FAMU-FSU College of Engineering

Department of Mechanical Engineering

Concept Design

EEL4911C/EML4511C– ECE/ME Senior Design Project I

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Project 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 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.

Each team is assigned a time slot for the practice round, and performance in the practice round will determine the order in which teams will proceed in later rounds. Then, all the teams that participated in the practice rounds will compete in the first round of the competition. The top scoring teams from the first round, generally the top five, go on to the championship round. Then, the top teams compete for first place with the top teams receiving awards for their placing. For each round, the AUVs will be expected to be able to pass through a gate, follow an obstacle course, drop markers into specified bins, shoot torpedoes at specific targets, pick up and surface with an object within an octagon, and then drop the object once the AUV has breached. All these activities will be performed while completely submerged unless permitted or required by the competition rules. The AUV is to be completely autonomous and may not have any communication with the team or any other source during the competition.

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1. Introduction:

1.1 Acknowledgements

The 2012-2013 FAMU-FSU RoboSub team would like to acknowledge the following individuals for their 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 questions we may have.
- Dr. Harvey for advising the team on questions we may have.
- 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.

1.2 Problem Statement

The aim of this project is to develop an Autonomous Underwater Vehicle (AUV) to participate in the 15th annual AUVSI RoboSub competition in San Diego, CA in July 2013. Competition rules for the 2013 competition will not be released until November 2012, so all preliminary design considerations must be made with respect to rules from the 2012 competition.

The competition provides a set of goals for the AUV to complete and imposes numerous design limitations such as restrictions on the size and weight of the vehicle. According to the 2012 rules, the AUV will need to be able to follow paths, identify and pass through underwater gates, bump into colored buoys, pick up objects, fire torpedoes at specific objects, and other tasks. A comprehensive discussion of the various rules and restrictions can be found in the *Needs Analysis and Requirements Specifications* document released by the RoboSub team in September 2012.

As a complex mechatronic system, there are both mechanical and electronic subsystems that will need to be integrated for the AUV to be able to perform the desired tasks. This year's FAMU-FSU RoboSub team will be building on the progress made by the team from the previous year, and many of the base components are already present. One of the biggest hurdles for this year's team is to integrate existing mechanical and electrical components to create a fully-autonomous vehicle. However, upon analysis it was also determined that some components would need to be redesigned or replaced to meet desired performance goals.

The project can be broken into three major subsections: mechanical and structural components, electrical and electronic hardware, and intelligence and control. A generalized approach to each of the subsections will be discussed in the following paragraphs.

The mechanical design consists of a watertight hull that will contain the electronic components and a frame which will hold all external sensors and thrusters. The AUV had both of these components built by the 2011-2012 team, but are both going to be replaced to reduce weight and significantly improve accessibility to the electronics within the watertight hull. Especial attention will need to be paid to the buoyancy, weight, and stability of the new physical design. Desirable parameters include low weight (below 85 lbs), buoyancy near neutral, and stability about all three axes of rotation.

The electrical hardware will remain similar to what was used last year, due to assumed similar power and processing requirements. A few of the boards used last year, including the main computer, have been burnt out and will be replaced. In addition, more microcontrollers will be bought for on-board control and spares. The power system proved challenging with the previous design due to the thrusters causing current spikes and burning out the electronics. As such, the new design will power the thrusters and the electronics using separate batteries.

The intelligence portion of the project is perhaps where most of the work will need to be done. The current AUV only has rudimentary motor control in the form of a demo program, and the computer vision has yet to be integrated into the control scheme. Programming will be done primarily in C++ and the specialized Arduino language. Controller design will rely on a model that will developed by the mechanical engineering sub-team. Before working on new code, all existing code must be tested in order to assess the functionality of present code.

2. Existing Parts

2.1 Existing Mechanical Parts

For the existing mechanical parts we plan on reusing all the main subsystems that were developed last year. This covers the claw mechanism, marker dropper mechanism, torpedo launchers, compressed air system, cameras, camera cases, thrusters, hydrophones, 8020 framing struts, and actuators. There is a pre-existing frame and electronics housing but these will be improved upon with the new design selection.

2.2 Existing Electrical Parts

Many parts of the electrical design last year are being reused in this year's AUV. However, there are also many designs from last year that are not practical and are being redeveloped.

