software allows the computer to recognize different shapes and colors that the camera picks up using a database that can be expanded for the uncommon/specific shapes that we will need for the competition. To make it easier for the computer to communicate with OpenCV, Robot Operating System (ROS) is used. It has a built-in support for OpenCV and common robotics capabilities.

The top level controller is in charge of the decision making of the AUV. This will be done through a state machine. Each task will be a state with sub-state to control individual actions of the AUV during each task.

The electronics hardware is an integral part of the AUV. The main components of the electronics hardware are 3 Arduino Unos, an Arduino Mega, and a mini-PC running Ubuntu 12.04 Linux.

2.2 Major Components of the System

2.2.1 Power System

Each controller, sensor, actuator, and thruster requires a specific voltage and current to function. To achieve this, a power system was 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	3.5A	1.5A
Arduino(s)	.75A	.5A
IMU	.075A	.060A
Thrusters	12A	3A

Table 1. Current consumption of electrical devices.

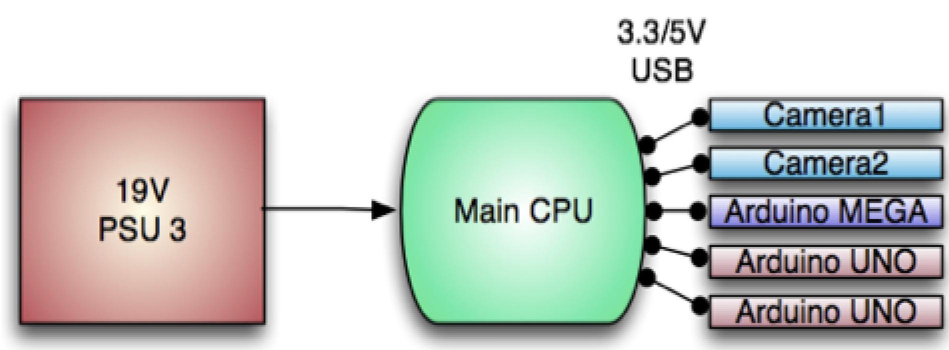


Figure 2. Block diagram of power supply to thrusters

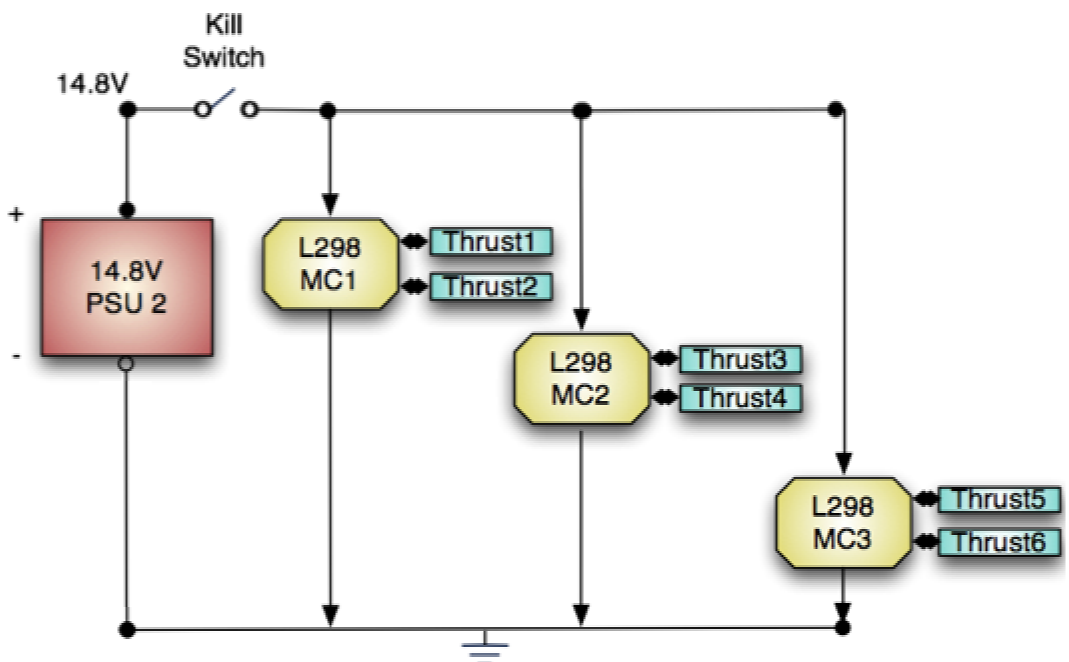


Figure 3. Block diagram of power supply to CPU and components

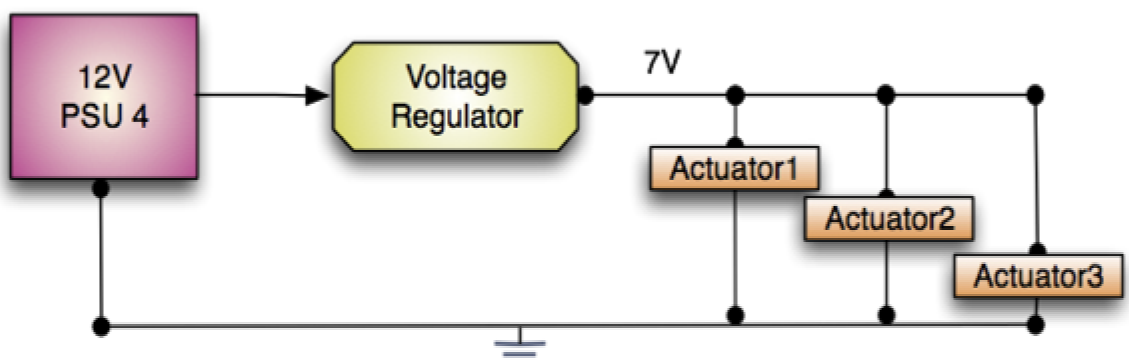


Figure 4. Block diagram of power supply to actuators

2.2.2 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 each other and other subsystems.

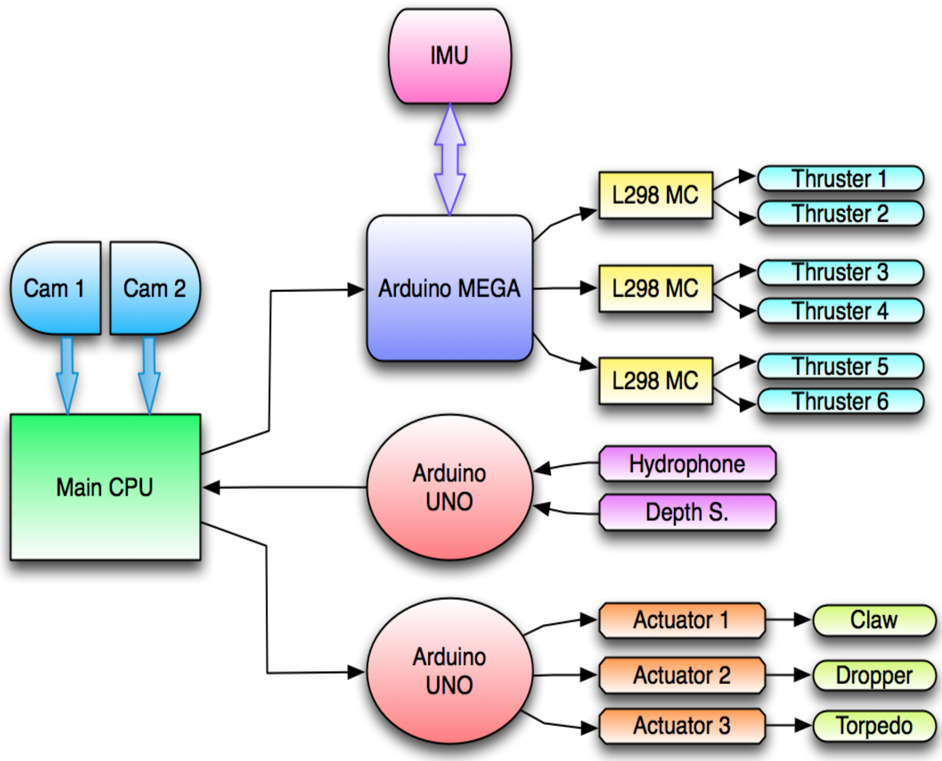


Figure 5. A simple block diagram of the proposed electronics system.

