Underwater Robotics at Arizona State: Design and Strategy for the 2021 AUV

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Abstract

For 2021 Underwater Robotics at Arizona State (ASUR) designed a robot with a primary purpose of accomplishing tasks that centered on navigation. The robot will also help ASUR gain necessary knowledge and experience to build better Autonomous Underwater Vehicles (AUV) for future competitions. This robot has not yet been constructed due to restrictions on in person activities, but the knowledge gained during the design process will be helpful for future AUV designs.

Competition Strategy

The 2021 vehicle was designed to complete tasks that primarily involved robot navigation. This was deemed as the minimum viable product for the competition and would allow the team to focus on getting all the fundamentals down first. It was decided to not design for any active manipulation tasks as the necessary complexity to achieve them was not ideal given our minimal experience with fully autonomous vehicles. The analysis of previous competitions showed that many teams who tried to complete every objective frequently failed to do so. It was seen that by ignoring the tasks that were complex and had the highest chance of failure it would be possible to build a robot that would rank higher than many other teams who tried to do everything and failed. However, recognizing the eventual need to complete the advanced tasks in order to achieve the highest ranks in future years, some initial work was completed to test systems such as computer vision and pneumatic actuation in order to begin developing the skills and knowledge needed to implement them into a future vehicle. The team believes this approach will allow for us to learn the necessary skills to design and field a highly competitive robot in future competitions.

Design Creativity

Mechanical

Due to the limitation around in person meetings very few custom parts could be manufactured. With the uncertainty of what restrictions would be like when the robot would be assembled it was decided that it was important to design it in a way that would allow for small groups or individuals to meet and construct and test individual subsystems without needing access to the whole robot. This led the team to select a multiple enclosure design. This would allow for subsystems to be worked on in parallel. The use of multiple enclosures would also allow for better balancing of the buoyancy of the vehicle by adjusting the placement of the enclosures on the frame.

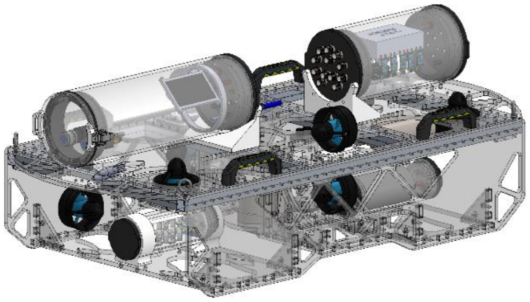

Figure 1: Render of AUV Design

The frame of the robot is constructed from clear polycarbonate due to its impact resistance and for its density being close to that of water. This allows for the frame to be close to neutrally buoyant, minimizing the amount of foam that would need to be added to offset the weight of the frame. Topology optimization was utilized during the design of the frame to help maintain the rigidity of the design while also reducing the dry weight of the robot. This involved using Finite Element Analysis to simulate the loads on the frame and remove material that was not contributing to the overall strength of the frame. This allowed for a weight reduction of 30 percent compared to the non-lightened frame.

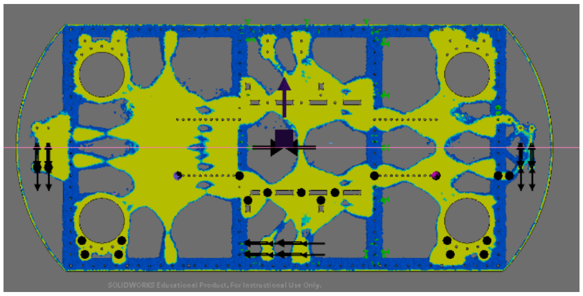

Figure 2: Topology of Main Frame Plate

The robot has 10 thrusters laid out facing along the cardinal directions of motion. The layout allows for full control of the robot in all six degrees of freedom. Four thrusters are used in the main forward direction of the robot as much more of the time in the course is spent driving forward and placing more thrust in that direction allows for quicker motion of the robot. A faster robot allows for more attempts at completing the tasks in the competition.