2.2.1 Electrical Power

Power Supplies

Last year's design used 2 batteries in series for a total of 32V output. This was very hard to regulate and control. These batteries will still be used, but only to power the thrusters.

Voltage Regulation

The voltage regulators from last year were custom made, but never worked as intended. Trying to regulate such a specific voltage from their one source was not working. With the change to the power system, the voltage regulators will only need to step down from 12V instead of 32V. We will not be using the voltage controllers from last year.

2.2.2 Electronics

Main Processing Unit (MPU)

In the previous year, a Zotac board with an Atom processor was used; however, that board has been destroyed. The design for this year uses the same concept but realizes the need for more processing power to control all the subsystems for the AUV. This unit will monitor and control each subsystem.

Subsystem Control

Using the same idea as previous years, the Arduino boards are perfectly suited for controlling each electronic subsystem. The motor control system is also being ported from last year's design as these devices still function as intended. We are left with 2 arduino's and 3 working L298 motor bridges from the previous year.

Vision

It is planned to use the same vision devices as were used last year as they are working.

Sensors

The hydrophones and depth sensor are working. These were never implemented year, along with the inertial measurement unit (IMU). All of these devices are working and we intend on using them. The only device we may not use is the current IMU because it was never intended to work with the arduino's we have.

3. Concept Design

The proposed design of the AUV can be separated into four distinct sections: the mechanical design, the electrical system (including power sources and component wiring), the electrical components required, and the software system design.

3.1 Mechanical Design Concepts

3.1.1 Concept 1: Reuse the previous years electronic housing and frame

Pros

- No time needs to be spent designing and building a new electronics housing or frame.
- Already meets 125 lb requirement
- Already has all components distributed on the frame
- No money needs be spent

Cons

- Does not meet 85 lb goal
- Constrained by previous year's design
- Poor accessibility to electronics housing
- Poor accessibility to inner compartment of electronic housing
- Weight distribution very poor
- Too much empty space in electronics housing

If we reuse the previous year's design this will save time and money that would otherwise be spent designing and producing a new electronics housing and frame. This design does weigh under the 125 lb requirement set by the AUVSI, but does not reach our goal of being under 85 lbs. Since this design has already been made to last year's specifications, there is minimal room for modifications to the design, even with the use of 8020 aluminum as the frame. This means that even though the frame does hold all the components necessary for the competition, there is no room for a redistribution of the components, which is a drawback of this design.

Other drawbacks that also come with this design include the current electronics housing. This is very bad for our needs because the frame must be partially removed, along with some of the components, just to get accessibility to the electronics housing. The housing is difficult to enter, taking up to hour just to get to the electronic components inside. The other problem with the current design is that the wires were exiting both caps rather than just one. This posed problems with the wiring since they had to be detached while removing the endcaps. Attaching wires again involved reaching awkwardly across the inside of the tube to the other end cap. This was a painstaking step in last year’s design that made them lose countless hours during testing. Finally the cylindrical housing had problems with the wasted space and extra material they had to use to place the electronics into the electronics housing.

