Cornell University Autonomous Underwater Vehicle: Design, Strategy, and Implementation of the Aurora and Leviathan AUVs

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***Abstract*—Aurora and Leviathan are Cornell University's vehicles for the AUVSI RoboSub 2022 competition. For the team's 21st year competing, we have once again attempted to push the boundaries of AUV technology. Aurora, the new sub this year, has been designed, manufactured, and tested from the ground up in just under ten months. Both subs have been designed to be capable of completing nearly every task.**

I. Competition Strategy

Cornell University Autonomous Underwater Vehicle team (CUAUV) has a tradition of pushing the boundaries of AUV technology and breaking the rules to do remarkable things. Six years ago our vehicles Thor and Loki became the first vehicles to be entered into TRANSDEC in tandem, forever changing the way our team approached the RoboSub course. This year, with Aurora and Leviathan, CUAUV has the potential to complete all the challenges RoboSub has to offer.

Each year the team faces the decision of choosing whether or not to continue designing, fabricating, and testing new vehicles. Choosing to re-use either one or both vehicles would save the team both development time and money, while also giving our software team the ability to develop missions on a stable system throughout the year. The top priority of CUAUV has always been learning. By rebuilding our vehicles each year, we are able to maximize how much our members are able to learn, and ensure that the knowledge we have acquired throughout the years continues to be passed on to our younger members. Additionally, rebuilding our vehicles each year gives our older members the opportunity to build upon their previous work and learn from any mistakes they made along the way. This often leads to major improvements in our core infrastructure which greatly helps to improve the reliability of our vehicles. We believe that redesigning only a single vehicle in a given year will strike the perfect balance between these two arguments. As mentioned, it will provide a valuable learning experience for our members while maintaining a stable system for software testing and senior members to take on more "experimental" projects that push the boundaries of underwater technology. As such, this past year we have chosen to only design one new sub, Aurora.

While Aurora and Leviathan are both designed to be able to complete a majority of the course on their own, we intend to have them both complete their own designated tasks so that they work as one cohesive unit. To ensure optimal timing in completing the tasks, our strategy for this competition is as follows. As Leviathan does not feature a downward manipulator capable of picking up objects, Aurora will start its run first, followed by Leviathan. Aurora will first pass through the gate, gaining the extra points for style. Once completed it will then proceed to the octagon to pick up the bottles before surfacing. While this is happening, Leviathan will proceed to the buoys task, completing our chosen side in parallel with Aurora surfacing in the octagon. Having completed each of these initial tasks, the vehicles will move onto the next set. We chose to surface in the octagon first because we believe it to be the tasks that we complete the most reliably, scoring us a respectable amount of points before trying less reliable tasks. Aurora will then move to complete the bins task while Leviathan moves to torpedoes.

The order and exact specifics of our competition strategy is subject to change as we continue to test and iterate over the summer, but the outline above highlights the key points.

II. Design Creativity

Cornell University Autonomous Underwater Vehicle has been designing, manufacturing, and testing AUVs for close to 20 years. Aurora and Leviathan are the culmination of our extensive experience and are the most capable vehicles we have designed to date. Given that this competition is the return to in-person competitions, we have focused on teaching new members how to design a vehicle for competition and give them the design experience necessary to do so. Both vehicles have been designed to complete a majority of the tasks. This approach has allowed us to greatly extend our potential competition strategies as well as created an additional layer of reliability in the event that one vehicle suddenly becomes unable to perform a task. Both vehicles build upon what the team has learned from designing its predecessors while still making strides in electrical and mechanical design.

A. Mechanical

Each year CUAUV completely redesigns and fabricates the majority of the mechanical components for each AUV. To restrain the amount of time spent machining, the mechanical team has taken to reusing some of the more time consuming components from year to year. Such components include the midcap for Aurora, the thruster shrouds for each vehicle, and the hydrophones enclosure. The choice to reuse these more complex components was made with the intention of giving more senior members a chance to help younger members with design procedure and to make efficient use of limited machining time.

One of the novel aspects of our mechanical designs are the interchangeable SEACON panels attached to the midcap of both Aurora and Leviathan. As our electrical design changes from year to year, the required electrical connections also vary. As such, the SEACON connections required also change from year to year. As the SEACON panels are easy and quick to design and fabricate, the interchangeability of their design allows us to continue to make electrical and mechanical innovations without needing to replace the midcap.

One of the most notable changes in the mechanical system for this year is the redesign of the frame for Aurora. Through more experimental frame design in previous vehicles, we have learned what design specifications lead to successful components. These lessons have been taken into account this year in designing the frame. Learning from last year's mistakes, the frame for Aurora was completely redesigned. The new frame features a smaller width profile compared to

Leviathan, while supporting the same required external enclosures. Additionally, the new frame also is able to support an external valve enclosure for the pneumatic actuating system, which will enable Aurora to complete tasks that require a manipulator or torpedoes.

For the internals of the vehicle, we chose to opt for a more spacious design. By spreading out the custom PCBs connected to the racks, we were able to gain valuable room to allow for easier integration and debugging. This has ultimately allowed us to experiment with new heating simulations and a proper channel for air flow as well as the easier board access described earlier.

The manipulators for this year are specifically designed to maximize reliability in picking up the bottles described in the handbook structures. Through previous designs, we have learned that variability can provide a large advantage. As such, for this year's design we chose to implement a simple scissor arm to which an interchangeable manipulator can be attached. The arm itself is driven and retracted by a single pneumatic piston. Extending the arm opens and closes the attached manipulator. As we continue to test our vehicle before the competition, our final manipulator design will continue to evolve.