A core design feature is maintainability. In order to achieve this, enclosures are mounted with one fixed end and one end that is held down by draw latches. This allows for the team to open an enclosure without needing tools. Where possible wires are only routed through the fixed end of the enclosures to make opening the enclosure simpler. A variety of mounting holes are located on the robot in order to allow for small design changes to not require the manufacture of a new robot frame.

The pneumatics system on the robot is designed to fit within the same size enclosure as the batteries in order to reduce the number of unique parts of the robot. To accomplish this a custom end cap for the pneumatics enclosure was made in order to be able to pass all the connections for both air and electricity through just one side of the enclosure. This enclosure is significantly smaller than previous pneumatic systems designed by the team for other competitions. This system allows for up to four actuators to be placed on the robot for use in future subsystems like torpedoes or droppers.

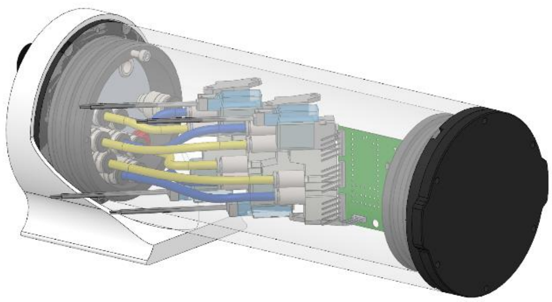

Figure 3: Pneumatics Enclosure

Electrical

The electrical systems of this robot consists of three main enclosures, and two battery enclosures. Each enclosure is designed with a specific subsystem in mind. Interconnections between enclosures are also important to maintain efficient control and power distribution. These enclosures ultimately consisted of the control enclosure, the power distribution enclosure, the pneumatic enclosure, and the two battery enclosures. These enclosures work together to ensure power is distributed properly, and communication between the Teensys and the Jetson is facilitated.

One major challenge of designing these boards is the PCB design. Due to the need for 14 PWM headers, 5 UART headers, and even more control headers, placement and wiring of the PCB can be challenging. Combining this with the size constraint set by the mechanical team, the PCB design is a big task. The other major challenge is the actual assembly of the robot. Assembly requires soldering 5 teensys to headers, then the headers to the boards. After this, all communication, sensor, and power components are required to be interconnected between boards.

The power enclosure handles the battery management and the nine thrusters of the robot. The electrical team decided to reuse a store-bought fuse board for this competition, although they do have plans to design a new fuse board for future robots starting next year. This decision was mainly due to issues caused by the Covid-19 Pandemic limiting the ability to prototype. The external killswitch was made to be waterproof in order to function properly during the competition. The killswitch also protects the computer from sudden power failure by only killing the thrusters, an improvement from last year's design. The power enclosure contains a 14.8V to 5V buck converter to power all 5v systems such as the arduino and teensy’s.

The teensy receives commands from the control system to determine what to send towards the thrusters. This involves a new system from the software team to offload complicated thruster mapping from the main computer. The teensy controller sends these signals to the nine electronic speed controllers of the power enclosure, each of which uses a 3-pin connector to connect the nine thrusters. The power enclosure also includes a leak sensor, voltmeter, and two connectors leading to the control system and pneumatic enclosure. All of this is Controlled by the teensy which passes updates to the in the control enclosure.

The control enclosure was created to incorporate the sensors, cameras, and inputs and to utilize the inputs to control the outputs which includes the display, motors, and pneumatics. The central microcontroller was a vital component of the system as it must be able to have the processing power and speed to switch and control the outputs depending on the inputs.

The main computer utilized was the Jetson Xavier AGX which fulfilled the requirements for our control system. The control system or enclosure contains a custom designed control board or PCB that was created in order to connect the DVL, IMU, depth sensor, leak sensor, cameras, the pneumatics and the motors. The pneumatics and motor enclosures both have their own respective control board accompanying the control signal from the main control board.

The control board inside of the enclosure was originally designed as two distinct boards: the communication board and the sensor board. The communication board handled the control signals from the Jetson Xavier AGX and sent the signals to the pneumatics and motor board.