2.2.3 Software System

The software system will be composed of three distinct modules that perform the required tasks, and potentially a fourth module which will be responsible for checking the work of the other three modules. Figure 6 shows the general layout of each of the components, and each component is described in detail in the subsequent sections.

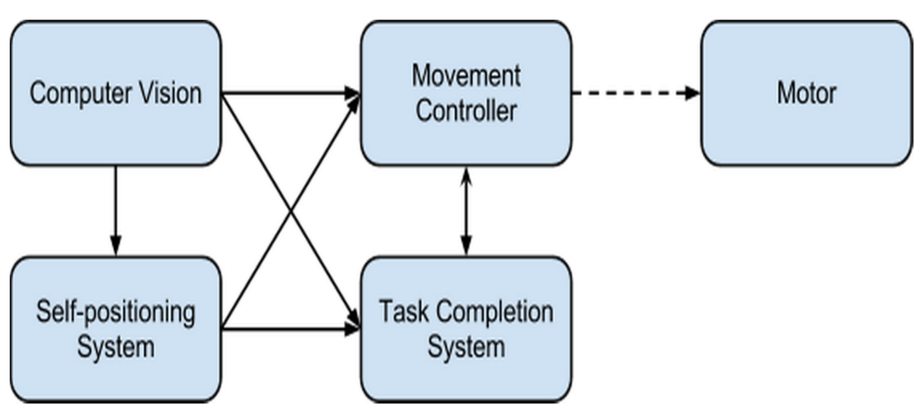


Figure 6. A simple block diagram of the proposed software system with its interactions with external systems indicated by dashed lines.

2.2.3.1 Top Level Control Module

The top level control module is the software system that will perform the overall task management of the sub. This module is the implementation top-level Mealy finite-state machine (FSM) that will instruct other system modules based on the current state of the sub, namely, the input from its sensors. Leveraging the apriori knowledge of the order of occurrence of tasks at the competition, a FSM can be designed that has the necessary number and order of states to satisfy the tasks.

The current design uses nested state machines. An outer level FSM will keep track of which task the AUV is currently perform and the next task. An inner level FSM will keep track of the primitive tasks that must occur during each task. Figure 7 illustrates this point.

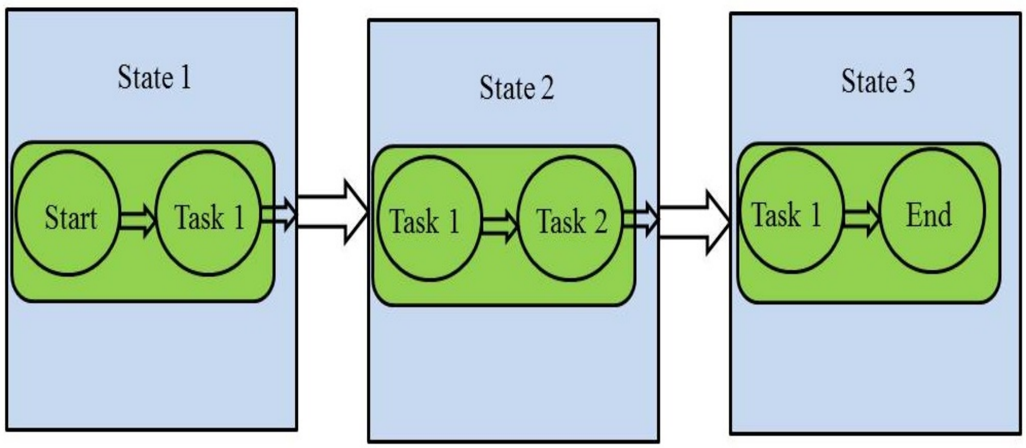


Figure 7. Nested state machine diagram. Blue represents outer FSM while green represents inner level FSMs.

Now that algorithm development for this module has been completed, these FSMs can now be implemented.

2.2.3.2 Vision System

The vision system is the software module that satisfies all of the necessary image processing needs of the AUV. Modules from this system will be called when needed by the top level control software. Written using OpenCV, this module will implement object recognition, a frequently occurring problem in the contest.

The vision module has a list of functions that correspond to each task. For example, at the buoy task, the AUV must identify circular objects of varying colors. A vision function involving the shape and color of the buoys will be generated that accomplishes this and sends its results to the top level for decision making. Analogous functions will be developed for other primitive actions found within each task.

2.2.4 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. Free space will decrease the overall density of the vehicle, making it more positively buoyant than is desired. As little aluminum as possible should be used to reduce weight as it is one of the main constrictions on the competition.

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 is done by using an O-ring in a channel that was cut using a CNC machine into the top part of the box. This will be clamped down by adding a flange onto the upper part of the walls, creating a lip, which is used to bolt the top lid down creating a tight seal. The original plan to hold the watertight seals was attaching clamps instead of using bolts to hold the lid in place.

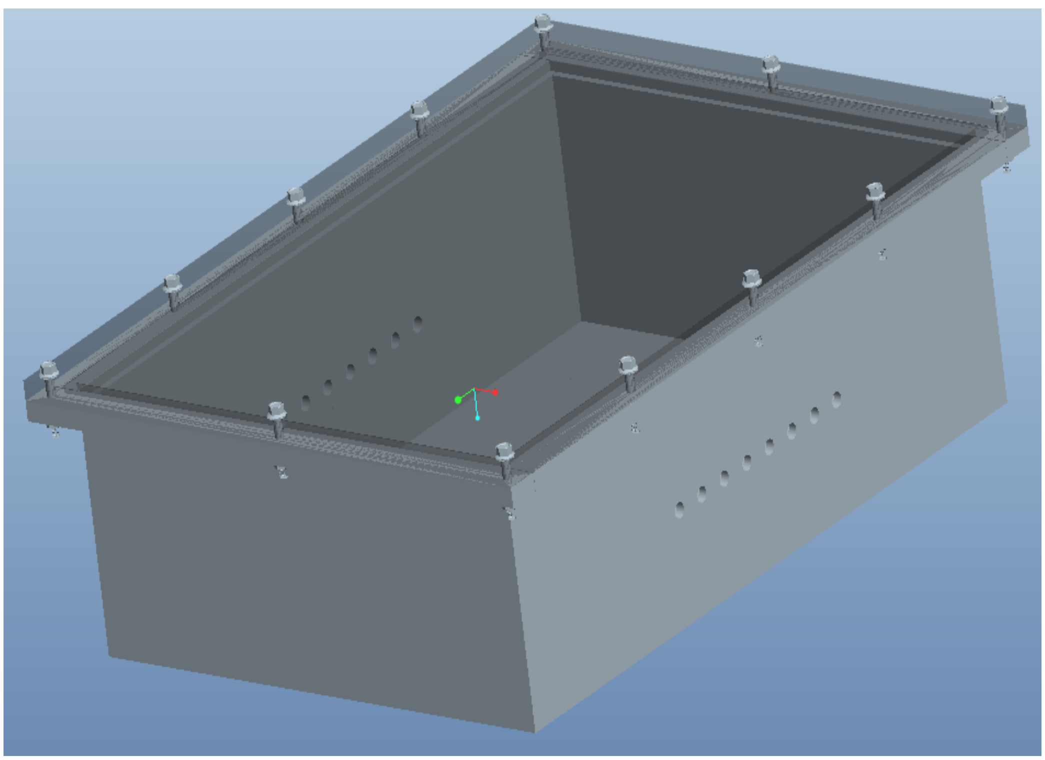


Figure 8. CAD model of Hull

2.2.5 Frame Structure

Arranging the components, such as the cameras, torpedoes, etc. , in a balanced manner is crucial to the success of the robot. The components and electronic hardware are arranged in a balanced manner throughout the sub based on the center of mass to prevent tilting. This allows the computer to focus on movement instead of stability. An image of the frame structure can be seen in Figure 9.

