Eagle II: Developing Autonomous Underwater Systems - execution and design

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Abstract - Eagle II is the latest Autonomous Underwater Vehicle (AUV) built at Cal State LA. Eagle II has been under development for about a year. Using our first generation AUV as a platform for testing, our team applied all the lessons learned throughout the year and engineered Eagle II to be more compact, ergonomic, and lighter. This year's team incorporated a fully dedicated group of Computer Science students keen to improve Eagle II existing autonomous capabilities.

I.   INTRODUCTION

Eagle II also known as "Nellie" was design with the International Robosub Competition in mind. The objective for Eagle II is to transverse the competition arena autonomously to score the maximum amount of points available at each obstacle station. The Robosub competition is held by the AUVSI Foundation and the Office of Naval Research in late July at the SSC Pacific TRANSDEC facility in San Diego California. Eagle's II design was influenced by many of the streamlined designs seen on the 2017 Robosub Competition. The main goal for this year's competition is to position our team's design among the best and surpass our performance from last year.

Given the experience the team gained working on underwater robotics for two years we created Eagle II in anticipation of improving our performance in the upcoming 2018 Robosub Competition. Figure 1 shows the CAD model of Eagle II.
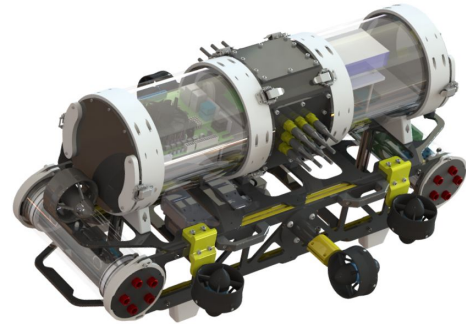

Figure 1. Solidworks Rendition of Eagle II.

As seen on figure 2, Eagle II is a close representation of the CAD design. This is the result of months of research and planning by students at Cal State LA.

Figure 2. Eagle II Eagle II model.

II. DESIGN OVERVIEW

Eagle's II design is broken down into a few different sections:

1) Frame-Auxiliary enclosures,
2) Hull,
3) Power systems,
4) Weapon Systems,
5) Communications board
6) Hydrophones
7) Navigation - Controls
8) Software

1)Frame-Auxiliary enclosures

The basic principle of the frame in the design was to be able to provide modularity and enough working space for all the systems. The 2018 Eagle II prototype features front and rear auxiliary enclosures, internal railing system, and handles for transportation. The frame consists of four major panels of 0.25" thick aluminum 6061. These panels can be seen in Figure 3. Each panel was cut out using a water-jet and anodized in black.
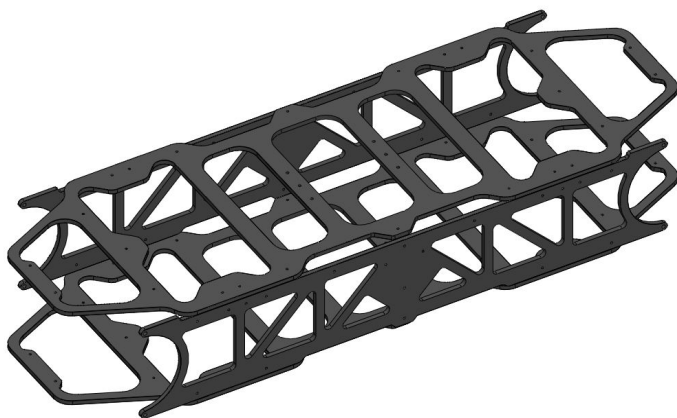
Figure 3. Isolated view of side panels of the frame module.

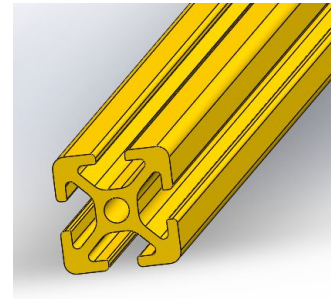These panels are held together using 20mm x 20mm T-slotted aluminum extrusions, seen in Figure 4.

Figure 4. Image of modified T-slotted Aluminum Extrusions[2]

A major advantage of using these extrusions as corner braces is to provide the interior of the frame payload mounting capabilities. This feature is indicated in Figure 5:
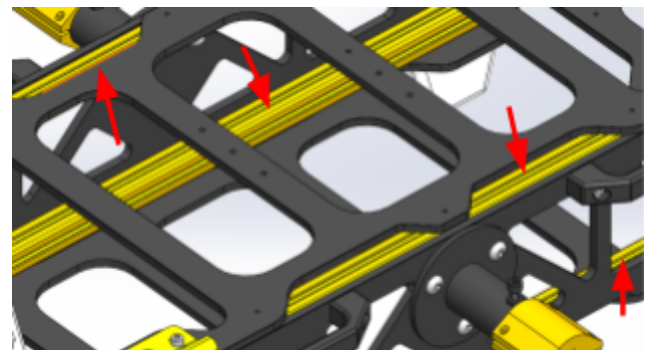
Figure 5. T-slotted Aluminum Extrusions shown inside the frame module indicated by the red arrows.

Another feature of the frame module includes the front and rear enclosures that were purchased off-the-shelf from BlueRobotics, seen in Figure 6. Capable of being submerged up to 300 ft, these enclosures are used as dedicated enclosures for the cameras and batteries.
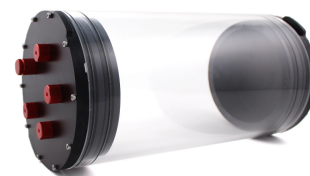
Figure 6. Watertight enclosures from BlueRobotics [1].

In order to mount the auxiliary enclosures, the frame included removable mounting brackets shown in Figure 7.

Figure 7. Auxiliary enclosure mounting brackets designed in SolidWorks.

These 3D printed ABS brackets are mounted on the front and rear of the side panels that would hold the enclosures shown in Figure 8.
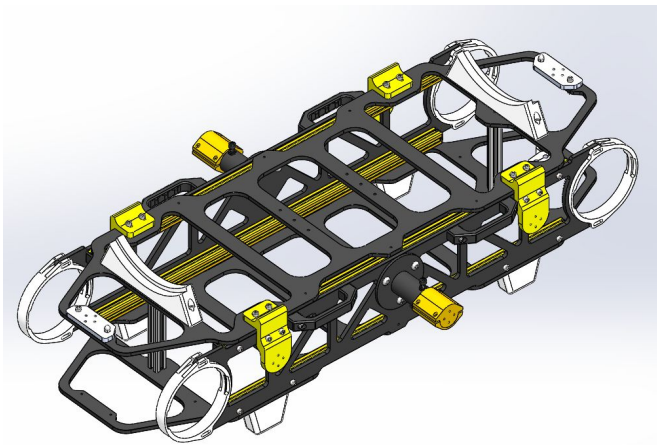

Figure 8. CAD Assembled frame module with carrying handles, vertical thruster, and forward thruster mounts.

The baseplate and side panels are also joined by the vertical thruster brackets that acts as mounting options to point four BlueRobotics T200 thrusters upwards for submerging and emerging operation shown in Figure 9.
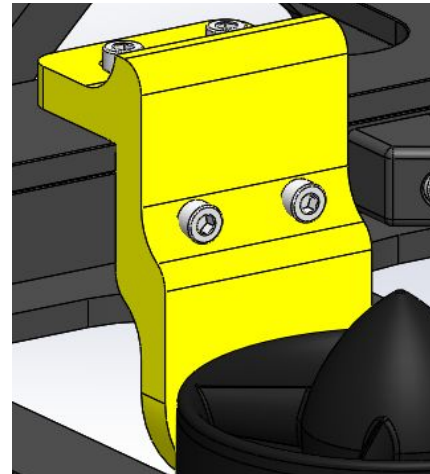

Figure 9. Vertical thruster bracket designed in SolidWorks.