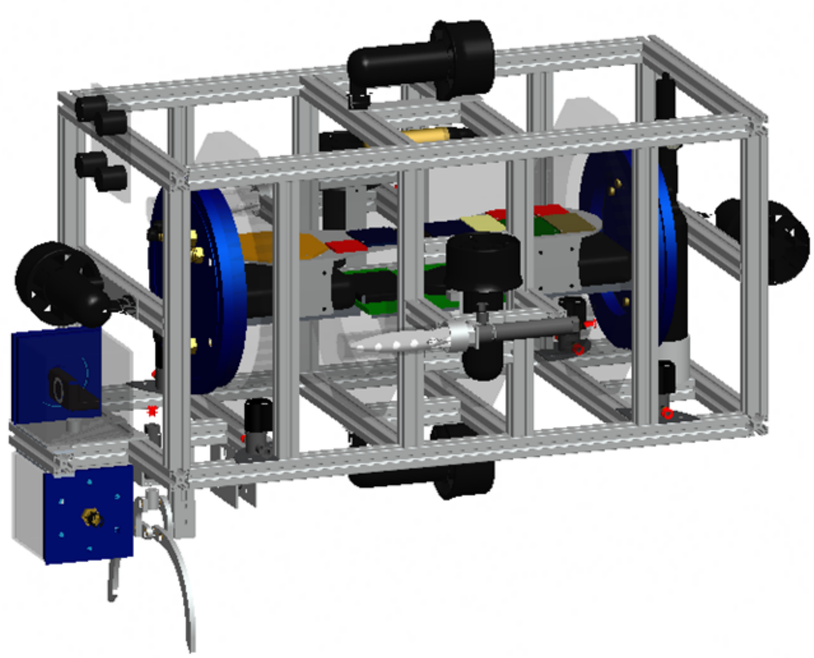

Figure 1. A CAD model of last year’s design

3.1.2 Concept 2: Only redesign the electronic housing caps

Pros

- Will allow reuse of majority of electronic housing and frame
- Easier access to inner compartment of electronics housing
- No time needs to be spent designing and building a new electronics housing or frame, only the caps will be redesigned
- Already meets 125 lb requirement
- Already has all components distributed on the frame

Cons

- Is constrained to the shape and size of existing design
- Does not meet 85 lb goal
- Bad accessibility to electronics housing
- Weight distribution is poor
- Must spend some money on new end caps
- Too much empty space in electronics housing

With the second concept we look at redesigning the endcaps for last year's design. This idea came about due to the difficulty that was found when trying to remove the previous years endcaps. This design concept looked promising because it would allow us to reuse the frame from last year and the outer shell of the previous year's electronics housing while increasing the accessibility to the electronics inside. While this redesign does increase the accessibility to the electronics it does not change the fact that part of the frame must be dismantled to allow access to the electronics case, and the frame will have to remain the same as the previous year since the shape of the housing hasn't changed. With this change there must be time and money spent on changing the design, though the time and money spent are less than doing a complete redesign. Other than the mentioned changes the positives and negatives of the design are the same as those for using the same design since it is the same design otherwise.

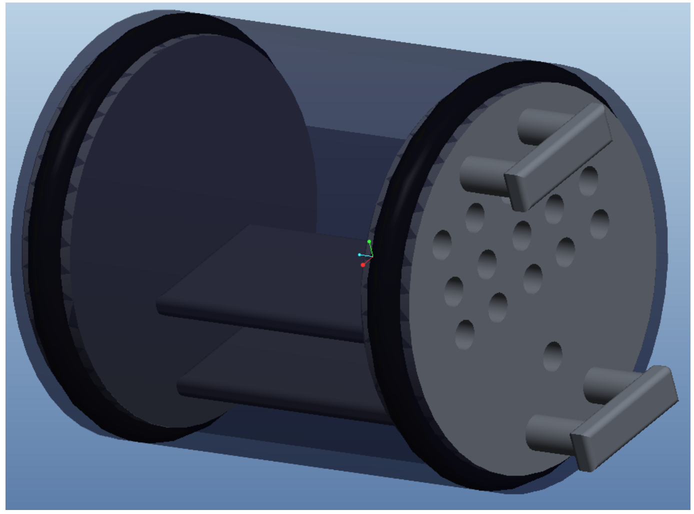

Figure 2. reconfigured end caps for last years design to be used with last years design (not scaled)

3.1.3 Concept 3: Completely redesign the electronic housing and frame

Pros

- Best accessibility into case
- Meets 125 lb requirement
- Not constrained by existing design
- has possibility to meet 85 lb goal
- better weight distribution
- reuses materials from last year's frame, just redesigned

Cons

- Time consuming
- Have to purchase new components for electronics housing
- Have to reconfigure weight distribution

The third and final concept that was developed was to create a new frame and electronics housing. The design we consists of an electronics housing box with the base and sides made from aluminum and the top made from impact polycarbonate. The frame would be made from the same material as last year, 8020 aluminum extrusions, but the layout could be changed since the box left for more possibilities versus the cylinder. With this design there is less wasted space and less material used on the frame. This allows us to achieve our goal total weight of under of 85 lbs. This design also allows for better weight distribution than last year since the frame can and probably will be modified as more components are added to it. Also with the current frame layout the top of the box is left accessible, so the time needed to access the electronics will be greatly decreased. The wires will enter and exit the box through the sides rather than through the top so that we can avoid the problems last year had with the wires.