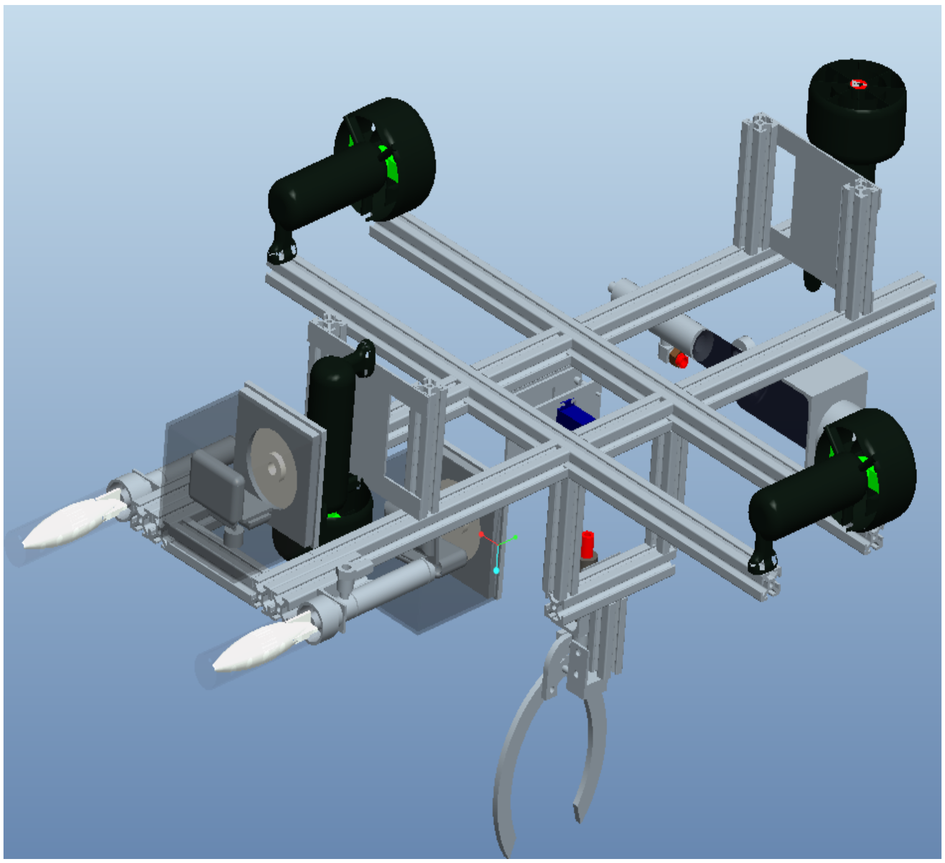


Figure 9. CAD model of framework and components

2.3 Subsystem Requirements

Each device has specifications regarding power requirements, signal protocol, placement, orientation, function, and design. Throughout this section you will find details about each chosen device and why it was chosen for the AUV.

2.3.1 Batteries

2.3.1.1 Thruster Power

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

2.3.1.2 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)

2.3.1.3 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)

2.3.2 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.

Detailed Specs:

- 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

Choosing a main control system is one of the most important tasks in designing the AUV. It must be able to handle bidirectional communication between multiple devices, interpret image data through the vision system, calculate algorithms, top level control, and also provide a stable system to operate. Many factors went into selecting a unit that can handle all of these tasks: Heat dissipation, power consumption, size, communication ports, price, and functionality.

- The Intel i3 mobile processor is more than enough processing power for AUV tasks
- Produces minimal heat, thus it has a great power-to-heat ratio
- Contains 6 USB ports which is necessary for all intended devices
- Requires a simple laptop battery instead of a regulated voltage system
- Ease of use and assembly.

2.3.3 Arduino UNO

Each serial device needs a "bridge" to communicate with the MPU. The Arduino UNO is a perfect solution to handle this communication. 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

The greatest advantage of using an Arduino is its versatility. Each Arduino will have its own subsystem process. This will allow that subsystem to be controlled by the Arduino, without always needing outside assistance from the MPU. This will take processing power off of the MPU and decrease unnecessary communication between devices.

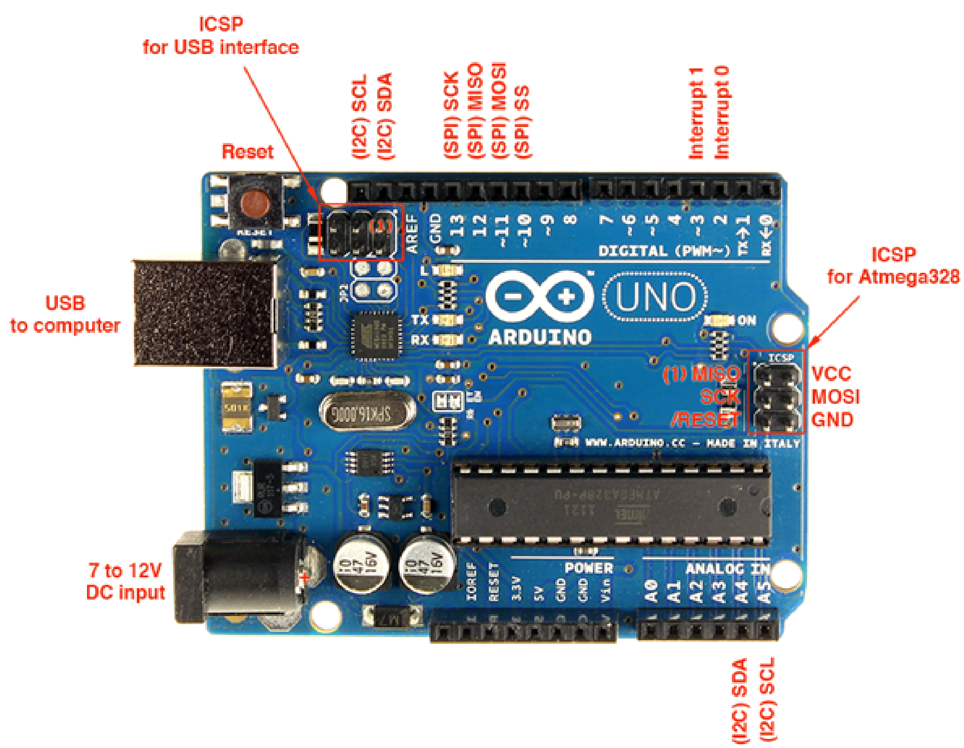


Figure 11. Arduino Uno Board

2.3.4 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

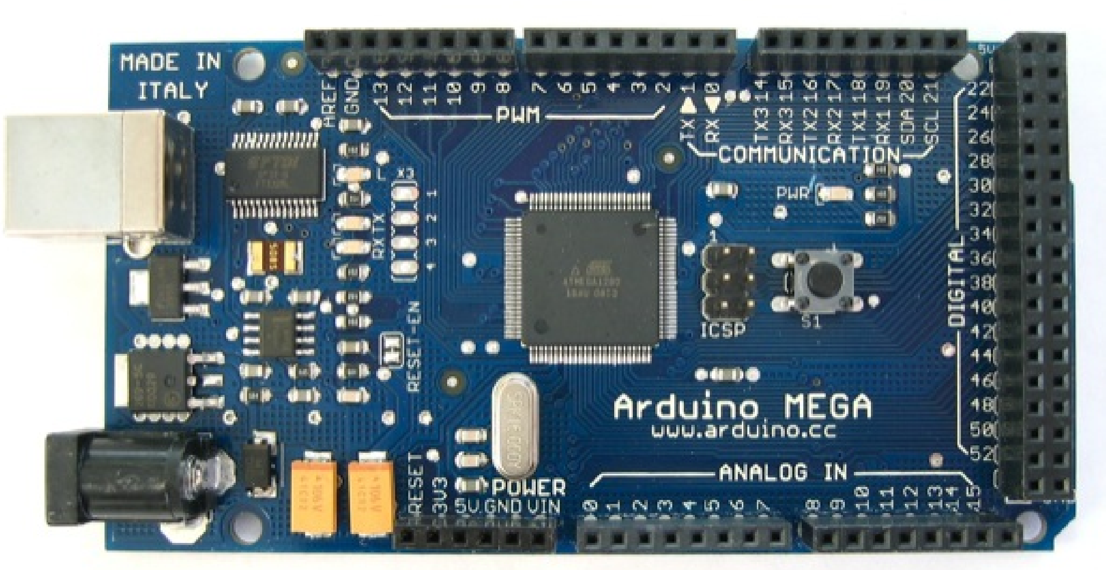


Figure 12. Arduino Mega Board

2.3.5 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

This specific IMU was chosen simply because it is the most documented. While it was slightly more expensive than others, it has the most support and documentation of any IMU on the robotics market. It’s also one of the most powerful designs with 9 degrees of freedom. This provides all the information needed to orient the AUV when navigating in the water.