The 3D printed vertical thruster brackets has bores that uses M5 hex-head screws as fasteners to join the base plate and side panels to the T-slotted aluminum extrusions.

An additional ergonomic feature added this year were the use of carrying handles shown in Figure 10. These handles allows easy and safe transportation of the Eagle II.
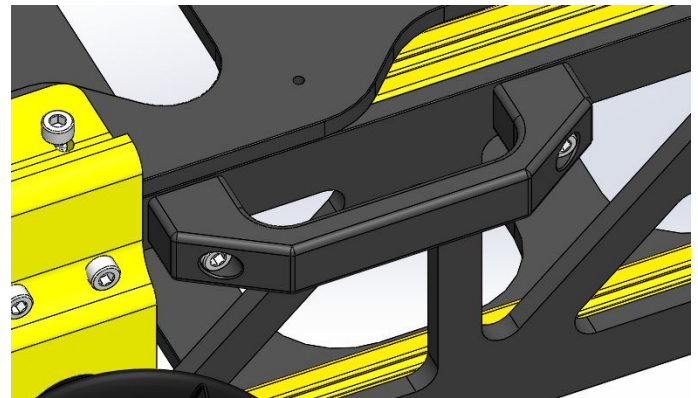

Figure 10. Image of handles used in assembly mated to side panel of the frame.

These features and design choices completes the frame module and can be seen in Figure 11.
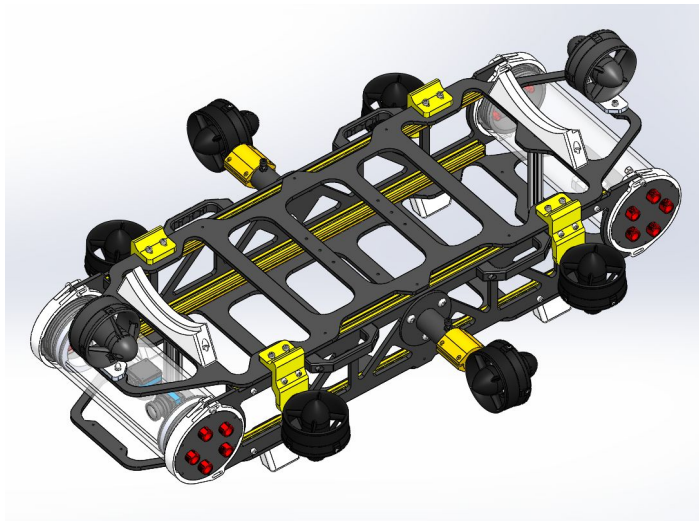
Figure 11. Completed frame module of Eagle ll.

2)Hull

The hull of the Eagle ll is the main waterproof enclosure that houses the major electronic components. This component was designed with accessibility in mind. The hull consists of a machined aluminum center, known as the bulkhead shown in Figure 12, with removable acrylic tubing on each end.

Figure 12. Bulkhead

This design allows for most of the electronics to be directly accessible. The added accessibility increases the space allowed for troubleshooting, wire management, and general operation of the Eagle ll.

The size of the hull was determined by finding the optimal trade off between the space needed to adequately fit all the needed electronics and the amount of buoyancy that the hull creates. This was done by modeling the main electronic components that were going to be used in Eagle ll beforehand, to properly provide enough clearance that the electronics needed.

An additional accessibility added to the bulkhead was the use of faceplates. The faceplates had predetermined water-jetted holes that would fits nine Micro-Wetcon Bulkhead Penetrators, shown in Figure 13, that were purchased from CrustCrawler Robotics.

Figure 13. Microwetcon Bulkhead Penetrator. [3]

For waterproofing the faceplates, O-ring grooves were milled behind the plate. To illustrate this, Figure 14 shows an exploded view of the bulkhead and the faceplate with its o-ring behind it.
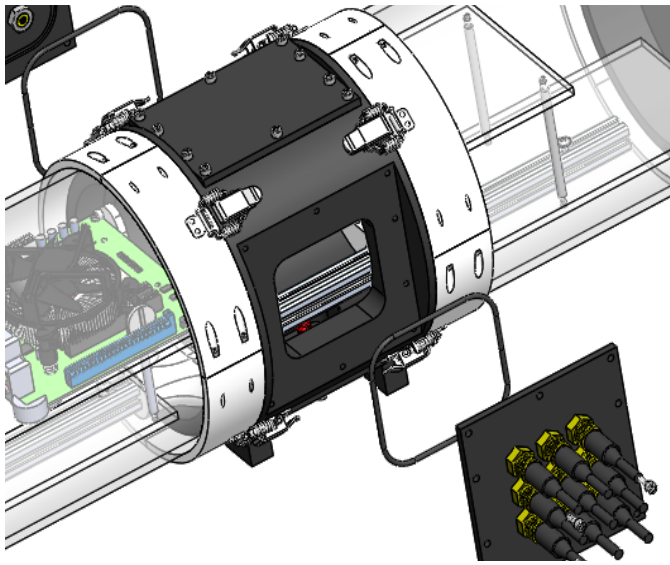
Figure 14. Exploded view of the O-ring between the bulkhead and faceplate.

Latches were added to the bulkhead to provide secure attachment of the acrylic tubing. Unlatching, would allow the tubing to be detachable. The entire upper module, Hull module, of Eagle ll is shown in Figure 15.
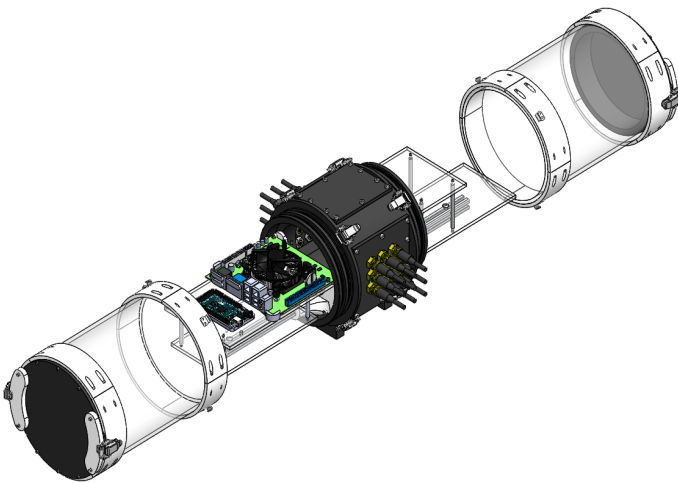

Figure 15. Completed hull module of Eagle ll.

3) Power systems

i) Power supply & batteries:

The electrical design was mainly focus on delivering an electrical system capable of providing all the different regulated voltages for all the electronics and power systems on the Eagle ll. A table of requirements is shown on Table 1 explains the need for each element.

