The Building of Leviathan

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***Abstract*— With an emphasis on education and outreach the University of Colorado Boulder RoboSub team invested in its newer members and updated several features on last year's vehicle, Leviathan. Through a mix of coursework, and workshops the team taught students critical robotics skills and applied that knowledge to the vehicle creating robust mechanical, electrical, and software systems. The vehicle combines the success of our last year's semi-finals placement with the improvements on the failures of our previous years' subs.**

A. Design Strategy

The team's strategy for the 2018 RoboSub started with an emphasis and investment in education. This was done with a multi faceted approach to see what method provided the most effective.

Based on our previous year's success with delegating complex tasks to capstone teams, we sponsored a computer science capstone team to help us build a simulator. We did so using the Unreal Engine 4 with a redis server for interfacing with ROS. This simulator has allowed us to prototype control algorithms without the need for physical hardware in the water, allowing us to be more efficient in development.

Workshops and tutorials were provided as well in order to share knowledge and experience with as many new members of the team as possible. These included PCB design, component design, software development, ROS basics, and using professional CAD programs such as Altium and Solidworks. Although the benefits of these programs are not apparent from the onset we feel very confident that by participating and organizing these events team members are honing and building necessary skills. The benefits will become much more apparent in years to come as new members gain experience at a faster rate and veteran students can practice the fundamentals of mentorship and learning to function in varied experience level project groups.

The more novel technique we borrowed from last year and executed this year was working with professors on campus to help cater course material to AUV related studies. This was done specifically with the advanced robotics class and incorporating advanced sensor fusion techniques into lectures and homework assignments. The results of this have impacted the team in a massive way. The software team improved in skill, passion, execution, dedication and forged closer relationships with college faculty. This classroom approach will continue to be aggressively pursued due to the effectiveness and viability.

B. Vehicle Design

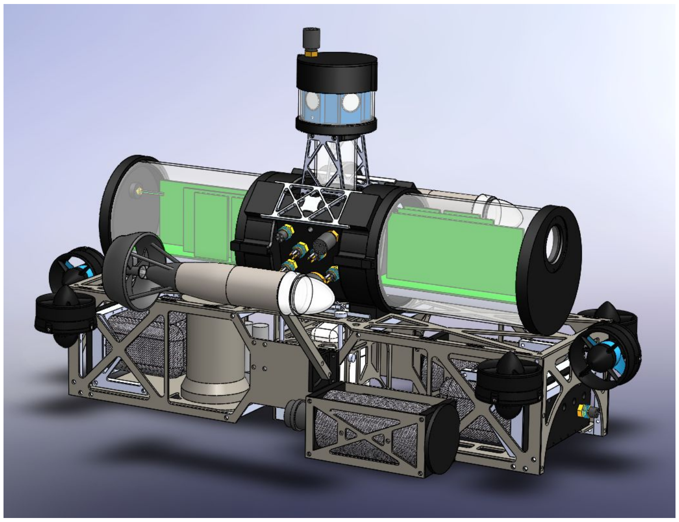

Fig 1: Complete Solidworks rendering of Leviathan 2017 competition vehicle

1. *Mechanical*

Due to the success of the mechanical systems from the 2017 competition we have chosen to keep the same architecture but improve several of the modules including the mid-cap and a few ancillary enclosures.

1.1 Midcap

Our vehicle's main hull is a three chamber mid-cap design. There are three spaces coming off of the central mid-cap where connections enter and exit the vehicle. The mid-cap design reduces cable lengths, and provides a stable and accessible electrical base for the vehicle. The largest focus of our mechanical team was redesigning the mid-cap. Performing a risk analysis on the old design we concluded that there were too many points of failure. The previous midcap was machined in three separate pieces due to manufacturing equipment limitations that needed to be epoxied together. At each joint a leak could lead to a catastrophic loss of all electrical systems. The new midcap design minimizes the failure points by being machined from a single piece of stock via a 5 axis CNC. This greatly reduces critical failure points removing as many epoxied joints as possible.

