# Technical Design Report for Charybdis

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***Abstract*— With interdisciplinary cooperation between team members, the Kennesaw State University Autonomous Underwater Vehicle Team (KSU AUV) has improved the design of the AUV Charybdis platform and has integrated new functionalities and behaviors for the 2022 RoboSub competition. The motor configuration and control systems of the AUV run parallel with rising paradigms used in aerial drones. This vehicle utilizes a PixHawk flight controller as both a motor controller and gyroscopic sensor. The communications between a dual camera system and the Pixhawk govern the movement of the AUV through a state machine. This paper discusses the 2022 KSU AUV competition strategy and highlights the technical attributes of Charybdis.**

***Keywords—autonomy, underwater, vision, machine learning***

## I. Competition Strategy

### *A. Preface*

The KSU AUV team is a 25-member student organization sponsored by Kennesaw State University which competes yearly in the RoboSub competition. For the 2021-2022 competition season, KSU AUV continued to improve on the design of Charybdis, the versatile platform developed during the 2021 season. Our team consists of three major sub-groups - mechanical, electrical, and software - which collaborate to design and integrate the necessary systems required to form a working autonomous architecture. The technical attributes of Charybdis are found in Sections II and III of this report in addition to the hardware and software specifications provided in the appendices. With the continuation of COVID-19 in the Fall of 2021, the team made the appropriate adjustments to resume physical meetings for design work, integration, and testing while meeting appropriate safety guidelines. The team continued to host virtual sessions to minimize inflection encounters among our members.

### *B. Competition Strategy*

Post-RoboSub 2021, the team identified numerous potential improvements to make to the Charybdis platform. Notable examples include an internal wiring overhaul, motor maintenance and replacement, killswitch redesign, overheating mitigation, chassis and fastener corrosion protection, and numerous frame improvements. For the 2022 RoboSub competition, the team identified three primary challenges to pursue:

1. Passing through the start gate while spinning
2. Object detection for “Make the Grade”
3. Mechanical Arm properties for “Collecting”

To meet these objectives, the team sub-groups focused efforts on improving movement-critical systems from the 2020-2021 season and developing a new torpedo system.

## II. Design Creativity

### *A. Mechanical Design*

*1) Outer Structure and Component Housing:* After the 2021 competition, team leadership identified several issues with the current submarine frame that required attention. Through in-depth discussions and proposals, it was decided that designing a new frame would be more efficient than adjusting the current frame. This would also allow the team a secondary backup submarine if needed. The main issues that required attention were: difficulty accessing mounted components, limited space and poor organizational layout of computer and electrical components, and ease of weight distribution adjustments. To address the first design concern, the mechanical team focused on overall frame structure and connection methods. Charybdis 2.0 is constructed from 5052-H32 aluminum plates of thickness 0.125 inches and 0.190 inches for light and high loading frame sections respectively. Due to supply chain issues, the cheaper alloy 5052 Al was used rather than the previous framing material of 6061 Al. The plates were cut on a water jet machine using DXF files exported from SolidWorks. Using custom-cut framing sets us apart from the competition in that it allows more freedom in design structure for optimization of space usage and mechanical design. Special care was taken in the aluminum frame connections to allow a semi-permanent fixture that can withstand the heavy loads required by the submarine weight and motion dynamics. Female slots and male tabs were used for alignment with special bolt slots for clamping. The bolt slot holds a nylok nut in place while the bolt is tightened with an Allen wrench. All of Charybdis 2.0 control electronics are housed in a large 8-inch acrylic tube to centrally house the sub’s critical controls. Weight distribution became an issue when new batteries needed to be purchased that were twice as heavy as those used previously. The old frame positioned the battery tubes on the rear of the submarine making it back heavy. A temporary solution was implemented by adding high-density foam board floatation, but the new frame design on Charybdis 2.0 incorporated a more permanent solution. Two longer acrylic tubes were positioned underneath the main electronics housing tube to align the center of gravity to the lower middle of the frame.