Table 1. Requirements of electrical system

Design element	Requirement	Comment
Loading Sharing configuration	Battery Hot-Swap	Special wiring configuration allows batteries to be disconnected one at the time without system interruptions
Relay LED Monitor module	Visual discharge rate battery monitor	Relay LED module to be connected to LED Array controlled using a PWM driver and microprocessor
Speed Controller 14.8V expansion card including fuse block and mosfet switching	ESC 14.8V fuse protection at 10A	An expansion card has been suggested to organized ESCs using a solder Slot socket. Existing plans include an aluminum heat sink bolted onto the main hull in order to dissipate heat effectively. A fuse bank will be integragrated on ESC expansion card
10A, and 5A fuse protection for microprocessors and sensors	5V @ 2A and 12V 3A fuse protections to step-down switching regulators	A total of 4 power rails at 5V and 12V are protected using fuses. Additionally, a switching mosfet is included working in tandem with a shunt resistor to sense current variations
Shunt - switching combo	Emergency shut-off	Shunt - switching combo allows to record small variations on current. Using a programmable shunt-resistor INA225 IC is is possible to set a shut-off current switch.
Low Voltage Kill Switch and Reed Switch	Kill switch to disable thrusters. Diver accessible	Using switching mosfet configuration it is possible to install a low voltage kill switch. A reed switch is also available to shut-down thrusters without disturbing computer systems
Expansion card ESC board signal control	Provide external access to ESC control signals	Single connector solution for accessing the ESCs signal pins has been suggested. Ribbon cable will be use to send signals from expansion card to microprocessor

ii) Power supply & batteries:

A total of two (2) Multistar High Capacity 4S 10000mAh Lithium-ion batteries operating at a nominal of 14.4 volts are the main power source for Eagle One's main systems. Since regulated voltage throughout the vehicle is essential Eagle One is equipped with a M4- ATX, 250W output, 6V to 30V wide input intelligent Automotive DC-DC PV Power Supply. Our Eagle ll utilizes the M4-ATX intelligent power regulating board to provide steady regulated power to individual electronic elements such as the main Motherboard, microcontrollers, NI DAQ unit, sensors and pneumatic systems (Figure 16).

Fig 16. Lithium-ion batteries [4].

iii) Power budget

In an effort to understand the needed power, a power budget was created to estimate the amount of power Eagle II will require is shown on Table 2.

Table 2. Electrical Power Budget

Part Name	Qty.	Max Current rating	Nominal Voltage	Total Power (Max)	*Estimated Usage Avg Power
Basic ESC R3	8	20A	14.8V	2368W	4 Thrusters 60% power, 414.4W
GeForce GTX 1060	1	n/a	n/a	250W	125W
Mini-TX Motherboard	1	2.5A,4.9A, 0.04A and 0.76A	5V, 12V, 3.3V	75.44W	60W
5V switching regulator	5	2A	5V	50W	30W
12V switching regulator	5	3A	12V	180W	90W
DVL	1	2A	14.8V	29.6W	10W
		Total @ Max = 155.1A			
				Power Total:	**2953.04W**	**729.4W**

iv) Run time and usage considerations

The calculations offered on this section were determined considering the average power required to run all the systems embedded on Eagle II. In order to maximize Eagle's II run time we decided to limit the amount of power given to each of the 8 - T200 Bluerobotics [5] thrusters installed on Eagle II since they require large amounts of power in order to work at full capacity. Since we know that during competition speed is not as important as precision we decided to run Eagle's II thrusters to 60% capacity. The goal is to effectively manage the current draw by these thrusters. This is an important parameter to consider since the thrusters are the primary source of power consumption within the system. Another consideration made to better manage power consumption has to do with the way these thrustes are enabled. Since the thrusters operate on independent coordinate systems all thrusters are enabled in alternating patterns thus giving Eagle II an extended run time. Figure 17 shows the correlation between current drawn and Pulse Width Modulated (PWM) signals applied. The graph below also shows the approximate current required to run the thrusters at about 60% power which is approximately 7 Amps.
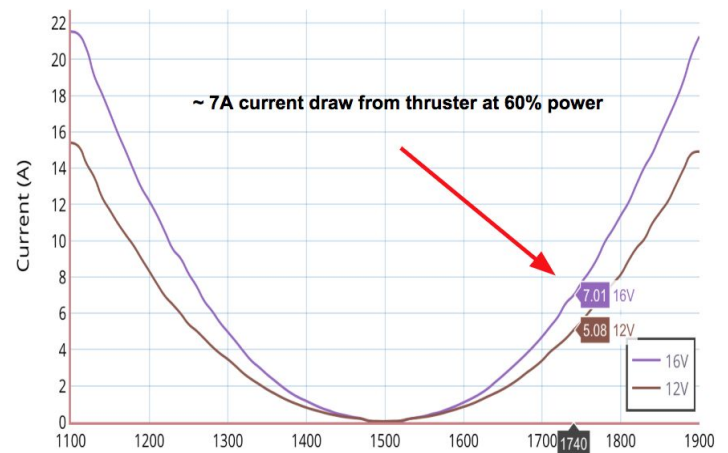

Figure 17. ~ current draw per thruster [5].

v) Electrical Design Overview

As seen on table 1, the total maximum current the system can draw at once is ~155.06Ah. This means that chosen battery configuration is able to support the system at full capacity. Although, it is highly unlikely for the system to operate a full capacity at any given

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time the proposed power configuration is in line with existing power requirements. Figure 18 shows the simplified power systems design implemented on Eagle II that includes a total of three custom made boards for the power systems. The thruster control board which will be explain in more detail in this document and the battery monitoring board with LED strips. The system complies with all the power requirements for all the subsystems found on Eagle II such: 5V power rails for microprocessors and sensors, 12V rail for hydrophones and DVL, kill switch, and power system fuse protection.
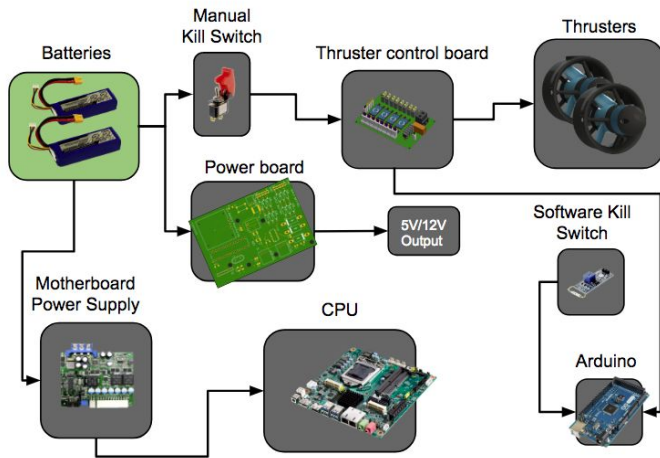

Figure 18. Overview of electrical design

A total of 2 - 14.8V Lipo Batteries@ 10000mAh connected is connected in parallel. These batteries are rated at 10C, 10,000mAh. Using Equation 1,

$$Amp_{total} = mAh_{battery\ rating} \times C_{rating} \quad (1)$$

the total of amp hours is calculated to be provide a total of 296W/h. Table 3 shows the the calculated run time for these batteries given their characteristics and system considerations.

Table 3. Calculated run time

# Batt	Nominal Voltage	Current	C-Discharge rating	Power	Estimated Avg usage power/t	Run time
2	14.8V	10,000 mAh	10C	296W/h	729.4W/h	~40 minutes

vi) Thruster board:

The concept design of the thruster control board was first done using Solidworks in order understand its spatial dimensions for integration inside Eagle II's hull. The electrical layout, schematics and PCB board was done using Eagle PCB design software. The board is used to control the thrusters that provide Eagle II its mobility. Since the thruster board has the speed controllers for the thrusters embedded it greatly simplifies integration of the power systems.