B. Electrical

Aurora and Leviathan feature almost completely identical electrical systems with interchangeable custom PCBs. Every custom PCB was designed, populated, and tested by members of CUAUV's electrical subteam. The team chooses to use custom circuitry in order to allow members to gain knowledge and experience in developing a full electrical system. This is important to CUAUV as learning is the team's primary goal. The two electrical systems are developed to be almost identical in order to make designing, testing, and maintaining the vehicles simpler. Having identical systems allows us to systematically swap boards between vehicles in the event of an issue.

One of the more novel aspects of CUAUV's electrical system design is the use of multiple backplane PCBs. Each vehicle has two backplanes, one which connects the custom PCBs, and a SEACON backplane, which connects the PCBs to the rest of the electrical system such as thrusters, the Jetson TX2 computer, and external sensors and devices. These backplanes increase system integration and allow for the plug-and-play capabilities of the other PCBs. This allows for changes to the system to be made quickly, as "extra" connectors allow for components to be integrated into the system that weren't originally intended. Furthermore, the backplanes help in debugging signal issues as they allow for simple and easy connectivity tests between PCBs and between PCBs and external devices. In the theme of designing for reliability, this year all of the custom PCBs feature duplicated signals on each side of their respective connectors.This ensures that signals will still be properly transmitted even in the event of connector damage. Furthermore, additional fuses have been added to the power paths of several boards in order to prevent damage to other components on those lines in the event of a major failure such as a short. This ensures that entire boards will not need to be replaced in the case of such an event.

One of the biggest challenges CUAUV has faced in terms of electrical design is our hydrophones system. As we chose not to use an off-the-shelf solution, our team has continued to build upon our tracking system to be more reliable and robust. Large strides have been made in our analog-design and digital signal processing for this year.

Additional testing of filters and auto-gain features have proved to greatly increase reliability and remove false readings. Additionally, a large effort has gone into developing a transmit functionality for our hydrophones system. Fully fleshed out, the combination of being able to transmit and receive acoustic signals will allow our two vehicles to communicate under water.

C. Software

Numerous software improvements were made this year for Aurora and Leviathan. In particular, we have been heavily focused on improving our vision and mission systems to allow our submarines to more reliably complete the competition course.

On the vision side of things, we introduced a new framework for keeping track of mission elements which may be lost momentarily by our vision system. Using this framework, brief interruptions in object recognition are automatically accounted for, eliminating the need for mission writers to add consistency logic at every step of their missions as they have in the past.

We have also continued work on supporting a machine learning-based vision system, creating a new web app for (even non-technical) team members to tag images for use in training and a new backend to serve these images. The system has the ability to serve each image to multiple members and combine their results, improving the reliability of our data.

On the mission side of things, we have developed a new framework for writing missions in an imperative, asynchronous style. As opposed to our previous system of complex tree-based mission logic which we have been using for several years, this new framework makes writing and iterating on missions significantly quicker, which has in turn led to a significant productivity increase across our team.

Another area of focus for the team this year has been on creating a new Unity-based simulator. This new simulator is easier to use than our previous C++ implementation, making frequent testing a more appealing prospect for the team. It also provides much more realistic simulated vision, which allows us to gain more confidence in our vision modules than we have previously been able to away from the pool. We are also working on using Unity's built-in physics engine to increase the physical accuracy of the simulation, which will be especially helpful while working on torpedos and bins because of their moving parts.

Another focus has been on the complete redesign of our shared memory architecture. This allows for significantly faster communication between all parts of our software stack. The new system is also able to store more data types and organize data with more complex structure than before, eliminating most of the work previously required to interface with the system from other parts of the stack.

We have also put time into improving our operational efficiency, such as by writing a new tool for automatically detecting and correcting the accidental reversal of our subs' thrusters – which often happens during reassembly. By noticing and acting on discrepancies between attempted and actual movement, this system eliminates all manual work in these instances.

III. EXPERIMENTAL RESULTS

We started designing Aurora, the newest vehicle, in the late Spring of 2021. The mechanical team largely employed ANSYS and Solidworks Sim to conduct rigorous FEA. The electrical team spent the Fall reviewing new board designs, creating and testing prototype boards, and re-designing the hydrophones system. During the winter, both the mechanical and electrical teams spent over five months manufacturing and populating the new components used for the creation of Aurora. The two design teams came together fully in the Spring for the integration of both vehicles. By focusing on validation during the integration phase, we have ensured intended functionality of Aurora throughout our testing phase thus far.

CUAUV's software team has a custom built simulator which allows us to test mission code in a simulated environment. 3D modeling tools are used to replicate RoboSub's task structures which are then loaded into the simulator. By doing this, we are able to test a number of aspects of our mission code including our vision modules and autonomous decision making. However, the simulator in reality simulates a "perfect environment". As such, testing our mission code in the pool is critical and often reveals additional checks and functionality that needs to be implemented to make our code function in a real environment. Since the end of Aurora integration, the team has spent countless hours at the pool practicing for competition runs.

Until RoboSub, CUAUV plans to continue testing our vehicles in the pool every day. This time in the pool will be spent perfecting the missions each vehicle is tasked to do and making each task robust to environmental changes. The manipulator design is also undergoing continuous fine tuning to ensure accurate drops of the PVC structures. The electrical team also continues to test and make changes to board firmware as well as populate backup boards for use in the event of a major board failure.

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