The three chambers of the vehicle are as follows. The front hull chamber allows space for the main computer, ethernet switch, USB hub, and other off the shelf electronics. The rear hull houses the custom backplane, which includes vehicle control and power systems. The periscope, located above the midcap, contains the 360 camera and Inertial measurement sensors. The inclusion of the Occam Omni 60 360 degree camera has been a major driving factor in the vehicle design the past three years.

1.2 Enclosures

Leviathan Contains a large number of ancillary enclosures including pre-fabricated ones such as the Nortek DVL in addition to custom, designed and fabricated, enclosures. The ancillary enclosures consist of the hydrophone array the battery enclosures, the pneumatic/actuation systems, and a downward camera enclosure.

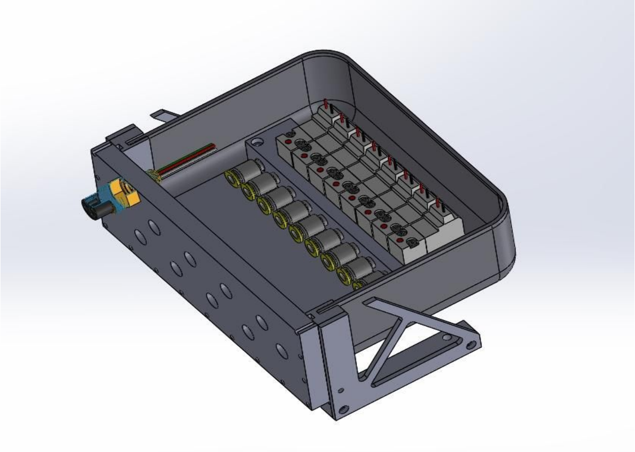

Fig 2: Pneumatic actuators box

Additionally, the mechanical team created a simple single base aluminum design for our hydrophone enclosure and our downward facing camera. This allowed ease of manufacturing and increased production speed.

1.3 Actuation

Our pneumatics enclosure this year consists of an 8-valve array with extra ports for contingency. It features a paintball canister supply and a simple torpedo system. This design emphasized simplicity over being feature rich.

2. *Electrical*

Learning from a few of our mistakes last year, we revamped our custom electrical designs to handle high current at lower temperatures. The custom electrical systems are our battery merge board, backplane, and power conversion board. In addition to our custom electronics we also have an advanced sensor suite to help with navigation and the many tasks RoboSub has to offer.

2.1 Merge Board

This year our merge board was split into two separate boards: one to handle interface with two LiPo batteries and another to be a kill switch for the 160A current going to the motors. This increases the reliability of our system, making it more robust to failures by allowing us to debug motor mosfet failures. We also increased merge boards copper density to minimize overheating.