One of the main consideration behind the design is the use of the thruster board in future designs. Some features included into the thruster board are: high current outputs for the ESCs, easy accessible connectors for power, low voltage kill switch, signals and individual protection for each speed controller. The Solidworks design of the thruster board is shown on Figure 19.
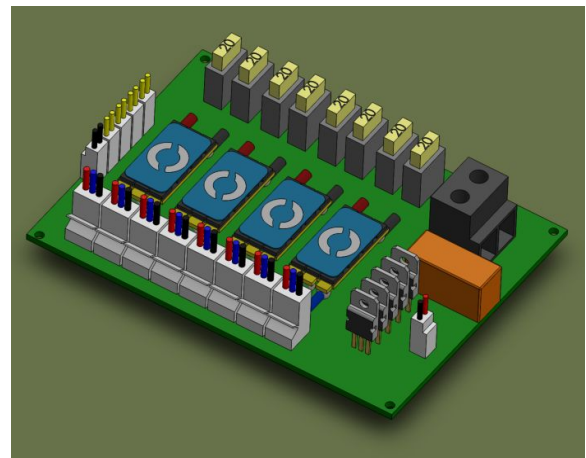

Figure 19. Solidworks design of thruster board

The thruster board was tested extensively before deployment and installation. The Eagle II was then tested using the thruster board without issues. On Figure 20 we can see the Eagle CAD model for the PCB board.
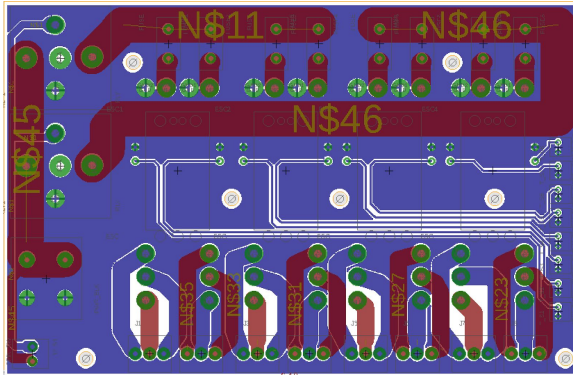

Figure 20. Thruster board Eagle CAD design

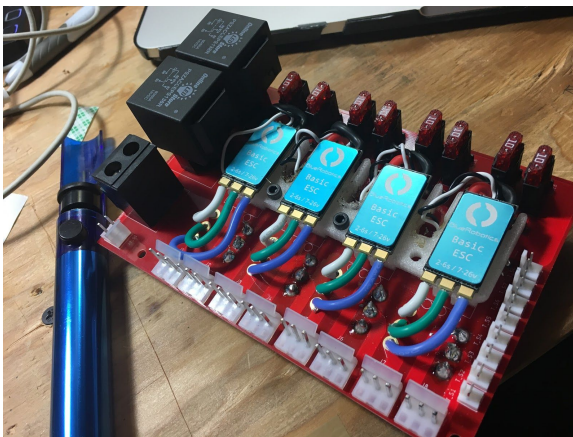The thruster board physical entity is shown on Figure 21.

Figure 21. Physical Design of Thruster Board

vii) Battery Monitoring Board with LED Strips

This year, our team have created a battery monitoring circuit board that shows the status of the batteries with a visual representation using LED Strips. This board uses an Atmega328 microcontroller bootloader with the Arduino IDE to communicate with the LED Strips. Currently there are 2 LED strips, one for each of the

batteries, and an OLED screen to display the voltage levels of the batteries. The LED strips are coded to be red (need to be charge) and green (batteries charged). The LED strips are coded with a proportion of red and green. As time increases on with the usage of the batteries, the number of red LEDs increases while the green LEDs decrease based on the voltage levels in the batteries. Also, when a certain number of red LEDs become vivid, then the remainder of the green LEDs will start flashing at a certain interval, to indicate to the team the urgency of replacing the batteries. Figure 22 shows the EagleCAD design.
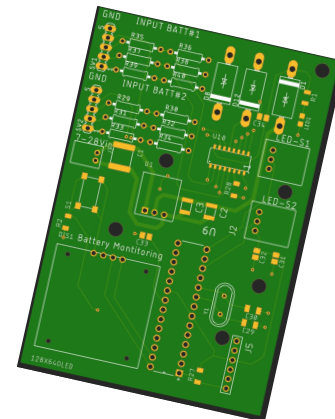

Figure 22. EagleCAD designs for Battery Monitoring board.

viii) Actuator Board

The actuator board is mainly used with the mechanical arm and torpedoes, Eagle II needs to use a total of 5 servos. By using the TLC5940 connected with an Atmega328 microcontroller Eagle II is able to control up to 16 servos from one controller. The Atmega328 is also loaded with the Arduino IDE for ease of programming. In addition, this board is capable of controlling 5 actuators. Figure 23 shows the fabricated PCB board.
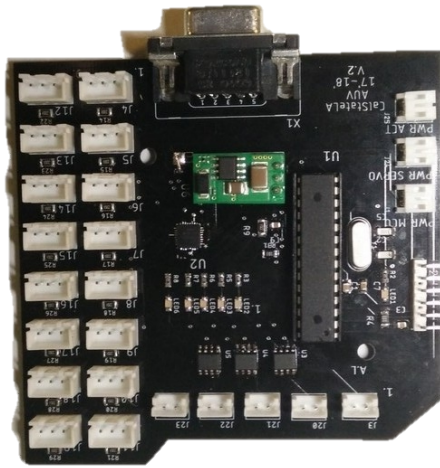
Figure 23. Servo Actuator board

viii) Power Regulator

Due to time constraints our team decided to simply purchase a set of inexpensive and reliable regulating boards requiring 3.3V to 12V. Over current protection feature on this board made it ideal for the Eagle II to protect Eagle II's expensive sensors.

The Yeeco DC DC Buck Voltage Regulator Power Converter Supply Adjustable 7 - 36V to 1.25 - 32V Step down 5A 75W with a Voltmeter display is shown on figure 24.

Figure 24. Voltage Regulator [6].

4) Weapon Systems

i) Mechanical Arm, Dropper, Claw

The mechanical arm is a multifunctional subsystem of Eagle II. The arm simulates a human arm, with the shoulder joint being the mounting interface with the Eagle II, and the forearm being the dropper as the payload release mechanism. The entire assembly is shown in Figure 26.
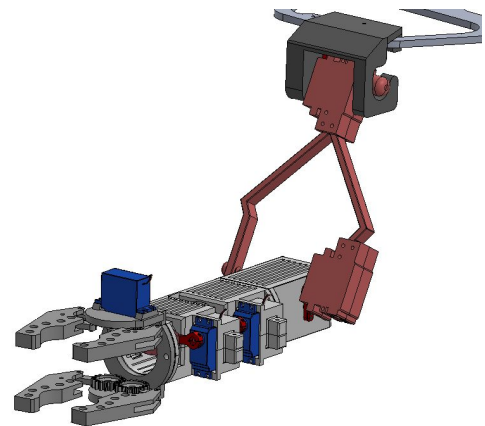

Figure 26. Assembly of MDC.

Seen in Figure 27, the dropper is designed to contain one "Firing Ball" and four "Chambered Balls"simultaneously.
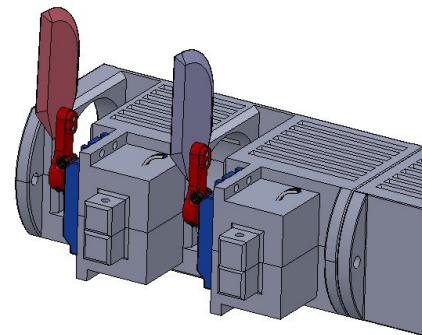

Figure 27. CAD model of the two gates in the dropper that allow the balls to be released.