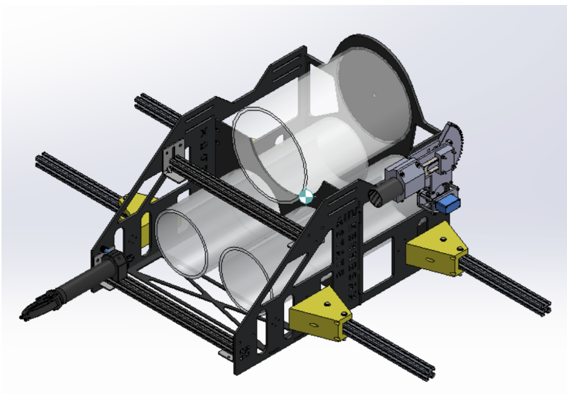

*Figure 1. Charybdis 2.0 Structural Assembly*

*2) Control Electronics Housing:*

All of Charybdis 2.0 control electronics are housed on a smaller, internal aluminum frame inside an 8-inch ID acrylic tube. The large amount of hardware requires a complex amount of wiring in a very small space. This created a mess of wiring that plagued the electrical team. To address the complexity of hardware and electrical component layout, the mechanical team focused on making efficient use of space with easy access and removable components. The electrical team worked on schematics and wire management which is discussed further in the *Electrical Design* section. Additionally, a 3D printed common carrier was designed within SolidWorks to house all the control electronics and keep their wiring short. The carrier also organizes the port and pin locations for repeatable wire and cable runs. The volume inside the tube was previously taken by excess wire lengths and poor organization of components, but having a set path aids in airflow for the processor and ease of maintenance. This process was chosen because it was fast, inexpensive, and allowed for the level of complexity and this part needed. While the team was initially concerned about maintenance access, a third tier was added to the main electronics housing mounted via wingnuts on custom brackets. This allows for removing the top and middle plates for quick troubleshooting or maintenance.

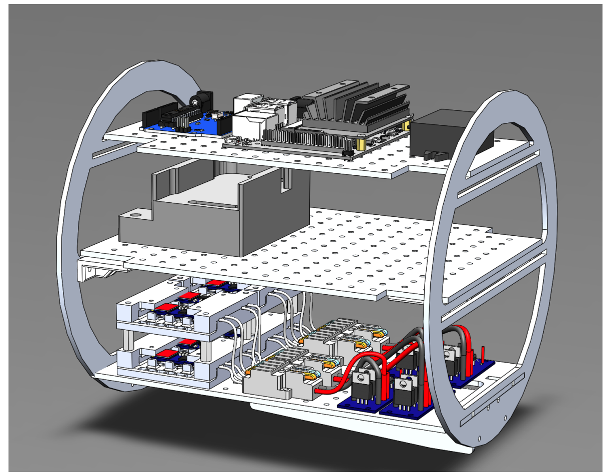

*Figure 2. Charybdis Internals Mockup*

*3) ESC Mounts:* The purpose of the mount design was to create better accessibility to the electronic speed controllers (ESC) avoiding inadequate management of wires when it comes to replacement or disassembly. Having the ESCs' wires clamped provided stress relief to the solder joints and forced the wires into an evenly spaced position for organizational purposes. Additionally, the mounts needed to address the issue with the large amount of heat created by the ESCs when the motors are running. The design allows for proper airflow on all heat sinks by the assembly having the ESCs with the least contact with any surface as possible. As well, the structure enables mounting a small size fan on the top of the ESCs to help with cooling. SolidWorks was used by members of the team to design and analyze the mounting structure with computational fluid dynamics (CFD) and thermal studies. Several design iterations were made to achieve the maximum air flow possible and increase the ease of assembly.

5*) Robotic Arm, Torpedo, and Marker Dropper Design:* The mechanical team spent many months researching and designing various iterations of sub-systems to complete competition tasks. The robotic arm proved the most complex to design and operate. The team has several Robotics and Mechatronics Engineering students who helped with this project and are experienced with operating robotics equipment such as Festo and Fanuc automation systems. A two-axis arm was decided upon with a Blue Robotics end effector due to its simplicity and time restrictions for the project. The arm is primarily servo actuated on the bending axis while the end effector is actuated with a DC motor and a stop switch. This system is controlled and linked to the software neural network and front-facing camera.

*Figure 4. Robotic Arm End Effector Testing*

This season's torpedo project was a continuation of the 2020-2021 competition season. Multiple torpedo designs were considered and were tested thoroughly leveraging the SolidWorks computational fluid dynamics (CFD) simulation package. Each torpedo was run through a series of simulations in an attempt to evaluate the performance of the torpedo before production. The launching mechanism remained the same from the previous year but was made of stronger materials for greater accuracy in aiming the torpedo. The launcher utilizes a rack and pinion actuated from a waterproof servo mounted to a 3:1 gearbox stepping up the torque. Compared to the other projects, the marker dropper was simple to design and implement. A PVC pipe is used to house the marker with a small flap at the bottom that is pulled out releasing the marker.

