Eagle One: Autonomous Underwater Vehicle Design and Implementation

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Abstract - The goal of the AUVCalStateLA team is to design, build, and test an autonomous underwater vehicle to compete in the annual AUVSI RoboSub Competition. Our team is run by undergraduate students and is open to all students from freshman to senior levels. We are committed to bringing real-world experience to students as they learn to solve complex problems and build connections between science, technology, engineering, art, and mathematics. We hope to provide a safe and fun environment for the development of autonomous systems to foment high-level thinkers concerned with social and environmental issues.

I. INTRODUCTION

The AUVCalStateLA team began working on the development of an Autonomous Underwater Vehicle (AUV) pet name "Eagle One" on June 16, 2016. Our objective is to design an AUV capable of traversing an obstacle course without human intervention for the annual AUVSI Foundation and ONR International RoboSub Competition 2017, held in late July at the TRANSDEC facility, part of SPAWAR Systems Center Pacific in San Diego California.

This is the first time Cal State LA will participate in the International Robosub challenge, and our team developed a design strategy which allows for us to effectively deploy the first iteration of Eagle One, and provides the platform for many more "Eagles" to come. Eagle One was designed to serve multiple applications at once, and while competing in the International RoboSub Challenge this year is our primary objective, Eagle One is meant to serve as a building platform for students at Cal State LA interested in underwater robotics systems (fig 1).

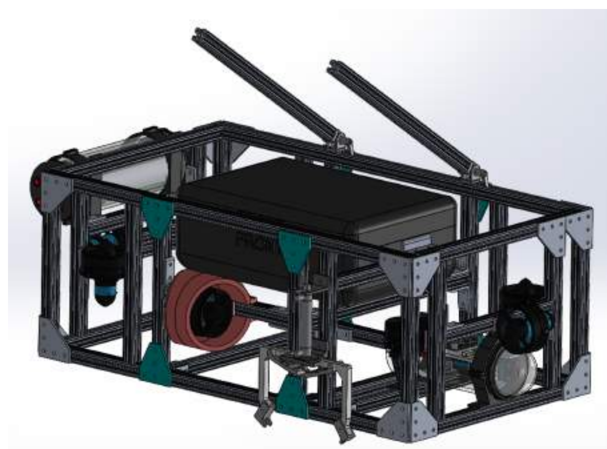

Fig 1. Eagle One – Solidworks CAD design

II. DESIGN OVERVIEW

The following offers a general overview of our project with context provided by individual team members who participated in the design and development of Eagle One and contains our team's findings, conclusions and recommendations relevant to underwater robotics and the development of autonomous robotic systems. During development our team experienced a number of challenges and exciting achievements that in one way or another shaped the outcome of our final product.

A. Design Strategy

Our team's general approach to design was mostly motivated by the desire to quickly and effectively introduce our team members to the world of AUVs, while maximizing learning opportunities and providing useful hands on experience. In order to optimize our time and effort our team built a quick PVC prototype aimed at helping us gather important empirical data and learn different fabrication techniques. This approach provided our team members with essential hands-on experience and we acquired knowledge which helped us understand important underwater robotics principles such as waterproofing, buoyancy, propulsion, and underwater maneuverability of a rigid body.

Fig 2. Eagle One quick prototype

B. Mechanical Systems

The Eagle One mechanical team designed and built a structurally solid frame, water proof hull, and mounting brackets to hold a total of eight (8) T200 Blue Robotics thrusters to provide the thrust required to control Eagle One's motion underwater. The main hull of our AUV is a waterproof Pelican iM23000 Medium Case.

1) Frame: Eagle One's frame is built out of clear Anodized T-Slotted Aluminum and various types of aluminum brackets. The total weight of the frame represents most of the sub's weight, which is approximately 40 lbs. Eagle One's frame is 100% modular due to the inherit modularity of the aluminum framing links making the installation of different sub-systems easy since many brackets and accessories can be added without any modifications to the frame. Additionally, spare parts can be purchased on the market place making the process of attaching different accessories to the frame even easier.

The main aluminum frame for Eagle One allows for our team to place the thrusters in different locations and positions. These are important features that helped our team test different thruster configurations during underwater testing. The aluminum frame also features an adjustable thruster plane to help balance buoyancy forces along the motion axis. The design of the frame makes it possible for the main hull to be positioned at different levels relative to the frame and thruster plane giving the design complete flexibility when it comes to buoyancy adjustments.