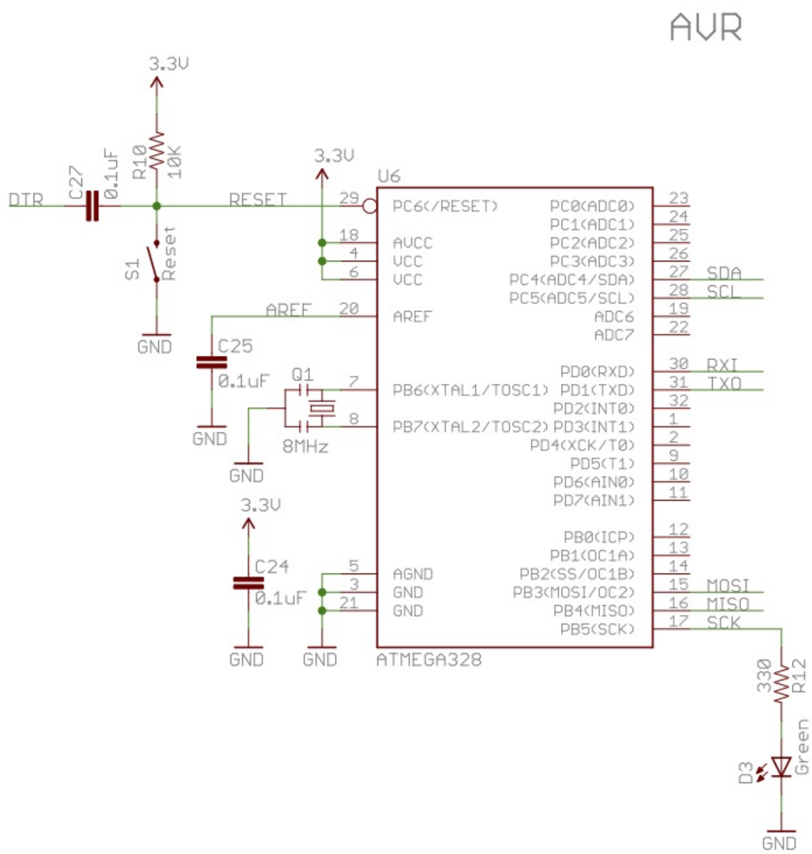


Figure 13. ATmega328 Schematic

2.3.6 Motor Controller

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 sends PWM signals to the motor driver, where it then takes the voltage from the batteries and adjusts the voltage output according to the duty cycle designated by the Arduino controllers.

- Operate at 6 to 26V
- 4A Total Drive Current
- Requires 5V for board power
- Motor Direction indicator LED's
- EMF Protection diodes

These are parts from last year. However, research was done to assure that they met the requirements of the competition. The existing motor drivers perform as needed and work well with the PWM signals from the Arduino. The greatest perk to these motor drivers is the ability to handle the higher voltages. Many motor controllers that can handle comparable voltages cost quite a bit more.

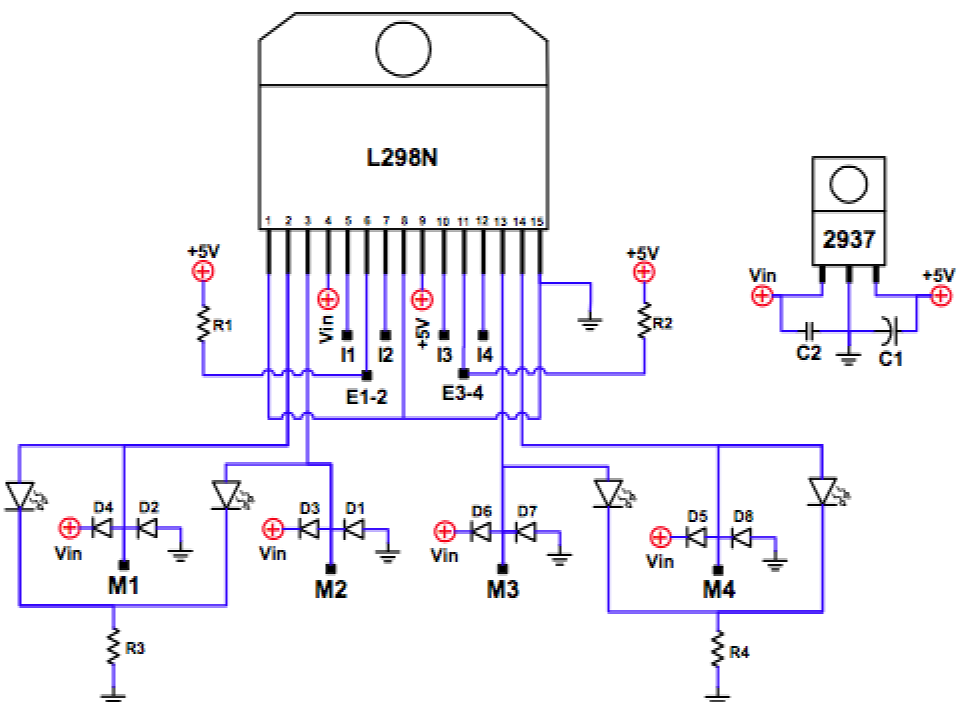


Figure 14 L298 Motor Driver Schematic

2.3.7 Sensor Systems

2.3.7.1 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.

Each webcam is powered via USB from the MPU, so no external power is required for them. One will be placed facing the floor of the pool to track the orange tape on the floor of the pool. The other camera will be the "eyes" of the AUV and it will be facing straight in front of the vehicle to interpret the unit's surroundings.

- 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)

2.3.7.2 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

2.3.7.3 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.

2.3.8 Pneumatic System

_2.3.8.1 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.

2.3.8.2 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.

2.3.8.3 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.

2.3.8.4 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.

2.3.9 Computer Vision

This subsystem will analyze the data from the cameras and output its findings in a form that is easily manipulable for the other subsystems. The team's preliminary communications protocol dictates that the computer vision module output the angle and distance to the next target. This system will therefore identify shapes and colors along the course and determine their location. In order to achieve the flexibility of identifying different course objectives, the computer vision system should use a state machine to differentiate between different targets to search for, such as finding a path instead of a gate.

2.3.10 Movement Controller

The movement controller will accept information regarding the distance to its next target, as well as its angle with respect to the AUV. It will then direct the output of the thrusters to reach the target position as nearly as possible, while accounting for the drift and inertia inherent to underwater movement. The mathematical model of the controller will be worked out separately, and then implemented in software.

2.4 Performance Assessment

All requirements of the AUV were identified in the Needs Analysis and Requirements Specifications. This section will detail the design decisions made in order to satisfy each requirement and capability.

2.4.1 Required Capabilities Assessment

For a complete list of requirements and capabilities, please see the team's Needs Analysis and Requirements Document. CAP-001 states that the RoboSub must autonomously complete all objectives. The implementation of the software system shall allow the AUV to store a preprogrammed set of actions in memory and execute them at system startup. The software system shall be sufficient in guiding the subs every move without external interaction.