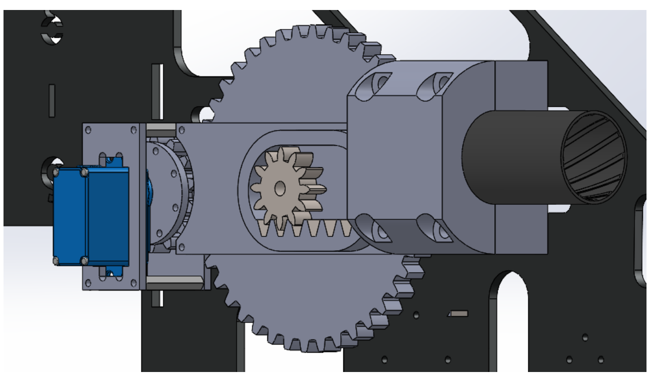

*Figure 4. Torpedo Launching Mechanism*

## B. *Electrical Design*

### *1) Wiring Reorganization*

The electrical team drew up a wiring diagram to aid in troubleshooting potential electrical issues in Charybdis. This streamlined the sub into compartments to better identify electrical issues. Components were desoldered and then re-soldered with a standardized wire that better-provided signal, power, and ground wire recognition throughout the entire system of Charybdis. The electrical team worked with the mechanical team on the creation of 3D-printed mounts to provide proper stability for electrical components. This also allowed for better wire management throughout the entire system to prevent wires from tangling up and damaging the sub's main components.

2) *External Electronics:* The connections between sub-electronics are shown in Fig. 4. Charybdis utilizes eight BlueRobotics thrusters for maneuverability. Eight electronic speed controllers (ESC) regulate the speed of the thrusters. The ESCs receive instructions by pulse width modulation from the PixHawk and give the ability to control the rotational speed and direction of the thrust.

*3) Power Distribution:* Five lithium polymer batteries power the sub's motors, onboard computer, and sensors. Power distribution is managed through the kill switches that were designed for sending power to the rest of the electrical system. The kill switches also manage the power distribution of the sub by acting as a way of killing all power to the sub via a switch located at the back of the sub.

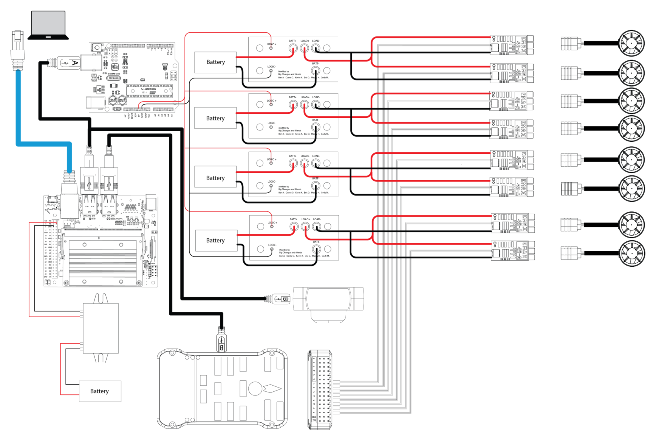

*Figure 4. Electrical System Overview*

*4) Kill Switch (KS) Redesign:* For the third iteration, it was a modified version of the 2020 KS board. Still using the same components as last year (optocoupler, resistors, and MOSFETs), the main focus was placed on pinpointing the cause for failure from the second iteration where the traces would overheat after extended run times. The design was created in EaglePCB software to lay out the original design and then optimized trace widths and thicknesses for their respective applications. In addition to tracing width modification, it was also designed for the physical geometry of the board to be directly attached to the chassis of the chamber along with bringing all of the existing components closer together.

*5) Hydrophones:* The RESON TC4013 are the hydrophones that were chosen for detecting the varying frequencies Robosub set. A pinger with a set frequency would act as the target for our sub to detect and perform the appropriate task accordingly. The hydrophone was tested by attaching to an oscilloscope and placing it in the testing pool with the pinger oscillating at a specific frequency. The test was designed to test the hydrophone's capabilities for a set range. Frequencies between 20kHz and 35kHz were produced by the pinger and were tested at a variety of distances. The hydrophones picked up the frequencies produced from the pinger and it's output was recorded by the oscilloscope.

*6) Pinger:* The JW Fishers MFP-1 Pinger was the device used to test out the functionality of the hydrophones. The pinger is a manual switch based frequency changer that can produce different frequencies but only allows for a singular frequency to be produced at a time. This allows for multiple tests of different frequencies.