2) Main Hull: The main hull for Eagle One is a Pelican iM2300 Case with interior dimensions of 17” x 11.7” x 6.2”. This type of waterproof case is normally used for military applications since they are durable, waterproof, and submersible. In order to verify the manufacturer’s claims of a fully submersible case our team conducted two (2) controlled tests. The first test consisted of submerging the Pelican case for 4.5 hours at an approximate depth of 5 ft. The second test was done overnight at the same approximate depth. Both tests concluded successfully.

3) Waterproof connectors: After extensive research our team agreed on the installation of 13 SeaCon Bulkhead Penetrators rated at 10,000 PSI suitable for all kinds of applications including underwater robotics. In addition to the SeaCon waterproof connectors we also installed a total of four (4) 6mm and 8mm diameter cable-penetrators (fig 2.)

Fig 2. SeaCon connectors

4) Electronics shelving unit: All electronics inside the main hull are organized in three (3) different shelving layers. The first layer is designed to host a total of eight (8) Blue Robotics speed controllers (ESCs). The second layer holds our data gathering unit from National Instruments, power distribution unit, step down regulators, main power supply, and microcontrollers (fig 3.)

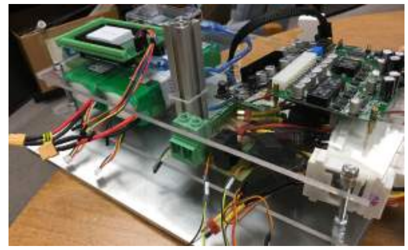

Fig 3. Electronics internal shelving unit

5) Propulsion: One of the most important and mind boggling tasks for our team was selecting the proper thrusters for our AUV. After extensive research and thruster comparisons our team settled on Blue Robotics thrusters. Some of the main deciding factors for our selections were: maximum thrust factor, dimensions, weight, power consumption, ease of maintenance, and affordability.

The Eagle One thruster scheme is as follows: Four (4) thrusters are used to control roll, pitch and depth. Two (2) thrusters allow for the AUV to turn left and right. The remaining two (2) thrusters on the configuration are used to move forward and reverse (fig 4.)

Fig 4. T200 Blue Robotics thruster

Based on the data obtained from different sources and manufacturers, our team’s approach was to favor affordability and rapid development. We concluded that even though the power requirements to power-up eight (8) Blue Robotics T200 thrusters is substantially greater than the power required by other brands such SeaBotix BD-150 and 400HFS-L (based on manufacturer specifications), the thrust, price, and weight of the T200 thrusters justified the installation of additional batteries. In summary, the T200 thrusters from BlueRobotics are capable of delivering a combined total thrust output of approximately 40.8 kgf effectively offsetting the added weight due to additional batteries.

6) Additional waterproof enclosures: The batteries used to operate our AUV were placed inside our main hull during early development stages, however, this approach made it hard for us to replace the batteries without having to dismount a few different modules. Our team decided to build a different power enclosure in order to gain unrestricted access to the batteries. We were able to deliver a solution to this problem at a very fast pace since most of the materials we readily available online and local vendors. As illustrated below the battery enclosure is fabricated from a 4" acrylic tube with modular end-caps with holes for cable penetrators (fig 5.)

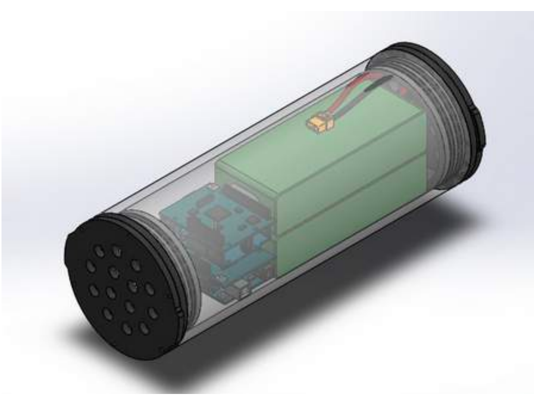

Fig 5. 4-inch power enclosure

Eagle One's cameras used for computer vision were also placed in an optical clear 4-inch enclosure (fig 6.) The camera configuration and computer vision details are explained in the following section (Electrical Systems) under sub-section 5.