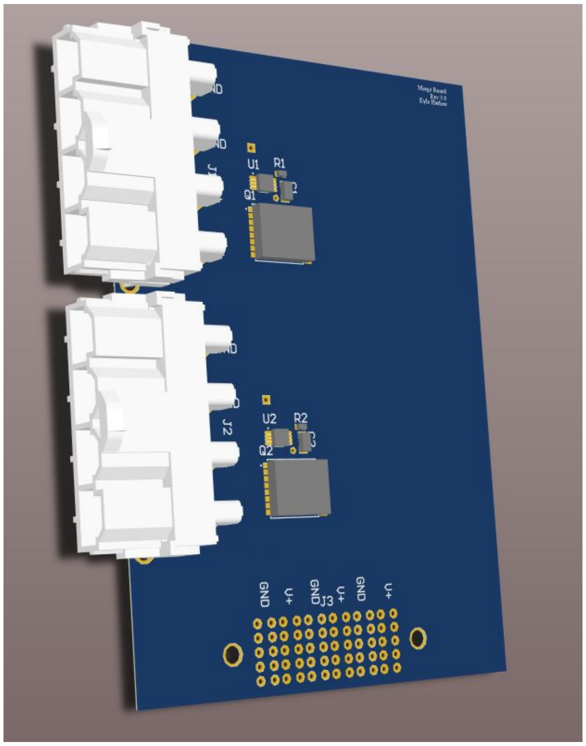

Fig 3: 3D Representation of the merge board

2.2 Backplane

Our backplance has changed slightly since last year. This board serves to route all power traces throughout the hull of the AUV. The primary motivation behind the backplane is to eliminate the excessive wires often seen inside AUVs. The backplane, like the merge board, is designed with higher density traces in order to accommodate the high current draw of our motors.

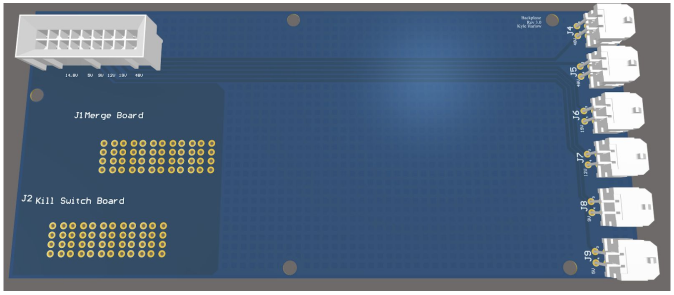

Fig 4: 3D Representation of the backplane

2.3 Power Conversion

The power conversion board takes in 14.8V from the merge board through the backplane and uses a variety of buck and boosting switching converters to provide various voltages to power each of the other electrical systems on the AUV. The largest change from last year is the 19V line, which we doubled the rated current output from 4A to 8A in order to account for the higher power draw of our Intel NUC, the vehicles new computer.

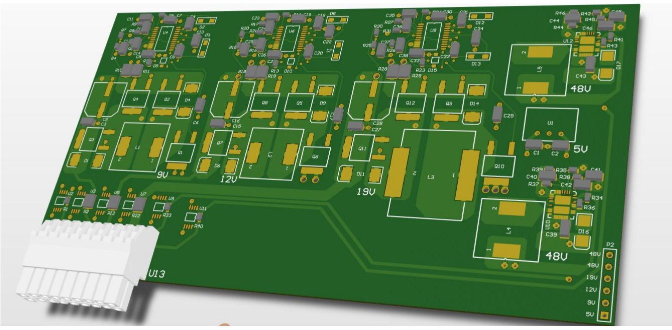

Fig 5: 3D Representation of power conversion board

2.4 Cameras

The Occam Omni 60 contains five 1.8 Megapixel cameras which are stitched together to provide steady 60FPS video in a complete 360 degree panorama of the vehicle, with each lens giving a 58 degree field of view. It operates over USB3.0 which plugs directly into our main computer. This camera should help with obstacle detection, and allow the vehicle to take non-standard approaches to tasks such as torpedoes, as well as the new octagon.

In addition to this camera we have a global shutter Point Grey (now FLIR) BlackFly 1.3 Megapixel camera as our downward facing camera. This camera is paired with a Theia Lense to give us wide FOV. This camera was selected to give us stable images while moving, and to assist on early path detection and control critical vision tasks present throughout the competition.

2.5 Hydrophones

Leviathan's hydrophone system consists of a 36 unit array of hydrophones in a 6x6 array. The location of the hydrophones relative to one another allows for the detection of acoustic waves between 20 kHz and 40 kHz while also preventing spatial aliasing. The hydrophones interface directly to an embedded system that is independent from the submarine's primary computer. This system's sole responsibility is to determine the heading, distance, and elevation of an incoming acoustic wave relative to the vehicle's location. The embedded system consists of an array of high-performance ADC chips, low noise amplifiers and a Xilinx FPGA. The hydrophone array – coupled with a custom FPGA algorithm – behaves as a passive sonar system rather than an acoustic point-source locator. In effect, the algorithm implements adaptive-beam forming, simultaneous multiple-source identification, and signal extraction.