CAP-002 through CAP-008 will all be satisfied by a similar approach. The primitive actions that the AUV must undergo each tasks described by each capability will be analyzed an encapsulated by an algorithm. This algorithm will be implemented by the realization of the software system which guides the AUV through each objective.

2.4.2 Requirements Assessment

REQF-0004, a requirement of autonomous operation, has been covered by the capabilities assessment. REQF-0003 and REQF-0005 refer to having the required equipment on the AUV during the competition. Since all equipment required to complete the tasks will need to be on the AUV and function before the AUV can function, this will surely be achieved. The other requirements are listed.

REQF-0001: The RoboSub should be under 105 lbs.

The team has taken this requirement into account by reducing the amount of extruded aluminum used from last year's design. The new frame uses roughly half of the material. The hull is anticipated to be heavier than last year's design, but preliminary calculations show that there should be an overall reduction of weight in total.

REQF-0002: The entire AUV shall be no larger 6' long, 3' wide, and 3' high.

The team has assured that no dimensions of the constructed frame exceed the target dimensions.

REQF-0006: Markers and torpedoes used by the AUV cannot be larger than 2"x2"x6" and weigh more than 2 lbs in air.

Suitable markers and torpedos have already been constructed.

REQF-0007: The AUV must be able to be supported in a sling for weighing and transportation purposes.

Currently the team has constructed a temporary cart to allow easier movement of the AUV. The modification of the cart to build a sling for the AUV is very doable and not a foreseeable problem.

2.5 Design Process

When designing the hull, several options were available. The first was to leave the hull as it was and simply continue to use it. The second was to alter the end caps for easier access and reuse the rest of the hull and frame. The third was to redesign the hull from scratch and create a new, more accessible hull.

Redesigning the hull from scratch was not the most cost efficient option. Nonetheless it was selected because it became evident that even with modified caps the hull left behind by the previous team had various flaws that could not be addressed without a complete redesign. Since ease of access was a priority, the new design took the shape of a box with a removable lid.

Last's year team expressed a concern with the power system. They burned out a few of their voltage regulators because their entire system operated on one battery, making it difficult to tailor the voltage to the different subsystems. This proved to be highly complicated and inefficient. A decision was made to modify this into 3 different, independent power systems. Each system now has its own battery and powers different components.

2.6 Overall Risk Assessment

This project contains many risky aspects because it is a large project with many separate and expensive components working in unison, and trying to complete the system within a time frame for competition.

Risk	**Level of Risk**	**Explanation**
Damaging components of RoboSub during testing or transportation.	Medium	Damaging components of RoboSub would require money, time, and a halt on testing. All of these things are vital to completing our task.
Completing RoboSub in time for Competition	High	The scope of the project compared with what the team has accomplished thus far into the year is not falling into line.
Running out of funding for components	Medium	Currently, major components and parts for the RoboSub have the necessary funding required to order them. However, if more are needed there may not be funding.
Having to redesign a feature due to poor design	Medium	Taking careful precautions and factors of safety in the design process now will ensure working features that hopefully will not need redesigning. For instance, the AUV mechanical design had to be completely redone from

		last year's because of poor design features.
Wrong parts delivered	Low	If the manufacturer, mechanical department, or a team member messes up in the process of ordering necessary parts, the project will have to be put on hold until a replacement part comes in.
Being behind schedule	Low	With setbacks from a task taking longer than previously thought, waiting for a team member to finish a part, or having to wait on a part to be shipped
Completing Gate passing task before competition	Medium	With a working and moving AUV, the camera case needs to be repaired and coding needs to be made for movement
Obtaining travel money to go to competition	Medium	Large amounts of money will be needed for the team to travel, transport the sub, and stay in the hotel if the team goes to competition.

Table 2 Risk Assessment

3 Analysis and Test Performance

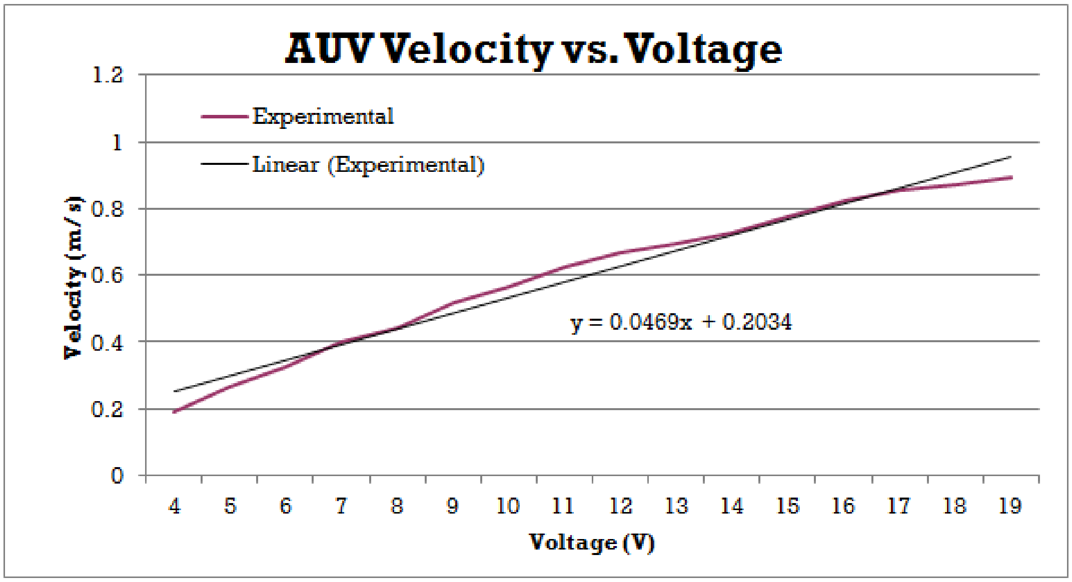
Research and testing was done on various parts of the AUV to ensure that its specifications were up to the standards of being able to compete. These include thruster performance, AUV buoyancy, weight, and size, OpenCV performance, and results of the manipulator components. Some components were left over from last year and had already been tested and documented and not mentioned. This section of the report details the testing procedure of all components of the sub.

3.1 Analysis of Systems

3.1.1 Thruster Performance

Upon getting the six Seabotix thrusters from last year's AUV team, no output of force with voltage application or any kind of data was available. After doing research online, the team found a journal article detailing an experiment to determine the force vs. voltage output and force vs. current output. Both of these show a linear relationship, and can be viewed in the appendix.

Basing testing on this, calculations were done to show the velocity the AUV could reach in the water with the thrusters acting on them. This analysis was done by assuming the AUV most likely resembled a flat plate and then taking into consideration other factors of drag in the water. Below is the experimental and theoretical results of the AUV velocity.



Graph 1. Velocity of AUV

The graph shows an almost linear relationship between velocity of the AUV and voltage input to the thrusters. Which is beneficial to the team knowing how much voltage to apply to achieve desired velocity.

3.1.2 Buoyancy

Due to the design of not having a controlled ballast system, the AUV was built to have almost neutral buoyancy and use the work of thrusters to elevate its position in water. The full volume of the AUV, its weight, and the buoyant forces acting on it are included below in a table.

Being Measured	Value
Volume of AUV	1.429 ft^3
Weight of AUV	92 lbf
Buoyant Force upwards	91.43 lbf

The volume shown was calculated in Pro Engineer on the CAD drawing done of the AUV. When determining the buoyant force, the density of salt water was chosen as the density variable.

3.2 Testing Systems

3.2.1 Power System Test Plan

Each battery was tested using a multimeter. This verified that the output voltage and amperage is correct in comparison to its specifications. After each battery was tested, they were connected to their component to ensure proper running.

3.2.2 Pneumatic Claw and Torpedo Test

Following a schematic from last year's design mentioned in the component descriptions, the air tank and regulator were hooked up and a signal was passed through to the actuator valves. The torpedoes fired properly at a range of around 3-4 ft while submerged and did not cause bodily harm. The claw mechanism actuated and released properly without causing bodily harm in its grip.