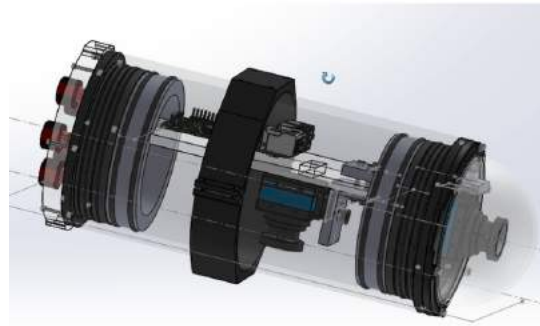

Fig 6. Computer Vision enclosure

C. Electrical Systems

1) 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 AUV 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 (fig 7.)

Fig 7. Lithium-ion batteries

The M4-ATX power supply is an efficient solution for our AUV due to its small size and its broad range of input voltage. The 5V output rail in the 24 pin ATX connection is used to supply power to the onboard Arduino boards. This output rail can supply up to 20A of current (fig 8.)

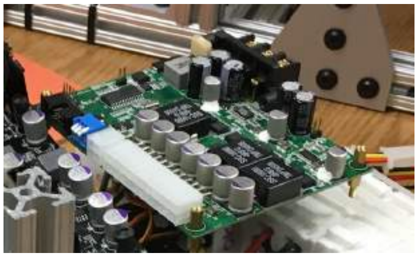

Fig 8. M4-ATX DC to DC power supply

2) Power Distribution board: The purpose of the Power Distribution Board is to provide a wire management solution by minimizing wire usage within the autonomous submarine thus helping us to gain precious space inside the main hull. EagleCAD software was used to design the power distribution PCB (Printed Circuit Board) layout. We created a circuit with the appropriate trace width to accommodate the amount of current going to each of the thrusters. By using a trace calculator, we estimated that each trace coming out of the batteries is ~6mm in width capable of handling ~40 amps. The power distribution board has eight (8) fuses to protect all electronics connected to the board. These fuses act as a switch that automatically opens to interrupt the circuit's current in the event of an overcurrent condition (fig 9.)

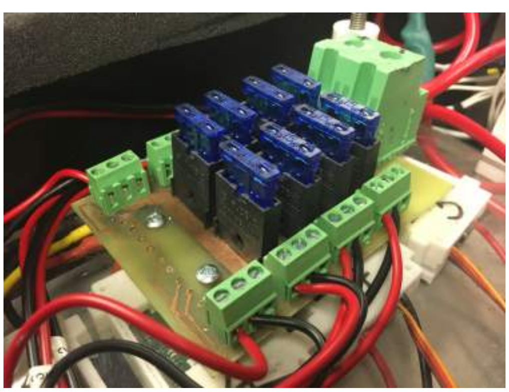

Fig 9. Power distribution board

3) Voltage Alarm System: The purpose of the Voltage alarm system is to monitor the general health and discharge levels of the Lithium-ion batteries installed in the AUV. When in operation the voltage alarm system will send a signal to turn on a set of RGB lights located outside the main hull. This visual cue can be seen from the surface indicating that the batteries are low and must be recharged. Using an Arduino Uno our power team developed the necessary Arduino code to quantized the analog signal obtained from a Lipo monitoring unit to enable and disable the relays that provide the necessary power for the RGB lights set. Using EagleCAD software our team designed a circuit that incorporates LED lights, Arduino microcontroller, and relays. The circuit includes a set of reset buttons used to re-initiate the circuit when needed (fig 10.)

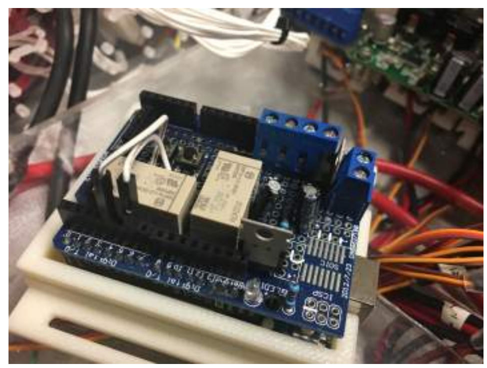

Fig 10. Lipo Battery monitor

4) Kill Switch: The kill switch was designed using Solidworks and 3D printed in-house. The sub has two (2) main power switches capable of shutting down two (2) different sections of the AUV independently. One is located inside the hull and it is meant to disable the speed controllers/thrusters of the sub without disturbing the main CPU. This approach allows for our CS team to work on the internal motherboard for extended periods of time. The main kill switch is located outside the hull and attached to the actual AUV aluminum frame. This switch is capable of shutting down the AUV completely once activated (fig 11.)