Theoretically, the algorithm is capable of determining the heading, distance, and elevation of multiple sound sources to within a tenth of a degree. The development of this system is ongoing and currently untested.

Once the telemetry is identified the data is packaged and sent to the submarine’s primary computer in real-time allow the software to make accurate planning predictions.

2.6 State Estimation Hardware

Pose estimation is a complex robotics problem and usually involves the integration of many sensors. Many top teams rely on Doppler Velocity Loggers (DVLs) to accurately find their position underwater. Our team is no different, using our newly purchased 1MHz Nortek DVL to sense our velocity, and integrate in order to map our position through TRANSDEC. The Nortek DVL is aided by a Sparton AHRS-8. This filtered inertial measurement unit (IMU), allows us to get our other state information, including orientation and linear accelerations.

Both of these devices are integrated into our system through an Extended Kalman Filter (EKF) in ROS.

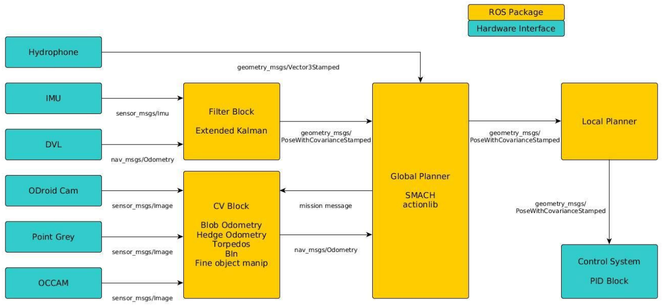

Fig 6. Software graph

3. Software

Maintaining last year’s architecture, our main achievement was developing a simulator for our vehicle. This allows us to test and restructure our global planning stack. Building on top of ROS we decided to break the system into two subsystems; Controls, Perception. Our goal with this design was to make the system easier to customize. ROS is used for the communication network between all of the software application. We planned a well organized set of topics, so any part of the application could subscribe to information it needed.

3.1 Control System

Our control system proved very effective last year, so we decided to not make many changes. The control system consists of two parts. They will be referred to as follows: Local controller, and Mission Planner.

The local control algorithms were designed using early models of the vehicle in Simulink. These models allowed us to tune controllers for heading, and velocity. The motor controls are based on the 6DOF the vehicle can operate in. With each degree of freedom having its own controller.

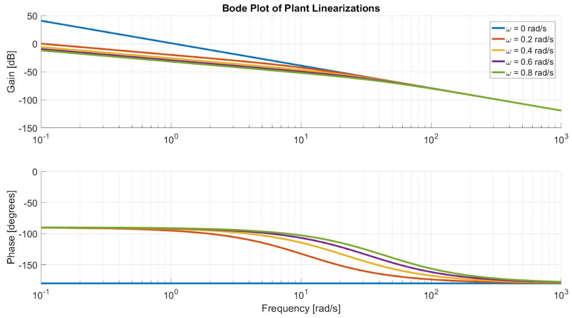

Fig 7: Simulated Bode response of vehicle plant linearized at varying velocities

The team implemented PID loops for the control of each of the DOF. Due to the high dampening of the water the controllers ended up being mostly proportional controlled.

Finally, each of the 6DOF controllers were combined using simple linear algebra in order to account for the interactions between the controllers, i.e. pitch and roll maneuvers potentially affecting depth due to the nature of the motor arrangement. These final signals were then converted to PWM signals and sent to the ESCs to control the output of the motors.

The Mission Planner is a State Machine implemented in the SMACH framework. This was chosen because it allowed for fast prototyping of the state machine. The planner uses actionlib to designate actions which spawns a subprocess for a desired action. This allows the Mission planner to send and monitor a desired task while continuing to monitor other aspects of Leviathan.