This design is not without its faults. The largest of these faults being the time and money that will have to be invested into designing, testing, and final building of the electronics housing. The only other major drawback that is noticeable at this time is that the distribution of the components on the frame has not been finalized yet, which could lead to delays in the final concept.

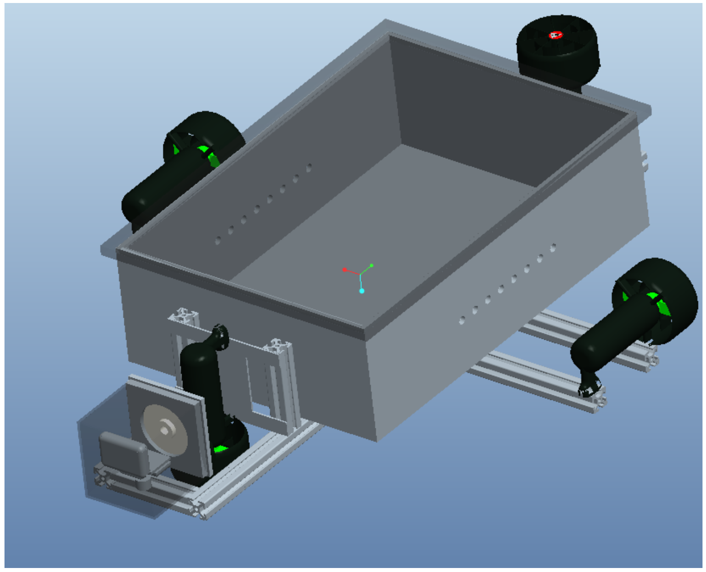

Figure 3. New Electronics Housing and Frame

3.1.4 Final Mechanical Design Decision

Using the decision matrix shown in Table 1, the team calculated that Concept 3 would be the best and most effective choice in accomplishing our set goals in this project. Concept 3 gives the best accessibility with the open design of the electronics housing compared to the more complicated ways involved in entering the other design's electronics housing. The open ended design of this decision allows fewer materials to be used in the frame and a smaller overall electronics box, thus lightening the overall weight of the sub. More time will be spent on building the design, but the benefits from this design far outweigh the cons of this. The cost was higher than the other concept options, but it remains within budget and the associated cost does not detract significantly from the benefits of this design. Our entire team was in unanimous agreement with the result produced by the decision matrix.

	Weight	Accessibility	Cost	Reproducibility	Building Time	Total
Weight	.25	.3	.2	.05	.2	1
Concept 1	5	1	10	1	10	5.6
Concept 2	4	4	6	4	8	5.2
Concept 3	8	10	3	8	4	6.08

Table 1. Decision matrix for Electronics Housing and frame

3.2 Electrical Design Concepts

The AUV will be powered by three separate power sources. The separation of power sources is intended to stabilize each electronic system so that fluctuations caused by the thrusters are not harmful to the other systems.

- The first power source are the two lithium-ion batteries from the previous years design. These batteries are rated at 14.8 V with a 30A maximum discharge rate each. They take ~10 hours to charge. This system is intended to power only the thrusters.
- The second power source is only for the main computer. This battery supports 19V and has a maximum discharge rate of 3A. With a rating of 4AH, it can support the main CPU's power for upwards of 3 hours.
- The final power source is a 12V battery intended for the remaining electronics. This would power all of the electronic subsystems that need external power. This battery has a 4A max discharge rate which can easily handle the power requirements for the current design.

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 2. Current consumption of electrical devices.

3.2.1 Voltage Regulation

Many of the devices used on the AUV require different voltages. This will be possible by using voltage regulators to step down or step up voltages to each individual device. The power source for each electrical component is supplied by the 12V battery. Many of the components in the current design require 5V of power. To achieve this, the high-efficiency Pololu step-down voltage regulator has been chosen.

Pololu Step-Down Voltage Regulator D15V35F5S3 :

- Input voltage: 4.5 V to 24 V
- Typical continuous output current: 3.5 A (Actual continuous output current depends on thermal dissipation.)