*7) Filter:* IC filters were chosen to detect certain frequencies and ignore irrelevant ones. Specifically, our team used band-pass filters because of their unique property to filter a specified frequency range (25kHz - 35kHz) and ignore all frequencies that are present. The LTC1068 chip was chosen due to its clock tunable bandpass filter. This would allow the use of a microcontroller to send PWM signals and vary the frequency to change the center frequency of the bandpass filter. This would enable the ability to switch what frequency is let through the filter on the fly.

*8) Amplifier Circuit:* The amplifier circuit was designed to allow for the sub to amplify the frequencies trying to be detected through the IC filters. The filters are connected to a series of capacitors to help amplify the signals passing through the IC filters. In addition, this helps with the processing software by providing clearer signals to prevent the sub from getting confused about where or what signals it is receiving.

## *C. Computer and Software Design*

*1) Hardware:* Previously we had planned to implement the Nvidia TX2 as a more powerful onboard computer. Due to supply-chain issues with other carrier boards for the Nvidia TX2 we had to revert to the Jetson Nano. However, with how lightweight our software is, the Jetson Nano provides enough processing speed and power to perform its instructed tasks.

Leveraging two Logitech C920 HD Pro webcams, Charybdis can take high-resolution images of its surroundings that can be cleaned up via software filters. By passing higher resolution images through the convoluted neural network, it can use them for object and task identification, measurement approximation, and real-time targeting.

*2) Software Architecture:* The software architecture of Charybdis is based on the Robot Operating System (ROS), which provides a message-passing system and networking capabilities, among other functions [5]. The packages we created were designed to take advantage of ROS and the open-source libraries that use it, including SMACH, MavROS, ROS Serial, OpenCV, and Tensorflow. Figure 5 shows the high-level overview of Charybdis and signal direction.

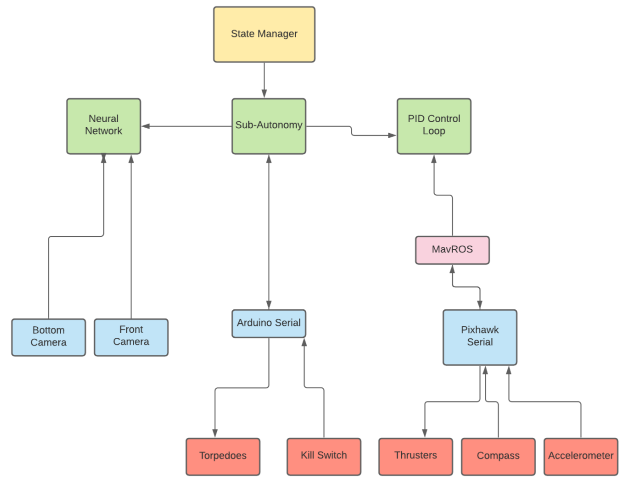


Figure 5. Software Architecture

*3) High-level Control:* High-level decisions about what Charybdis should do are made in a state machine implemented in SMACH, a ROS package that defines a state machine structure. [6]. Each state performs a competition task or part of a task: for example, to get through the gate, Charybdis passes through up to seven different states. One is the start state, four (implemented as a smaller state machine) combine to form a search pattern, one tracks the gate once it has been detected, and one passes through the gate once Charybdis is close to it. The implementation of the other tasks is architecturally similar. SMACH allows us to create complex state machines.

*4) Vision:* Video input is received from two USB cameras, one forward-facing and one downward-facing, and sent to the object detection algorithm via ROS. Due to the visual noise, variability in the environment, and other factors, the use of machine-learning-based object detection was deemed more effective than the creation of hand-crafted detection algorithms. The decision was made to use the SSD (Single Shot Detector) architecture with MobileNet, implemented in Tensorflow, because of its availability and performance - while not perfect, SSD is accurate enough for this application while still performing well on the Jetson Nano hardware. After taking a snapshot using one of the two cameras, the state machine will hand off the image to OpenCV to run some filters to better enhance the image. These filters include: Color Correction, Contrast Stretching, Binary masks, Whitebalacing, and Edge Detection via Canny Filter. This improves the neural network's ability to correctly identify objects by over 30% when compared to non-filtered images based on test results.

Figure 6 is the result of using a binary mask to filter out every color except for a specific range of black to better acquire the position of a pole on the camera. This section of the image is then sent to the neural network to be classified.