Shown in Figure 28, the golf balls used in the competition is positioned in the idle state that depicts how it looks when it is inside the dropper.
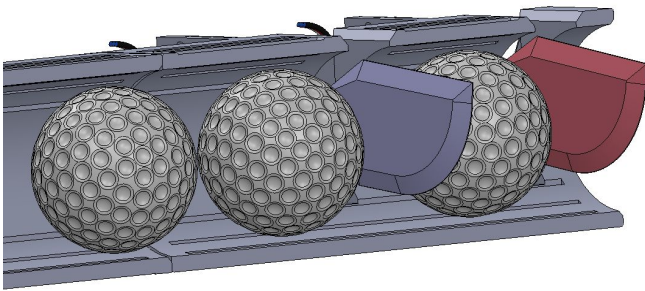

Figure 28. Cross-section of the dropper shows the golf balls positioned behind gates.

ii) Torpedos

This year, the torpedo system has been designed to be spring powered instead of pneumatically driven. In an effort to reduce weight, using servos provide significant weight reduction than reserving weight for an air tank. Seen in Figure 29, the torpedo system is a double barrel design to allow two torpedos to be fired from one unit.
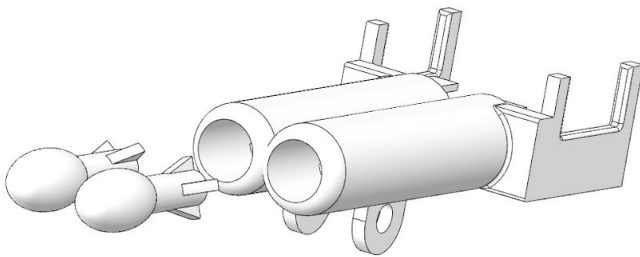

Figure 29. CAD model of torpedo system.

The servos that are used are the DS3218 20kg servos from DSSERVO. These are capable of rotating to 270 degrees and are shown in Figure 30.

Figure 30. DS3218 Servo from DSSERVO. [7]

5) Additional Accessories

i)Battery Enclosure shelving

The battery auxiliary enclosure has a main shelf to keep the battery in place. The shelf itself is held using a set of o-rings pressed against the acrylic tube as shown in Figure 31.
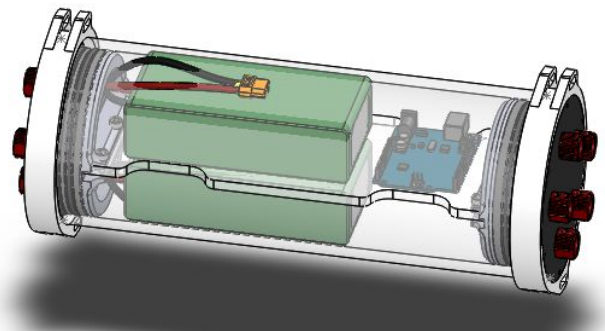

Figure 31. Image of the shelving components that holds the batteries.

ii)Buoyancy Calibration

The Eagle II is equipped with a buoyancy control system that uses a series of adjustable weights to achieve a desired buoyancy and to aid with the balancing of the Eagle II. 3D printed shells lined with marine epoxy are used to protect the weights and to act as an adapter to mount the weights onto 20mm slotted-T frame extrusions located at the bottom of the frame.

By strategically placing weights at specific locations of Eagle II, the optimal moment created will balance Eagle II when it is in operation. The
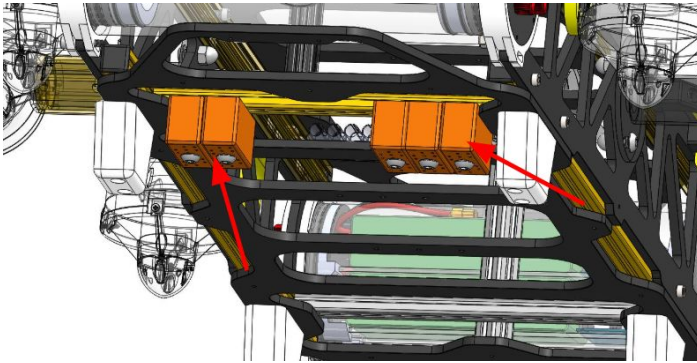
buoyancy calibration system is shown in Figure 32.

Figure 32. Shown in orange, the weights are attached underneath of the frame.

5) Communications board

This year Eagle II CalStateLA team will be incorporating a brand new control. The control board will allow expansion cards to be mounted on it in order to better organize the electronics inside the main hull. Figure 33 shows the boards connected to each other.
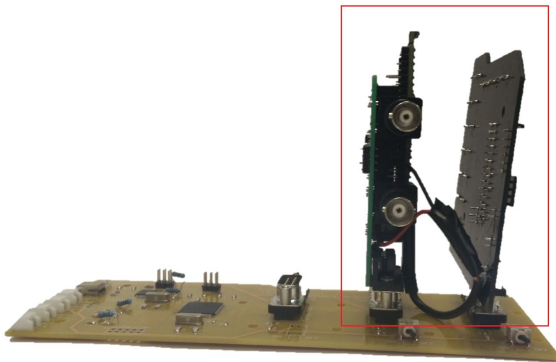

Figure 33. Communications and data board

DataBus architecture

In order to communicate from the control board and with the expansion cards, a common data bus protocol called Inter-Integrated Circuit,

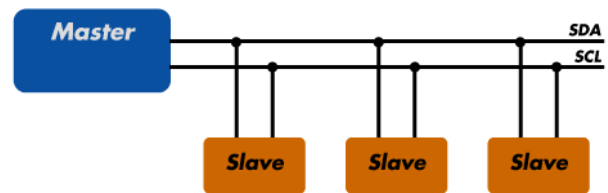also known as I2C shown in Figure 34, will be used.

Figure 34. I2C data bus

I2C protocol works on the simple idea based on master and slave configuration. In essence the master controller transmits data to any slave devices connected within the network.

I2C is a two-wire serial communication. This means only two pinouts are needed from the master controller to establish I2C. The two pins are SDA (Serial Data) and SCL (Serial Clock). Although only two pins are needed, to establish a I2C data bus, pull up resistors are also needed. The Master controller of the I2C bus is the Atmega2560, seen in Figure 35.
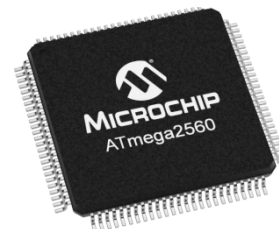

Figure 35. Atmega2560 Master Controller in I2C bus [8].

This micro controller is commonly seen on the Arduino Mega. It features many pinouts and the mass memory space makes it an ideal choice as the master controller within the control board.

Based on the datasheet, the microcontroller features 256KB of flash memory, 32KB of SRAM, and 4KB of EEPROM [14]. It is capable of storing longer scripts, and more variables. Another beneficial use for using the

Atmega2560, is due to its compatibility with the Arduino IDE.