3.2.3 Marker Dropper Test

Applying voltage to the DC motor with is the marker dropper allows the pusher arm to rotate and move a marker out of the carriage and down beneath the AUV.

3.2.4 Vision System Test

Tests images were generated for vision modules. The test images generated as input for the developing functions were created to simulate images that would be present during competition. To test the ability of OpenCV to recognize shapes and colors and follow them, the team performed several tests. Running the program with colored objects in front of the camera, the program outlined and shaded the area of the colored objects. Although this does not truly simulate competition conditions, it does show that the software is capable of completing its required tasks.

3.2.5 Electronics Housing Test

The housing was submerged in a pool to test for any leaks in the welds and lid. Tissue papers were placed inside to indicate if any water entered the housing. The housing reached depths of around 16 ft, which is the posted limit in the competition rules.

3.2.6 Kill Switch Test

A requirement for the competition is to include a kill switch that kills power to the AUV stopping movement to stop it in case of erratic failure. Wiring the kill switch, that is located on the side of the AUV, through the main thruster batteries created a perfect switch that allowed instant powering and shut off of the AUV's power.

3.3 Testing History

Task	Date Completed/Planned	Result (Pass/Fail)	Reason (if fail)
Test Thrusters/Arduinos	10/15/2012	Fail	Improper motor driver documentation
Test Thrusters/Arduinos	11/13/2012	Pass	
Hydrophones	10/16/2012	Fail	Improper testing procedure
Water tightness	1/16/2013	Fail	not enough pressure on Oring
Hull Watertightness	2/3/2013	Fail	Welds not watertight
Hull Watertightness	2/12/2013	Pass	
Torpedo test	2/12/2013	Pass	3-4ft range
Camera Case water tightness test	2/24/2013	Pass	
Thruster Test	3/28/2013	Pass	
Buoyancy Test	3/28/2013	Fail	Too Buoyant
Buoyancy Test	4/8/2013	Fail	Too Buoyant
Buoyancy Test	4/12/2013	Fail	Too Buoyant
Buoyancy Test	4/14/2013	Fail	Not Buoyant enough (test ended early due to

			weather)
Control and drift Test	4/15/2013	Pass/Fail	Neutral Buoyancy established. Control of thrusters via hardwire connection in water, and failure of camera cases being watertight

Table 3 Testing schedule

4 Future Work

Much work still needs to be accomplished to get a working AUV ready to compete for in July. Intelligent control still needs to be created; Implementing the vision system to recognize targets, sending that information to be processed, and having a resulting algorithm to control the thrusters to move the AUV toward the goal.

Using the sensors to obtain data about the AUV also needs to be accomplished. The depth sensor needs to be tested more to be able to obtain pressure levels for depth control. The IMU needs to be integrated to get the intelligent decision making acknowledge when to slow down or stop. More test runs to see how the coding and actual running of the AUV and its components behaves is very necessary.

5 Schedule

A Gantt chart illustrating the schedule for the spring and summer of 2013 can be found in the appendix. There are a few items of interest that can be gathered from the Gantt chart. Firstly, it can be noted that programming tasks accounts for a large portion of the anticipated time to complete the project. Programming was one of the points where the previous year's team encountered the most setbacks, so attempt was made to incorporate sufficient time for the tasks. The second item of note is the fact that a few of the tasks are behind schedule. Deviations from the included schedule include receiving incorrect orders from component supply companies and having far greater difficulty setting up the chosen software.

Delays have been experienced with programming tasks. More time than initially expected was involved programming OpenCV to recognize competition objects. As a result, the revised schedule for completing OpenCV tasks has been extended to just before the competition since it is now expected that the team will be able to complete every competition event. Integration of the sensors with the software is another continuing challenge.

The team is making a concerted effort to compensate for lost time. The mechanical sub-team decided to forego the planned miniature prototype of the AUV hull and moved right to production of the full-scale model. Lengthy work sessions have been arranged to install the required software, eventually the vision software was completed. The team members with the most programming knowledge have been reassigned to work with the vision software due to the sheer difficulty of this portion of the project. Testing also took up much time. Preparing the AUV, working with the availability of the nearby aquatics' center outdoor pool, and the team's own personal schedule was difficult and led to time being wasted.

Even with the aforementioned setbacks, we still anticipate completing the project ahead of the July competition. The schedule was planned with a buffer period of over two months during the summer to allow for potential delays. The anticipated buffer period will now be used to complete essential project tasks. Due to the limited number of members with programming experience, an attempt will be to improve the skills of the remaining members so that they can assist in these tasks.

6 Budget Estimate

For the completion of this project, the team was allocated a total of $2,200. A budget plan was made as follows:

- Electrical Components: $880
- Mechanical Components: $880
- Prototype/Testing: $220
- Emergency Fund: $220

After buying required parts and materials, making repairs to existing components, and registering for competition the receipt for expenditures is shown below.

Starting Funds	**$2200.00**
Z-Box computer	$332.00
Arduinos/Arduino Mega	$109.00
Batteries	$186.00
RAM	$36.00
IMU	$125.00
Prototype Materials	$126.00
Hull Materials	$417.00
Bolts	$20.00
Air Tank Repair	$40.00
Competition Registration	$500.00

Remaining Funds	**$309.00**

The remainder of the funds the team has will go into any changes that are made (if any) to the submarine. Once it is up and running, different parts such as PVC pipes will be bought to create a practice course for the submarine. The biggest expense the team faces is the travel costs to the competition. This includes transportation, food, and lodging for the entire team. The remaining budget is not enough to send the team to competition. Potential sponsors have been approached with hopes of obtaining more funding for the team. An estimate on expenditures for the competition is included below.

- Airfare for 7 team members, about $500 per person: $3,500
- Hotel for the team, 2 rooms at $150 a night per room for 6 nights: $1,800
- Shipment of Robosub to and from San Diego, $100 each way: $200
- Total: **$5,500**

7 Conclusion

Much has been accomplished in the past several months. The hard work of the entire team has yielded a constructed AUV with functioning components. Testing has demonstrated the ability to interface with thrusters, mechanical manipulators, have a suitable power setup, and In addition, we are in the early stages of developing the vision software.

Despite a few delays in initial setup of computer systems and acquisition, it is still anticipated that the project will achieve a sufficient level of completion to participate in the competition. Regardless of whether this design competes, the robustness and flexibility of the design demonstrate a high level of forward thinking and should prove to be an excellent platform for future FAMU-FSU Robosub teams.

8 References

"RoboSub Competition Rules." *AUVSI Foundation*. Web. 11 Dec. 2012.

Jepson, Antony, Ryan Kopinski, and Hang Zhang. *AUVSI Robosub 2012*. *AUVSI Robosub 2012*. FAMU/ FSU College of Engineering, 15 Apr. 2012. Web.

Kelly, Kurran, and Pedrow Brandt. *Robosub AUV Thruster Analysis*. Rep. RoboSub Club of the Palouse, 7 Dec. 2012. Web.16 Mar. 2013.