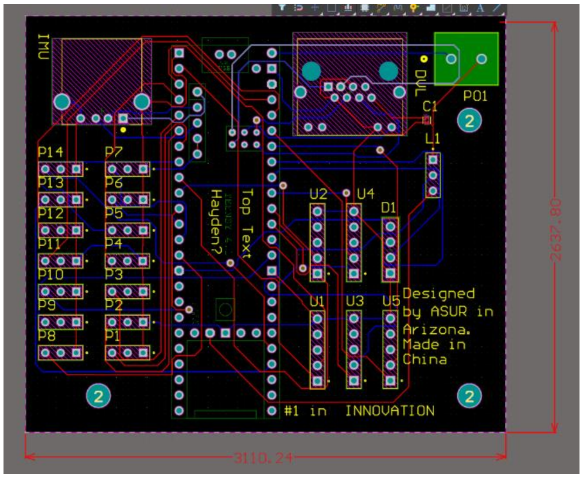

Figure 4: Main Control Board

For the robot the team decided to create a separate enclosure that contains all the pneumatic systems. The pneumatic enclosure features solenoids that are used to control the torpedo launcher and features a custom PCB for an Arduino teensy to control the solenoids. This custom PCB is designed to take 5V input from the power enclosure and use that to power the solenoids and teensy. The teensy is designed to send a signal to the NPN transistor to act as a switch that will either turn off or on a 5V power rail to the solenoids. This will allow for the teensy to control the actuation of the solenoids.

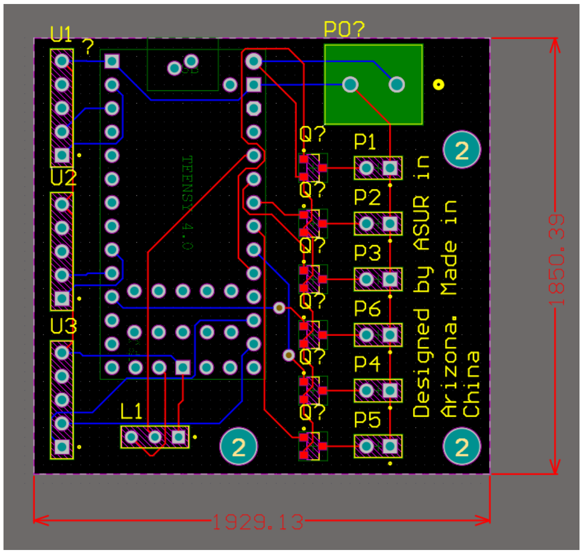

Figure 5: Pneumatics Board

Figure 5 shows the custom PCB that was designed for the teensy. This figure also shows the connection of the teensy to the NPN transistors and how those transistors allow for power to be sent to the pins that are connected to the solenoids.

Instead of having the battery system of the robot be in one central compartment, the electrical team decided on having two separate battery enclosures for the robot. This allows for a maximal amount of current draw and voltage output. Inside both enclosures, a battery is connected to an 8-pin penetrator to send power to the other enclosures. One battery enclosure feeds into the power enclosure, while the other sends power to the control system. Since the motors are only connected to one battery, the kill switch only needs to shut off the battery connected to the power enclosure in order to “kill” the robot.

Software

The AUV software system uses the Robot Operating System (ROS) in Ubuntu Linux to offer system functionality and implements a modular system design that encapsulates and isolates system components from each other facilitating communication through predefined data protocols. The use of ROS allowed for seamless integration of several AUV systems ranging from Image Recognition to Motion Controls and even the handling of software to hardware communication; along the modular ability, use of this system allows for delegation of several complex tasks to already developed and released systems to aid in development.

Motion Control was achieved using the auv_gnc system released by Ted Sender from Ohio State University [1]; this allowed for integration of the Nortek DVL, IMU, and processed camera data. Using a virtual representation of the robot the system uses a constant feed of data to calculate the necessary thrust for each defined thruster; the motor control data that is used is determined using the integrated linear quadratic regulator in the auv_gnc library.