- Output voltage selectable as 5 V or 3.3 V
- 700 kHz switching frequency
- 15 mA typical no-load quiescent current (150 µA typical quiescent current with EN=0 V)
- Integrated over-current shutoff
- Small size: 1.68" × 0.46" × 0.3" (43 × 12 × 8 mm)
- Weight without header pins: 0.1 oz (3 g)

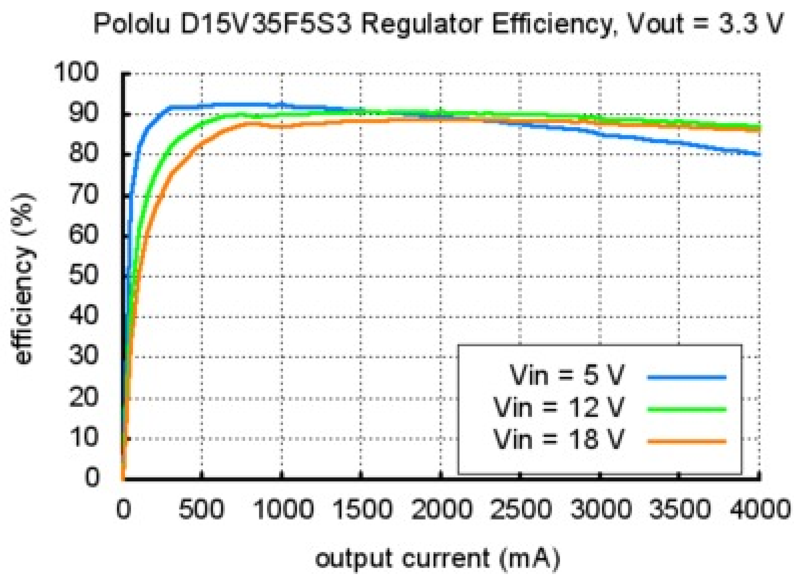

Figure 4. A plot of the Pololu voltage regulator efficiency versus output current for various input voltages.

3.3 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.

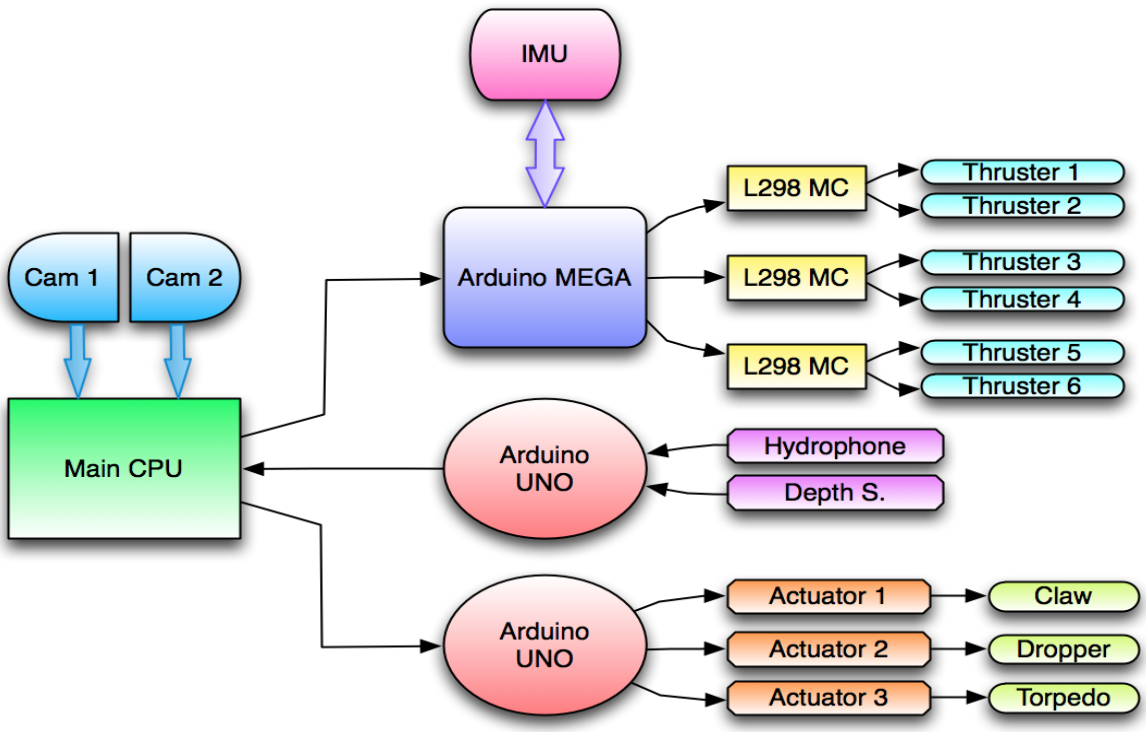

Figure 5. A simple block diagram of the proposed electronics system.