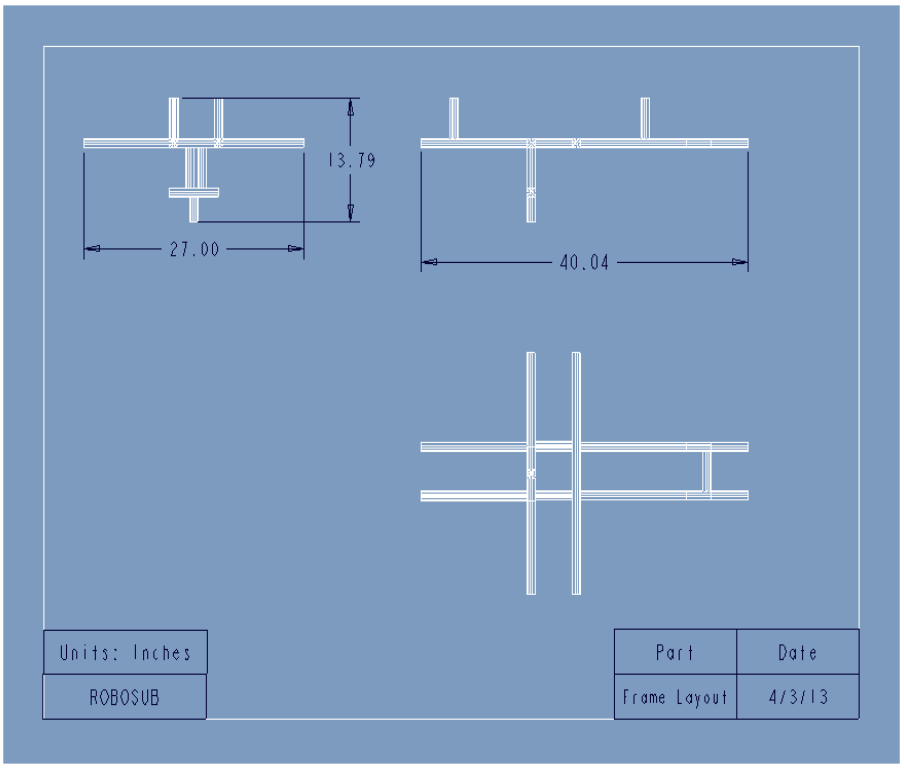
Appendices

Bill of Materials

Name:	Quantity:	Name:	Quantity:

BOX BASE	1	CLAW NUT	1
BOX FRONT	2	CLAW REL ADPT	1
BOX SIDES	2	CLAW PIN LONG	1
8020 27" long	2	CLAW ARM VALVE CONNECTOR	2
8020 4.5" long	11	CLAW ARM	2
8020 13" long	4	CLAW RELEASE BLOCK	1
THRUSTERS	6	FLANGE 21" long	2
8020 3" long	2	FLANGE 14" long	2
THRUSTER PLACE PLATE WIDE	2	BOX TOP	1
CAMERA HOUSING SIDES	2	ARM BRACKET TORPEDO LAUNCHER	2
CAMERA HOUSING SHELL FRONT	2	CONNECTOR TORPEDO LAUNCHER	2
CAMERA HOUSING CAP	2	AIR PISTON TORPEDO LAUNCHER	2
CAMERA STAND	2	BARREL TORPEDO LAUNCHER	2
CAMERA STAND CON	2	TORPEDO TORPEDO LAUNCHER	2
CAMERA	2	AIR TANK ANGLE	1
MARKER ANGLE	1	AIR TANK BOTTOM CAP	1
MARKER PLATE	2	AIR TANK	1
MARKER SCREW	4	FLANGED BOLT PARTIAL 1/4"	12
MARKER SCREW TUBE	12	NUT 1/4"	12
MARKER CHANNEL	4	O-RING 1/4" diameter 20" long	1
MARKER SERVO	1	ACTUATOR	4
8020 6" long	1	SEACON 3 PRONG	9
8020 2.75" long	1	SEACON 6 PRONG	2
CLAW ANGLE	1	SEACON 4 PRONG	1
CLAW PISTON	1	SEACON 5 PRONG	4

Assembly Drawings



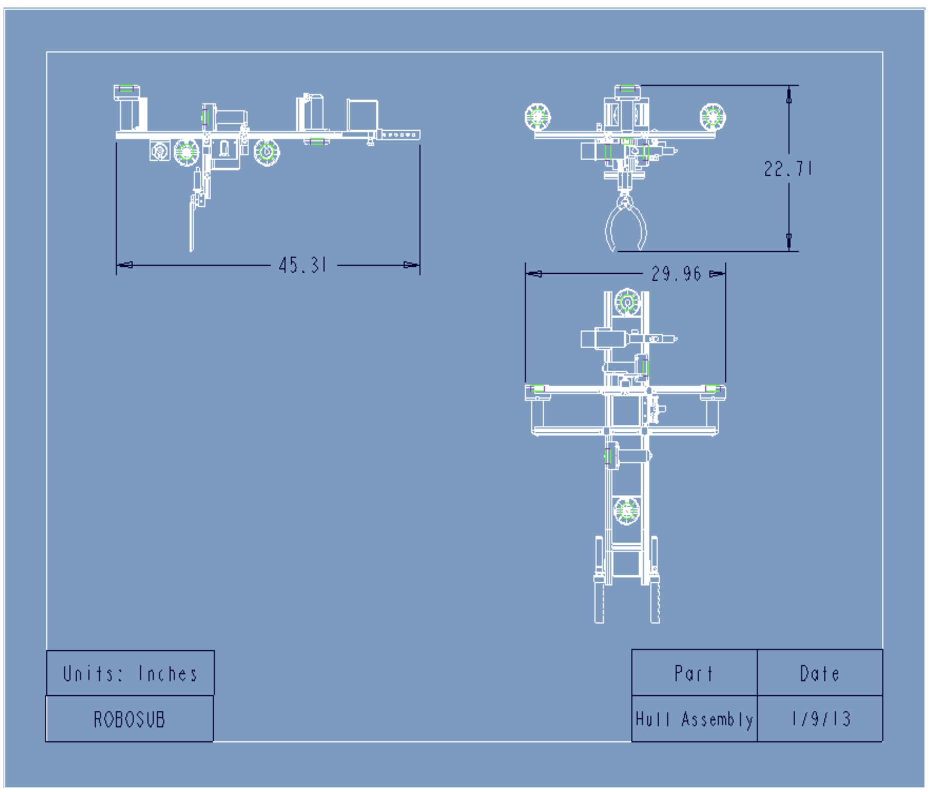
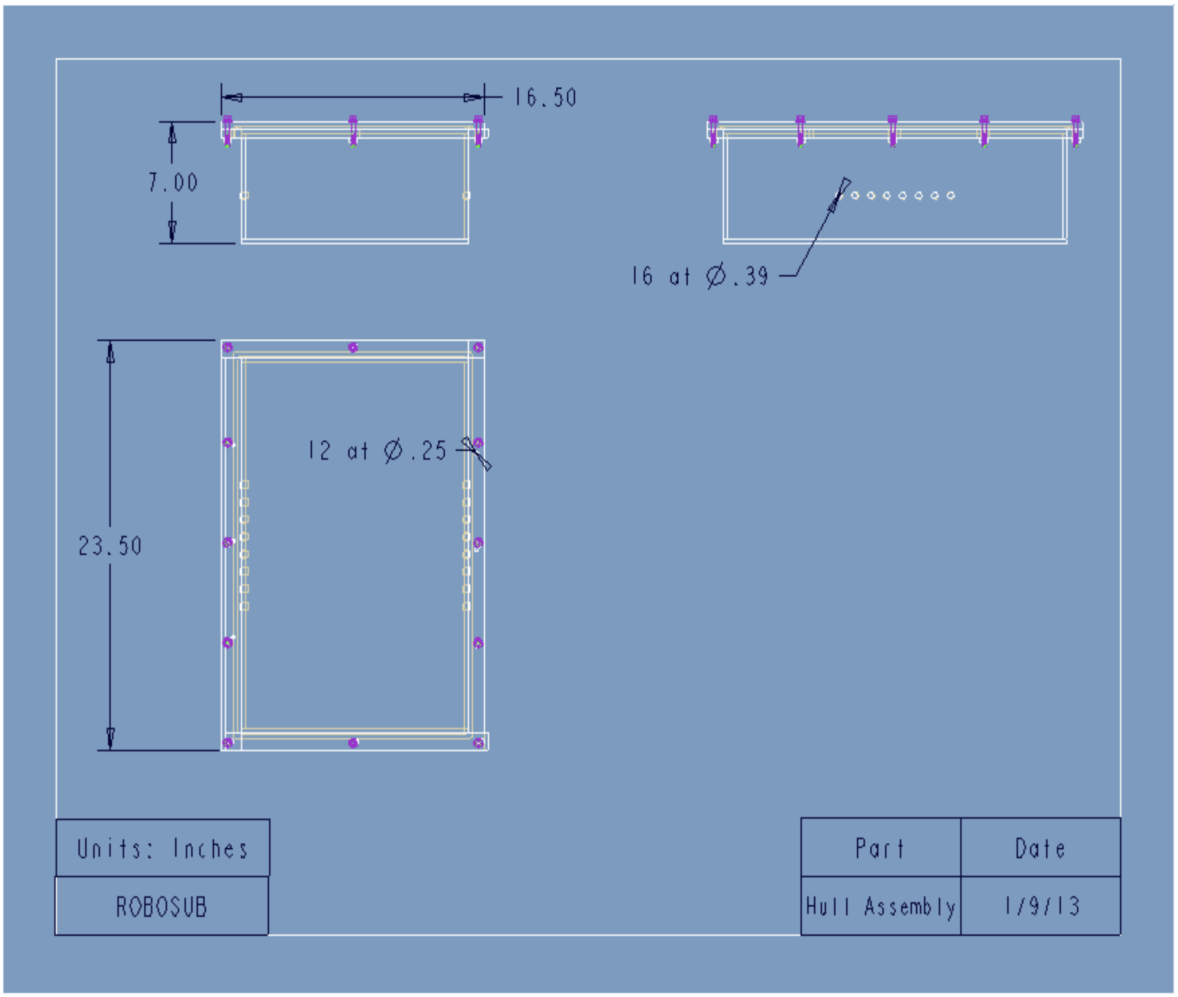