While this library provides a powerful foundation to build a custom motion control system there are a few significant challenges inherent to the system. The first and most significant challenge addressed the number of defined thrusters available; as the auv_gnc library only supports up to eight thrusters, since the design as specified contained ten physical thrusters. This challenge was the first point where the software system began to alter the method of the library. The solution was to define virtual thrusters as the center of thruster clusters, such that any thrusters which sat adjacent or provided equal control as a single thruster at a variant point would be considered a single thruster of variant power when digitally represented. This solution allowed for an increased extensibility of the library, and allowed for more thrusters, but does need a greater extent of testing and refinement to ensure correct and accurate digital representations.

In order to handle image recognition and camera vision OpenCV was used to integrate cameras and image recognition. One major point in this decision was the built-in algorithms for OpenCV that allowed for reasonable integration and application with little or no labeled data or a need to train the system on. This allows for a quick development time, minimizing the training period of development and allowing for any training after integration to refine the system. The ability to quickly develop and produce results was imperative to the development cycle for this project; being able to devote more time to integration of the camera and vision systems with the rest of the software systems and not development and training of the image recognition algorithms.

Experimental Results

Due to restrictions on in person meetings lasting the entire year construction of the vehicle has not yet started. However, the team has a set of tests we plan to run once the robot is built. Mechanically the robot enclosures will undergo a waterproofing test that will start with a quick submersion to test for initial leaks, then a 15-minute test at 8 feet of depth, testing concludes with a 6-hour test at 8 feet of depth. When enclosures pass those tests, they will have the electrical components integrated into them. The electrical integration test will consist of powering on the enclosure and verifying that the robot detects everything inside the enclosure. Software integration test will start with turning on each thruster independently, then turning all of them on. Next the robot will be tested with manual piloting to ensure thruster mappings are correct. Once thrusters are verified work will begin to verify the results from the Doppler Velocity Log. This will start with moving the robot a set distance and verifying the reported distance from the DVL. Upon completion of that test the robot will be told to move a specific distance and the results will be compared. Once all of this testing is completed work will be carried out to ensure that the robot is ready for the competition. It is expected that the testing will take at least a week to complete. As of right now the plan is to spend most of the time before the next competition working on software development for this vehicle so that it will be ready for the next in person competition.

Acknowledgements

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References

[1] T. Sender, “tsender/auv_gnc,” *GitHub*. [Online]. Available: https://github.com/tsender/auv_gnc. [Accessed: 27-Jun-2021].

Appendix A: Component Specifications

Component	Vendor	Model/Type	Specs	Cost (if New)
Frame	Andymark	CUSTOM WATERJET	Waterjet Polycarbonate	1900
Waterproof Housing	Blue Robotics	WTE-6 WTE-3		1300
Waterproof Connectors	Blue Trail Engineering	Cobalt		1714
Thrusters	Blue Robotics	T200		Reused
Motor Control	Blue Robotics	Basic ESC		Reused
Battery	Blue Robotics		14.8V 18Ah	Reused
CPU	Nvidia	Jetson Xavier AGX		Reused
Internal Comm Network	BotBlox	Gigablox	Gigabit	250
Inertial Measurement Unit	Sparton	AHRS-M2		Reused
Doppler Velocity Log	Nortek	DVL 1MHz		Reused
Cameras	FLIR	BFS-PGE-13Y 3C-C	1.3MP	Reused
Algorithms Vision	OpenCV			
Open Source Software	Auv_gnc			
Team Size	11			
HW/SW Ratio	8:3			
Testing Time Simulation	0 Hrs			
Testing Time in Water	0 Hrs			

Appendix B: Outreach Activities

Our team does outreach at many community events. Our main outreach events are the ASU homecoming tailgate, Passport to ASU and School of Earth and Space Exploration Events. We also volunteer at different events in our community such as the Fulton Schools Career Fair, and FIRST Lego League Qualifiers.