The EagleCAD design of the control board shown on Figure 36 includes two microcontrollers. One of the microcontroller is in charge of managing the I2C data bus while the second microcontroller is responsible for the communication between the controls board with the Central Processing Unit (CPU) on our motherboard. The controls board will also carry a varying number of input and output connectors, specifically D-Sub connectors. The D-sub connectors will serve as the interface between the controls board and the the expansion cards.
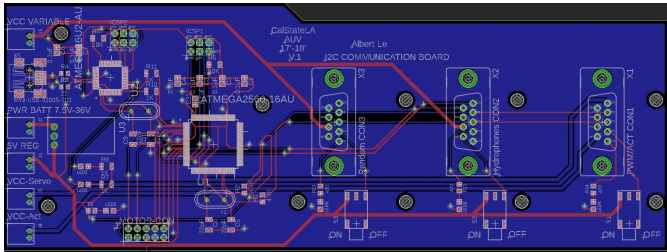

Figure 36. Communications board

6) Hydrophones

The purpose of the acoustics system is to localize two acoustic sources or pingers at each course. Navigating to these pingers will lead us to two obstacles, the roulette and the cash in square. A system that works in real time is crucial. In-order to localize each pinger, the system first identifies a pinger's frequency and then compares the signal captured by four hydrophones to determine the direction of the pinger. Simplicity is a major factor during development since the design needs to be understood by Robosub members that will be competing in upcoming years.

The final design consists of four hydrophones, four active high-pass filters, a PSOC 5 development board from Cypress Semiconductors, and a custom circuit board that holds every component together. A block diagram depicting the system overview is shown in Figure 37.

Figure 37. Hydrophones system overview

Most of the components used were chosen for economical reasons. The printed circuit board measures two by four inches. Single stage high-pass filters were designed to save space and at the same time to effectively lower low frequency noise for each signal. The PSOC 5 development board was chosen due to its size, clock speed of 75 MHz, and simple graphical user interface (GUI), PSOC Creator by Cypress Semiconductors.

Although the embedded board is perfectly capable of frequency and spatial calculations, it was mainly left with the tasks of gathering important signal information and sending it to the main computer. Python, the programming language used to run ROS, takes care of these calculations. Since only one pinger will be active at a single time during competition, as shown in Figure 39. Therefore, filtering methods to separate different frequency signals are not needed. In terms of functionality, the embedded board will filter, amplify, and compare the analog signal gathered by the hydrophones to convert each positive half-wave of the pinger signals into 5-volt pulses. This process is shown in Figure 38. Four rising and falling edges will then be time stamped with with the use of four synchronized timers inside the PSOC.
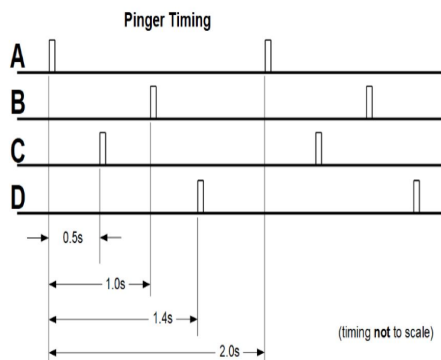
Figure 38. Robosub 2018 pinger timing [9]

The range based method time difference of arrival (TDoA) is then used to localize the pinger. This method relates the time delay between the signals picked up by two hydrophones to the distance between each hydrophone to the pinger. Figure 39 shows how this method manages to relate the distance to the time delay. In this figure the distance of one hydrophone to the pinger is labeled as 1 and the difference in distance between each hydrophone and the pinger can be explained by the following equation:

$$X_2 - X_1 = vt \qquad (2).$$

in which v is the speed of sound underwater and t is the time delay between the signals picked up by the two hydrophones.
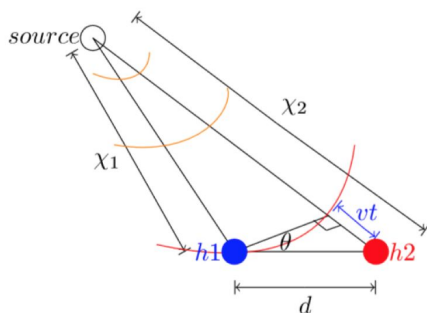

Figure 39. Geometrical relation used in TDoA technique

With the angle information as well as the information acquired from the navigation systems Eagle II will be able to localize each pinger at the Robosub competition of 2018.

7) Navigation - Controls

i) Sensorsuite

Eagle II is equipped with various sensors used to process its environment: an inertial measurement unit (IMU) is used to measure the specific force, angular rate and magnetic field surrounding Eagle II. A sonar composed of four hydrophones is used to locate an underwater sound emitters. An stereo vision camera set gives Eagle II depth perception and 3-dimensional structures recognition. A barometer or depth sensor is used to actively measure depth. A Doppler Velocity Log (DVL), measures velocity of Eagle II relative to the bottom of the pool using the doppler effect. The IMU and DVL work in tandem to derived the position, direction and location of Eagle II, shown in Figure 40.
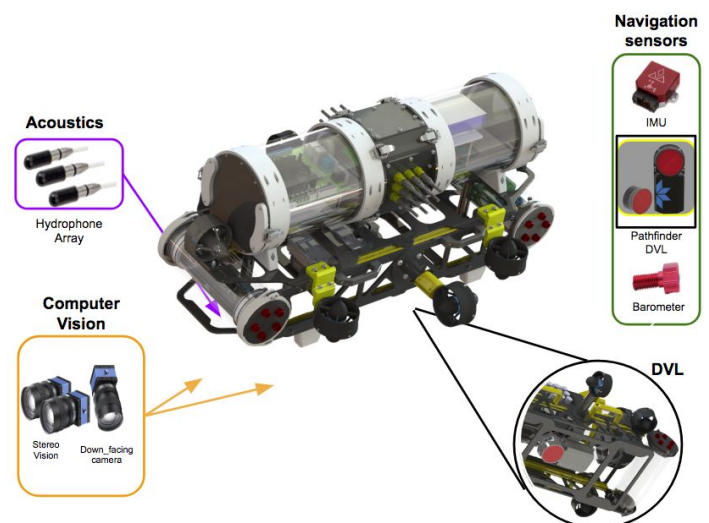

Figure 40. Eagle II sensorsuite

Underwater operations are challenging since terrestrial localization systems such GPS

are not currently achievable underwater. Instead the Eagle II relies on its navigation sensors to accurately navigate underwater. In order to keep the Eagle II stable and at known location the data obtained from its navigation sensors is fused together and processed using four independent closed loop control algorithms to remove any orientation errors while the vehicle it in motion. By knowing the vehicle's exact velocity and having precise control of the Eagle II's roll, pitch, yaw and depth it is possible to keep the vehicle stable and to know its location at all times. In Figure 41 we can observe the general configuration for the navigation sensors centralized on the idea of an integrated synchronous Kalman filter to resolve sensor data.
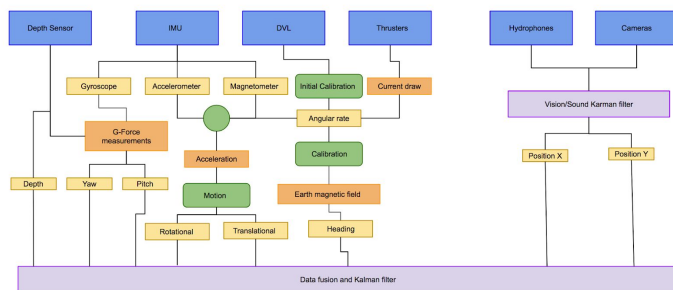

Figure 41. Navigation sensors block diagram

The closed loop control system implemented on the Eagle II revolves around the idea of having full control of the system while minimizing directional errors and optimizing the results. A PID closed loop control system is ideal since we can change the behavior of the system by simply modifying a few key values within the main PID controller.