3.2 State Estimation

Localization is achieved by fusing data from the

DVL and AHRS sensors. This data is fused with a Kalman filter using a simple omnidirectional model. The KF takes these two components and generates a pose and odometry estimate for the sub allowing the mission planner and local controller to have accurate information about the subs current state

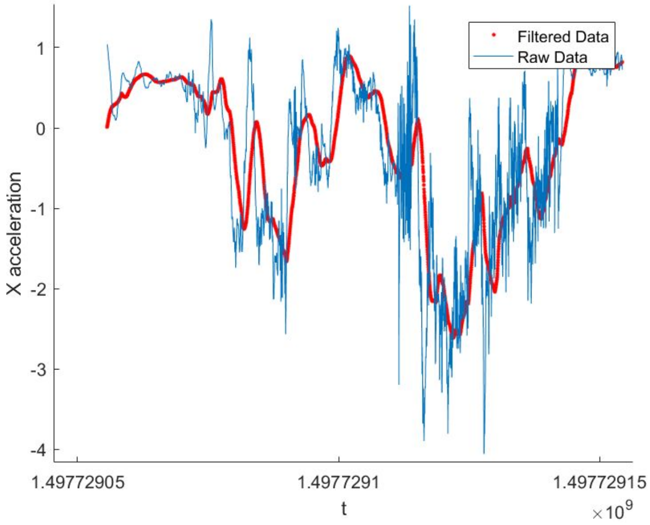

Fig 8 : Above is shown the filter results on one axis of the IMU acceleration.

3.3 Computer Vision

Computer vision (CV) is used to aid in the completion of many of the tasks. We will use computer vision to localize and determine the number of a die in the shoot craps task. This is done by the use of openCV libraries that allow for quick application of many image transformations.

CV helps with the buoy, and the hedge, by detecting the obstacles in Leviathan’s field of view then determining if they are a part of a task at hand, a path indicator, or debris. Our algorithm involves first recognizing a type of object via a neural network, finding the contours of the object and calculating its position with respect to Leviathan. This algorithm has a large draw back. Due to the nature of neural networks we do not know what image features it is relying on, making it susceptible to be overfit to the data we used to train it. We do not have training data of the die and roulette table before competition, so we cannot tune our neural network before the competition starts. Additionally if conditions change significantly throughout the competition, such as lighting or water clarity then our algorithm may not be able to adapt.

4. Business

This year the business strategy was largely similar to last years in that we focused on creating as big a presence as possible on campus and in the community, but also reached out for corporate support and sponsorship from professors. The central idea being that as our profile increases our ability to raise funds and recruit new members will scale accordingly.

These efforts include participating in a variety of events from on campus efforts such as the annual welcome festival and having regular tabling events for promotion within the engineering center to traveling to the local maker faire, the annual sparkfun AVC competition, and presenting in front of the grassroots Boulder is For Robotics meetup community.

Additionally we received support from a few of our members’ corporate employers such as Syncroness.

Our largest business achievement this year was making a partnership with a robotics research lab on campus. Our club will take on a new face by testing estimation algorithms and receiving a sponsorship. We believe this will complement our participation in the competition.

C. Experimental Results

Rigorous testing has occurred on Leviathan’s many subsystems throughout the design process. This has culminated in 50 hours of pool testing over the school year.

In addition to electrical testing the mechanical system was tested as critical components were developed. Several weeks of testing went towards the seals of our new main hull. Initially, the hull leaked due to some improper sealing techniques. But switching to a more heavy duty marine epoxy, as well as adding final hardware including our connectors reduced the leaking significantly.

D. Acknowledgements

We would like to thank our faculty sponsor Nikolaus Correll for enabling us to work on this project. Also our many sponsors including Syncroness, the COHRINT lab, Nortek, Aquarian Audio, Molex Connectors, PNI, Sparton, Occam, MacArtney, Video Ray, and XIO technologies.

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