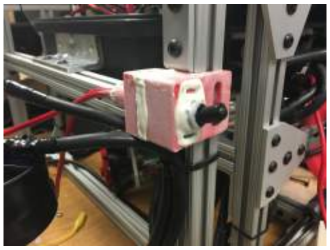

Fig 11. Main kill switch

D. Control Systems Sensors

The control systems team has taken a reliable yet simple approach to design. Eagle One's current systems controls include: An Arduino Mega 2560, three (3) Arduino Uno (custom PCB boards), and a central processing unit (CPU). The Arduino Mega is in charge of all the heavy lifting required to facilitate I/O communication between Eagle One's thrusters and the main central processing unit. It is also the host to an IMU unit used to stabilize the sub. Eagle One can also be controlled from the surface using a CAT 6 Ethernet tether via a remote desktop application installed on Ubuntu 14.04 operating system. The team also developed a Graphical User Interface (GUI) which runs a Python program to control the speed of the thrusters installed on Eagle One.

1) Internal Measurement Unit (IMU): An MPU-6050 unit was chosen due to its extensive documentation, reliability, and price. The IMU unit is used to calculate the sub's angular position relative to its initial position within the x, y and z-axis. The IMU unit communicates over an I2C protocol to transfer data from the sensor connected to an Arduino Mega. The MPU-6050 has an integrated 3- axis Gyroscope along with a 3-axis Accelerometer (fig 12.)

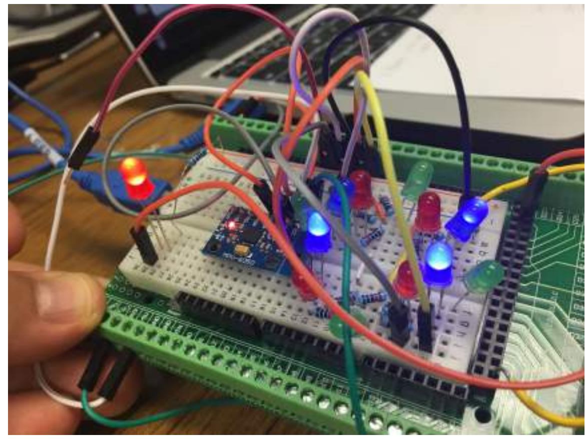

Fig 12. MPU-6050 IMU Unit

2) Temperature and pressure unit: The temperature and pressure unit is used to monitor the ambient temperature inside the main hull. Our controls team developed a streamlined solution to monitor the internal temperature in the main hull using a TMP102 sensor that communicates with its host Arduino Uno via I2C bus. The TMP102 was designed to work as a stand-alone solution and includes a relay and a mini-SD card allowing the unit to double as a data logger unit (fig 13.)

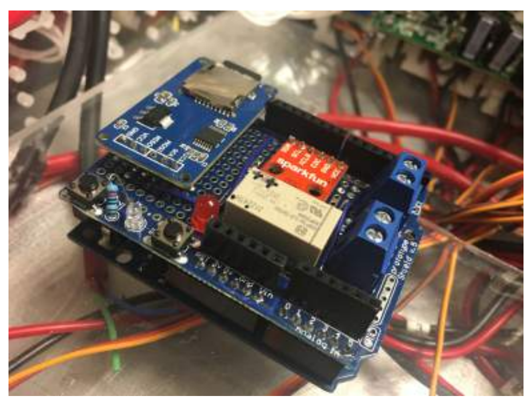

Fig 13. Temperature Alarm system

3) *Main Processing Unit (CPU)*: The computer system consists of a Mini-ITX SBC MANO882 mini motherboard equipped with an Intel i5 Processor, eight (8) Gigabytes of RAM memory, 256 Solid

State Drive, 4–IN & 4-OUT Digital I/Os plus a variety of connectivity COM ports (fig 14.)