3.3.1 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 output communication to each of those subsystems. 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

The benefits of using this device are myriad. Firstly, it is intended as a lower power and low heat media PC, thus it is designed to produce as little heat as possible while producing enough power for the image processing required of the AUV. Secondly it powers it's own hard drive straight from it's motherboard, without needed external power. Thirdly, it doesn't require a 24-pin ATX like many iTX and Micro-ATX motherboards require. It is essentially a laptop system only requiring 19V DC to power itself. Lastly, it has 6 USB ports to power and communicate with each camera and Arduino.

3.3.2 Arduino UNO

Each serial device needs a "bridge" to communicate with the MPU. The Arduino UNO is a perfect solution to handle this communication. Essentially each Arduino will control a peripheral: motor driver, 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 not only take process power off of the MPU, but also decrease unnecessary communication between every device.

3.3.3 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 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.

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

3.3.4 Vision System

The vision system will use last year's Logitech C615 Webcams, which are perfectly functional and work with OpenCV. OpenCV is an image processing library used by many high ranking teams from previous years' competitions. It works in C++ on multiple platforms including Windows, Linux, Mac, and even Android. This will increase the efficiency in image processing while also making programming easier for detecting and tracking throughout the project. 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 units surroundings.

3.3.5 Air Release Actuators

These actuators are used for controlling the marker dropper, the claw grabber, and the torpedos. Each actuator requires a 7V input to actuate. This will be controlled by an Arduino, but the voltage input will be taken from the 12V battery designated for the electronics.

3.4 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.

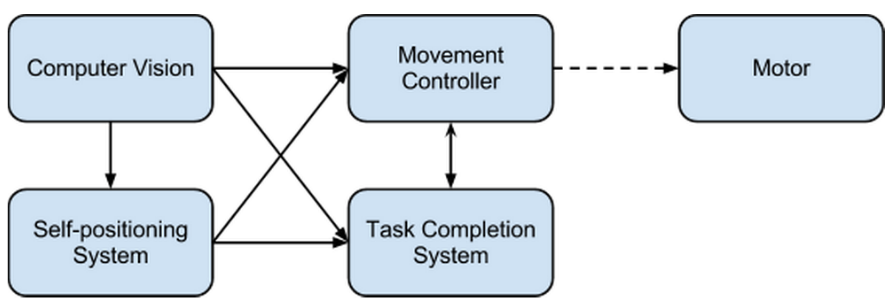

Figure 6. A simple block diagram of the proposed software system with its interactions with external systems indicated by dashed lines.

3.4.1 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.

3.4.2 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.

3.4.3 Self-Positioning System

The self positioning system will use the IMU and the computer vision data to determine where the AUV is with respect to its destination. The self-positioning system can then provide this data to the movement controller or to the task completion system to allow for intelligent corrections. The output protocol has not been decided yet, as it is pending further development of the artificial intelligence system in the sub. This module will decide whether the main system believes a task to have been completed.

3.4.4 Task Completion System

This system is not required for the operation of the sub, although it may be useful in allowing the AUV to account for unexpected situations. As such, this system has been deemed optional, and will only be implemented if the team has time to do so. This system will examine the outputs of the three main operational modules and determine if they are in agreement with each other. This system may also attempt to determine whether other tasks have been completed, such as ascertaining whether an object has been picked up, a gate has been passed, or a marker has been dropped.

In its final implementation, the task completion system should have the final say on the completed status of the current task, and on whether a task should be paused and continued later if it cannot be completed at this time. For debugging purposes, the team may also choose to implement a tracking system to monitor which tasks have been completed; such a system would also be maintained by this module.