The desired X, Y, and Y position of the Eagle II is optimized by programming into the PID algorithm a desired set point. Ideally, we would like the Eagle II to remain at specified position and location at all times. By setting up a desired position the PID controller will compare the current position of the Eagle II and the set point to create a position error. This error is then process through the PID algorithm. The integral products are added to an accumulator and the total values added back to the corresponding proportional products. The obtained velocity rates are then multiplied by the derivative coefficients to create the optimal PWM pulses needed to run the stabilizations thrusters. In a similar fashion the depth PID controller is coupled to the pitch, yaw and roll PID controllers to provide total stabilization even while the Eagle II is submerging or emerging.

Additionally, the same PID control algorithm incorporates control parameters for forward and reverse motions in order to keep the Eagle II at a fixed position. This is an important feature since it helps the Eagle II stop at the desired position gradually effectively working as a control braking control system. The main ideas behind the PID control system is illustrated on Figure 42.
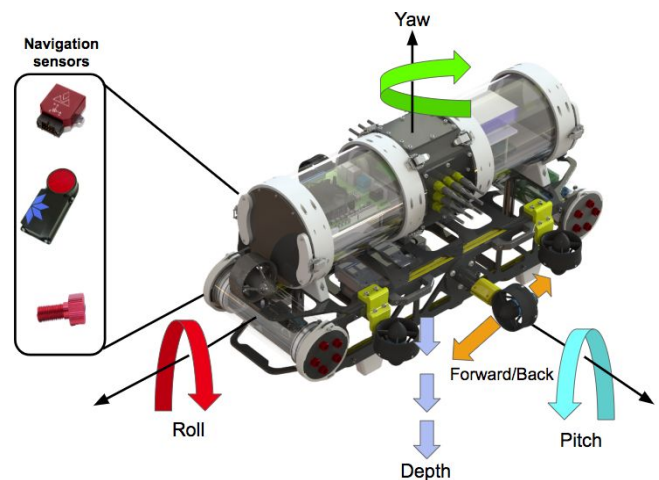

Figure 42. PID controller axis of motion.

ii) Stabilization and development

Experiments

A single axis rig's was fabricated in order to test the PID algorithms. The rig served as

initial testing bed and was helpful to develop the first PID algorithm loop related to the roll motion of the Eagle II shown in Figure 43.

Figure 43. Single testing stabilization rig

After PID algorithm for one axis was developed, a four thruster testing rig shown in Figure 44 was fabricated to test a PID control system for roll and pitch suitable for the Eagle II.

Figure 44. Two axis stabilization rig

The thrusters used on the Eagle II were purchased from a company called BlueRobotics. The model of the thrusters is T200 each thruster also included the Afro electronic speed controllers (ESC) rated at 30 Amps. These thrusters came with two distinct propellers. One of the propellers is a clockwise propeller and the other is a counter-clockwise propeller. After extended research, the proper position and configuration of each propeller were determined. This configuration is seen in Figure 45.

The configuration of the propellers is very important in terms of stabilization. By placing the propellers at a specific rotational position (opposite to each other) it is possible to negate rotational forces created during operation of the thrusters. Additionally, by installing the propellers following this configuration we were able to determine the precise combination of thrusting vectors related to individual maneuvers executed by the Eagle II such emerging, submerging, and stabilization (roll & pitch).
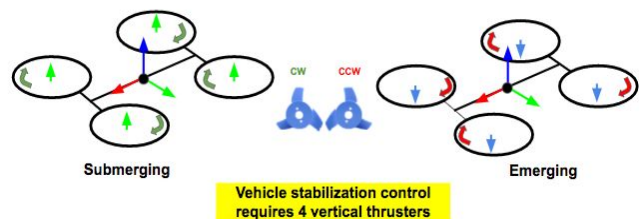

Figure 45. Propeller rotation and configuration

With the use of PID controllers, the Eagle II will stabilize automatically using a feedback loop. The feedback loop dampens the oscillating forces when the Eagle II correct itself upon the rolling and pitch axis. The PID controller was tested on an Arduino that controls four BlueRobotics T200 Thrusters positioned at 4 corners. The Solidworks renditions of the experiment with four T200 Bluerobotics thrusters mounted on T-slotted Aluminum extrusions can be seen on Figure 46.
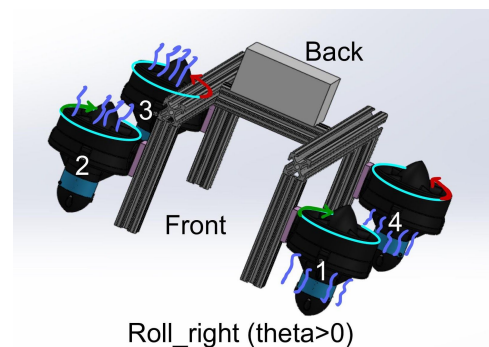

Figure 46. Solidworks rendition

The completed thruster rig was fully tested yielded satisfactory results.

8) Software

Due to the complexity of the project, there were a variety of different existing resources and technologies used in the implementation of this project. The main purpose of using previous works and technologies was to save time and find solutions which have already been found for specific problems and finding ways in which to incorporate them into the project. Furthermore, there were a number of different libraries and resources which prove to be invaluable for the implementation of the code.

i) ROS and Architecture

ROS is a middleware that works between the operating system and the hardware. ROS provides ways for the software to communicate messages, control devices, and power motors. This was indispensable for the team because without ROS the team would have been stuck writing code to maneuver the Eagle II from scratch. ROS provided a simple solution to powering motors and other necessary hardware as well as a simple way for different pieces of hardware to communicate with one another.

The main usage of ROS is for it to be a communication system. The team has designed each program module around being a ROS communications node. ROS allows for each node to publish data to general access data streams that any other ROS node can subscribe to. This allows each node to operate independently on its own thread, allowing a natural multithreaded design to occur for the program in general without the usual multithreading.

In addition, ROS is used for the control systems of Eagle Two to communicate with the hardware such as the motors, hydrophones, torpedo, and claw. This works by passing information between ROS and a built in ROS Python serial communication node, which then will communicate with the Arduino over serial communication to allow for broadcast messages between ROS and the Arduino. This allows the control systems to receive information from the sensors and then dictate commands to the hardware with the given information.Figure 47 shows the block diagram and the communication between the hardware and software.
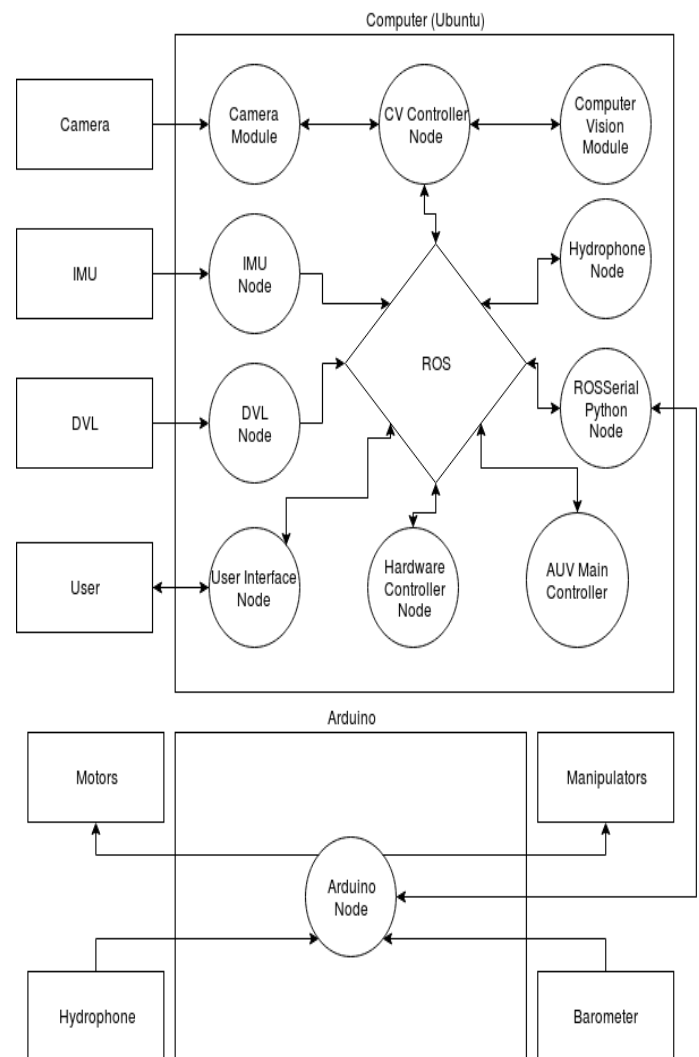