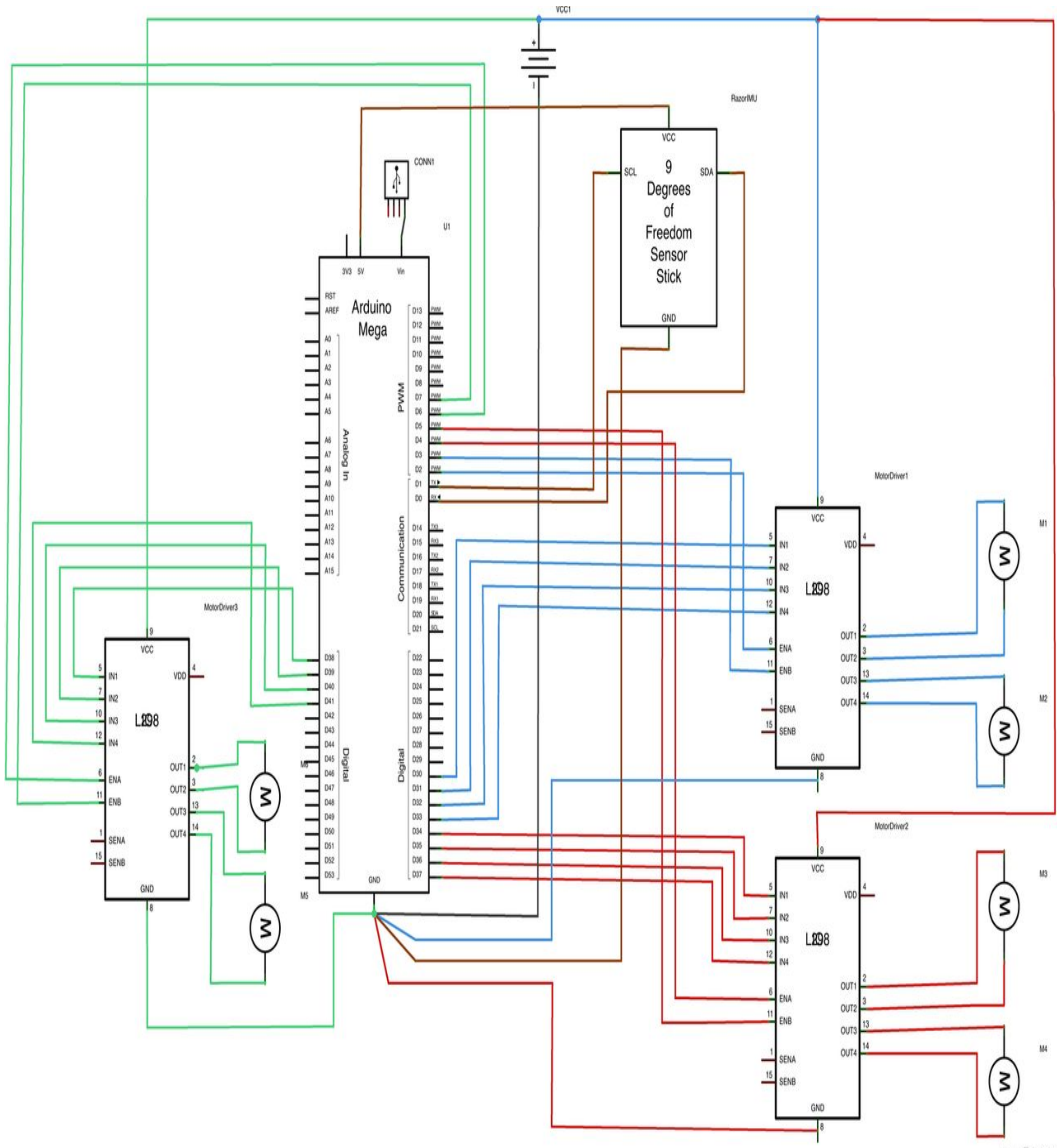
Figure 2: Pro E model of frame with components



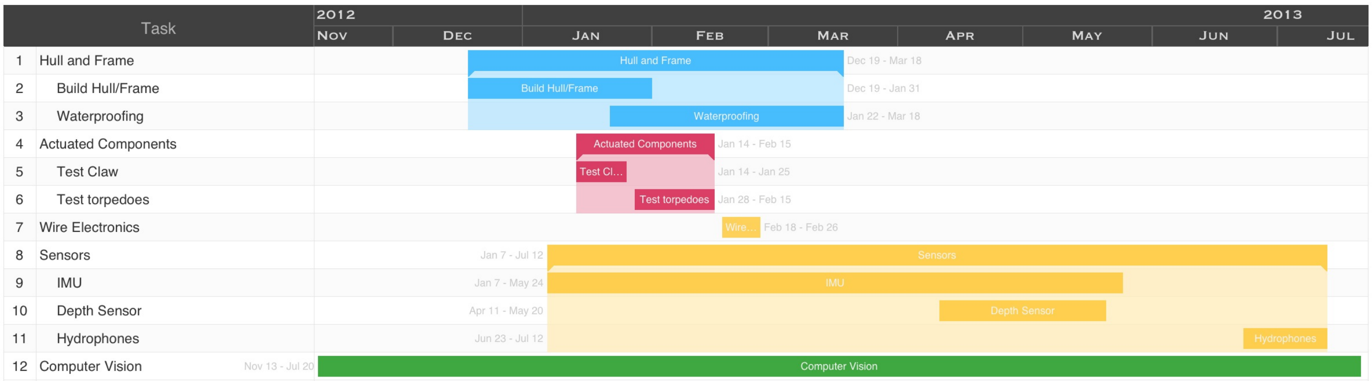
16.50
7.00
16 at Ø.39
12 at Ø.25
23.50
Units: Inches
ROBOSUB
Part
Date
Hull Assembly
1/9/13

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.



Schedule


Task
2012
2013
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
1 Hull and Frame
Hull and Frame
Dec 19 - Mar 18
2 Build Hull/Frame
Build Hull/Frame
Dec 19 - Jan 31
3 Waterproofing
Waterproofing
Jan 22 - Mar 18
4 Actuated Components
Actuated Components
Jan 14 - Feb 15
5 Test Claw
Test Cl…
Jan 14 - Jan 25
6 Test torpedoes
Test torpedoes
Jan 28 - Feb 15
7 Wire Electronics
Wire…
Feb 18 - Feb 26
8 Sensors
Jan 7 - Jul 12
Sensors
9 IMU
Jan 7 - May 24
IMU
10 Depth Sensor
Apr 11 - May 20
Depth Sensor
11 Hydrophones
Jun 23 - Jul 12
Hydrophones
12 Computer Vision
Nov 13 - Jul 20
Computer Vision