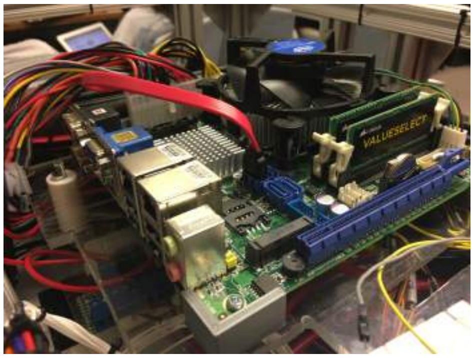

Fig 14. Main Processing Unit

4) Software: Eagle One's main signal processing and logic operations at the software level are resolved using the Robotics Operating System (ROS) under Ubuntu 14.4 OS. In order to fully understand the relationship of ROS, Ubuntu, and Eagle One's controls systems, it is important to provide a short definition of ROS. "The Robotics Operating System (ROS) is a set of software libraries and tools to help students build robot applications. From drivers to state-of the-art algorithms and with powerful developer tools" (ros.org).

The main idea behind the use of ROS as the backbone for control systems begins with the integration of the MPU-6050 unit, independent magnetometer, and barometer units. The combination of these three (3) sensors is responsible for most of Eagle One's guidance systems.

Our controls team's solution to the integration of the ROS environment with Ubuntu was to create a suitable platform that allows communications and data exchange among microcontrollers and the required sensors. In order to make this communication possible our team developed a classical ROS environment that contains several nodes, and a ROS Master that communicates via publishers and subscribers (fig 15.)

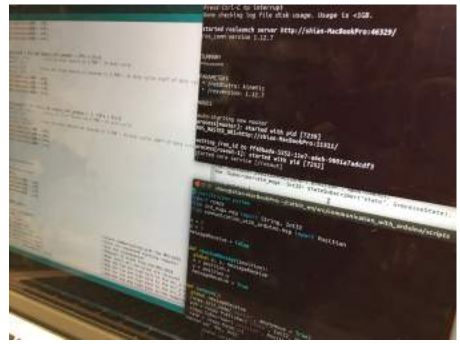

Fig 15. ROS-Arduino Node

5) Computer Vision: Eagle One's computer vision design is meant to help the sub navigate the competition course during competition. The goal for these systems is to identify possible obstacles and/or competition tasks by analyzing images in real-time. The video feed for the vehicle is provided by two (2) Imaging Source DFK 22AUC03 color cameras. These industrial cameras have a high color sensitivity and wide FoV. These features help the image processing software identify and analyze the objects the sub encounters while submerged. One of the cameras is facing directly forward while the second camera is faced down. This allows for a clear view of the tasks that are directly ahead of the sub and for a clear view of the path markers.

All video processing is done using a popular imaging processing software called OpenCV. The video feed obtained from the cameras is sent to the onboard CPU for image processing, then different algorithms are used in conjunction with OpenCV libraries to identify unique features found along the way. Using OpenCV and customized algorithms Eagle One's computer vision system can smooth out the images it gathers and remove some noise from the live feed. After analyzing the system, it is able to detect essential geometrical cues to assist Eagle One understand the surrounding environment and make decisions based on the camera inputs (fig 16.)

Fig 16. DFK-22AUC03 USB 2.0 Cam

6) Hydrophone systems: Three (3) Aquarian Scientific AS-1 Hydrophones are mounted on the front of Eagle One and configured in a predefined pattern. The hydrophone array is set in such a way as to allow for our team to calculate the time of arrival of the sound wave to each hydrophone.

Each hydrophone is connected to an Aquarian Scientific PA-4 Hydrophone Preamplifier with a Balance Line Driver in order to amplified the signal obtained from an underwater pinger. The amplifier is then connected to our NI 9222 with BNC 4Ch=/-10V 16 Bit Simultaneous Analog Input. In order to conduct proper testing at our school's pool we acquired a JW Fishers 20-50 kHz MFP-1 Multi-Frequency pinger. Signal processing is partially explained in the following block diagram (figs 17 & 18.)