Figure 47. Software Arch: Flow chart containing ROS nodes, program modules, and hardware

ii) Navigation

Eagle Two's navigation design is to make provide easier for the Eagle II to be controlled by the user. Navigation will receive 3 different inputs to navigation through the course. These inputs include rotational movement, height movement and directional movement, which can be called "r_nav", "h_nav" and "m_nav" in their respective order. The "r_nav" will be used to control the yaw axis of the Eagle II. The "h_nav" will be used to control the depth of the Eagle II. Finally, "m_nav" will be used to move the Eagle II on an x, y plane. The navigation of the Eagle II will be determined by the task at hand as well as by the data being received by either the computer vision or hydrophone sensors. Once a desired location is determined by the Eagle II using either sensor, the Eagle II will use navigation to broadcast r_nav, h_nav, and m_nav over ROS. On the other end of ROS will be an arduino waiting for those commands which will instruct the thrusters to move the Eagle II towards its location. A brief schematic representation of the directions for each command can be seen on Figure 48.
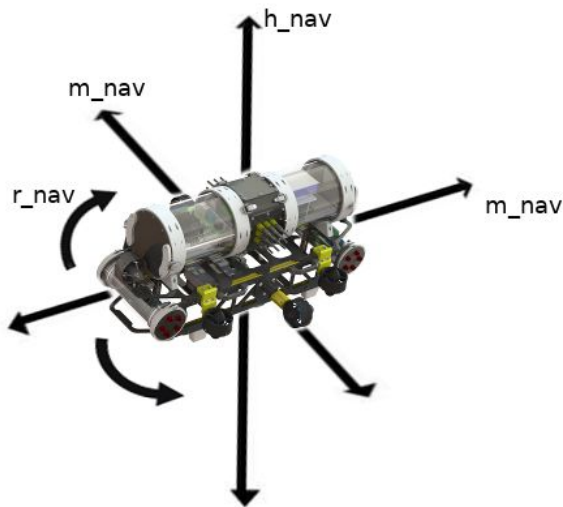

Figure 48. Navigation of the sub

Eagle Two is also equipped with a DVL. The DVL gives a constant stream of position and velocity data that we are able to use. Our DVL provides the position data in three dimensions in relation to Earth, allowing Eagle Two to constantly record where it has previously been. This allows us to easily calculate the direction and distance between various points so that Eagle Two can return to previous positions and also facilitates position holding.

iii) Computer Vision

The computer vision incorporated the use of several critical Python libraries. The most significant of which was OpenCV. OpenCV provided the bulk of the preprocessing and image fetching capabilities to the software. Several examples where OpenCV was used for include; fetching images and video, providing different color filtering to the images, edge detection, gaussian blurring, and other transformation. OpenCV allowed the computer vision team to reduce the complexity of integrating algorithms on image files. Additionally, the scikit-learn library provided the machine learning algorithms necessary for training and accuracy prediction. Furthermore, the computer vision team used other Python libraries such as Numpy, Pandas, Keras, and Matplotlib. These libraries were used to provide further functionality on top of the image manipulation. Functionalities include machine learning algorithms, optimized matrix and vector manipulation tools, data analysis, abstracted neural network constructions, data plotting and graphing, etc. The gate recognition algorithm in action is shown on figure 49.

Figure 49. Example of CV Detection: Image is of a positive find of a gate during pool testing

The computer vision module, seen in Figure 50, receives images from the cameras then runs the images through various preprocessing filters.
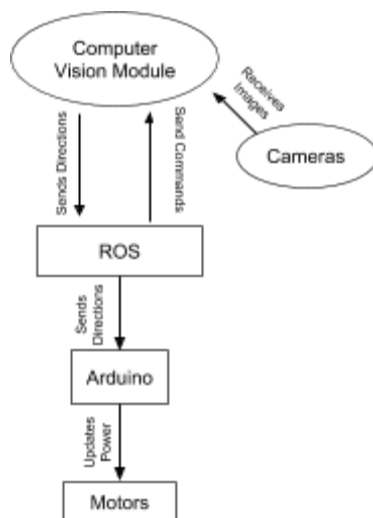

Figure 50. Flowchart of computer vision module communication throughout the system.

The purpose of the preprocessing is simplify the distinction of regions of interest within each image which might contain the target object(s). The step is done in order to reduce the computational workload used by the classification algorithms, by only having to run the algorithms on these regions of interest rather than on the entire image. The majority of the tasks use a Support Vector Machine for classification of candidate regions, with Histogram of Oriented Gradients used for feature extraction. An example of this processing is shown in Figure 51.
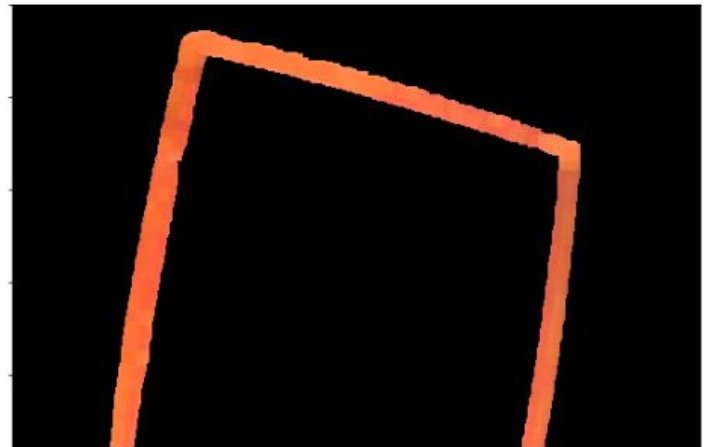

Figure 51. Example of image preprocessing: Image after a frame has been through our preprocessing pipeline.

When the classification algorithm is run on each region of interest if a positive is found the computer vision then updates the directions being sent to the ROS module.

IV. CONCLUSION & SUMMARY

In conclusion our team has successfully designed and tested a fully functional autonomous underwater vehicle. The Eagle II was fully tested at 13 ft depth and was able to execute different maneuvers underwater such submerging, emerging, turning in various directions as commanded while keeping itself stable. Additionally, our Computer Science team was able to gain full control of the Eagle II and pre-program a few underwater routines including actively searching for the competition gate and dice. Through the use of various software and different manufacturing techniques our team was able to program and build the

entire Eagle II using all resources offered at Cal State LA campus. Shown in Figure, the entire vehicle was rendered in SolidWorks. Shown in Figure 2, the actual vehicle was assembled and tested. The vehicle will begin its training and calibration for the competition held on July 30th to August 5th at the RoboSub competition this year.

V. ACKNOWLEDGEMENTS

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