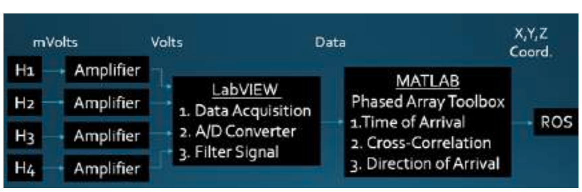

Fig 17. Sonar signal processing diagram

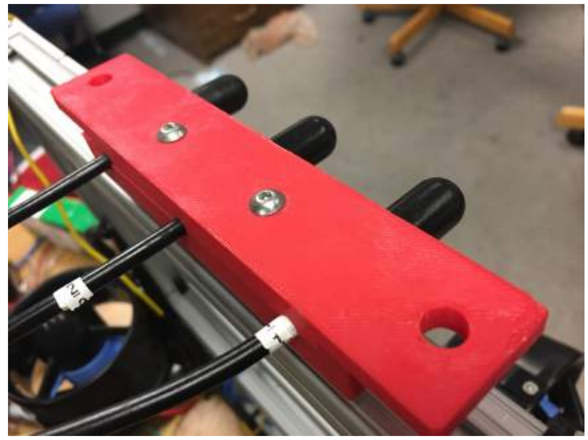

Fig 18. Hydrophone array

e) Pneumatic systems

The pneumatic system consists of two (2) mediums: compressed air and electrical current. Both the torpedo launcher and mechanical claw are powered by compressed air, which is held in a Ninja HPA paintball air tank, and the air pressure is lowered by the Ninja Pro V2 regulator attached to the air tank. The pressure is further stepped down with a three-way regulating manifold, capable of isolating and supplying minimum pressure for the torpedo launcher and mechanical claw. Both mediums are controlled by an Arduino Uno. As an alternative objective, the approach to this concept is also to provide more than one method of achieving the same task. However, the system can be fully integrated using a single medium.

1) The Mechanical Claw: is powered by a double actuating air cylinder controlled by an Air Directional Control valve. Powered by 12DCV, it is a solenoid that provides air pressure between 29-145 PSI to the air cylinder. When activated, the pressure extrudes the air cylinder arm that closes the claw, and with another built-in solenoid the control valve allows the air cylinder to retract. To waterproof the solenoid, epoxy was applied to crevices that may interfere with the circuitry of the solenoids.

2) The Torpedo Launcher: comprised of 2-way 2-position normally closed electronic solenoid. The minimum required working pressure is 0.8 MPA, an equivalent of about 116 PSI. When engaged, the solenoid allows air to bypass the valves to pressurize the 3D printed chambers. Due to the check valves providing one direction air flow in the 3D printed chambers, the chamber is pressurized until the chamber provides adequate pressure to expel the torpedoes (fig 19.)

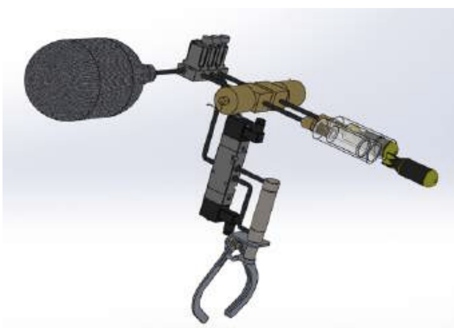

Fig 19. Pneumatic systems visualization

3) The Marker Dropper: is comprised of HiTech 35646W HS-5646WP waterproof servos attached to a 3D printed mount. The servos act as an air cylinder that releases each marker. For the marker dropper to function, an elbow with a bobbing pin is used to translate the rotation of the servo arm into a unidirectional movement. This allows latching and unlatching of the marker droppers (fig 20.)

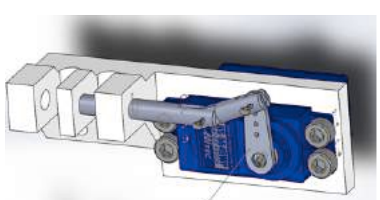

Fig 20 Marker Dropper Solidworks

III. CONCLUSION

The Eagle One project represents a great opportunity for students at Cal State LA to initiate research and development on underwater robotics. The present AUVCalStateLA team is proud to have been the first team to accept the challenge of building the very first underwater AUV for Cal State University Los Angeles and we hope Eagle One will become a stepping stone that helps other students develop more complex AUVs in the years to come. Plans for further developments include enhanced autonomy capabilities and additional instrumentation to aid researchers in solving the challenges posed by underwater exploration.

IV. ACKNOWLEDGEMENTS

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