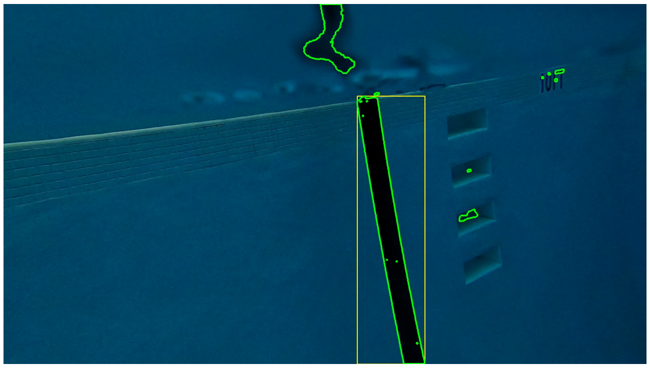

*Figure 6. Result of Binary Mask*

Once the network classifies the detections, Charybdis can perform movements based on that information. The Neural Network takes two points from the field of view: one provided by the SSD and one provided by the center of the camera. The program calculates the error between the two points and processes the error through a PID control loop, then outputs an RC value published to MavROS.

*5) MavROS:* MavROS, a ROS wrapper for the Pixhawk's MavLink software, serves as an all-in-one package to control the movement of the submarine by publishing virtual RC controller values to the Pixhawk flight controller. [7]. We used the Pixhawk controller because the open source community which developed Ardusub has created custom firmware for controlling AUVs that is easily wrapped with MavLink and MavROS for communication [8]. This allows for a plug-n-play format, in which we can both operate effectively while afforded some level of flexibility

*6) Arduino Auxiliary Control:* Controlling external mechanisms on the sub requires an external interface, which has been implemented through an Arduino over serial communication. The Arduino facilitates the ability to send commands to the manipulator while also monitoring the sub's killswitch to keep it aware of its current state.

*7) Simulation:* To make the debug process more efficient, we decided that a way to test Charybdis' states and functions prior to an in-person test would be crucial. Thus we decided to use Software-in-the-Loop with Ardusub, using MavROS to send communications. This allows us to get a visual simulation running of Charybdis and to test functions and states before executing them on the physical sub in water. This has streamlined the software design process and improved the speed of implementation for new behaviors.

The simulation's physics models an underwater environment using Ardusub. However, it isn't a perfect 1-to-1 recreation of how it handles Charybdis' physics directly. This introduces a small but noticeable amount of error between the simulation and actual physical tests with Charybdis. That being said, these fluctuations are minor and easily corrected once in-person tests are performed and software is adjusted.

## III. Experimental Results

### *A. In-Pool Testing*

Our pool testing focused on verifying that the elements of the sub worked correctly, specifically the updated frame, wiring, and neural network architecture. While limited testing was conducted in both the fall and early spring semesters, our primary testing period was cut short by the onset of COVID-19. In response to this unprecedented challenge, the software team developed a novel simulation environment during the summer to virtually test novel project aspects prior to commissioning as discussed in Section II.C.7.

### *B. Design of the Internals*

The design of the interior was a complicated problem. It had been "solved" several times, but while each design looked great in CAD, the solutions proved too complicated or cluttered in real life.

To better understand how components would fit in person, the mechanical team decided to subvert the traditional use of computer-aided design, and instead, implemented "cardboard-aided design" to create mock-ups of the sheet metal front tube racks. This was done by cutting sheets of cardboard, and laying out scale models of the computer components. The team produced four competing ideas to find traits that would benefit the sub: an improved, removable, version of the current rack, a trifold design, a "T" shaped design, and an "I" shaped design. The cardboard mockups were given to the electrical team to get feedback on what traits work and what traits hinder

## IV. Acknowledgments

The team would like to thank Dr. Muhammad Tanveer for acting as our faculty advisor, all our engineering and technology professors for their instruction, the KSU Student Activities Board Advisory Committee, the KSU Alumni Association, and all of our generous sponsors that helped make the Charybdis platform a reality.

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## APPENDIX A: COMPONENT SPECIFICATIONS

| Component | Vendor | Model/Type | Specs | Cost (if new) |
|---|---|---|---|---|
| Buoyancy Control | N/A | | | |
| Frame | KSU AUV | Custom | 30in x 36(motors out)in x 18in | $880 |
| Waterproof Housing | Blue Robotics | | 1 in8 and 4 4in Enclosures | $972 |
| Waterproof Connectors | Blue Robotics | red/black penetrators | N/A | $96 |
| Thrusters | Blue Robotics | T200 | | N/A |
| Motor Control | | EMAX Formula Series BLHeli | 45A | $140 |
| High Level Control | Amazon | Pixhawk 3 | | N/A |
| Actuators | N/A | | | |
| Propellers | Blue Robotics | | N/A | N/A |
| Battery | HobbyKing | Multistar | 10000mAh, 4S | N/A |
| Converter | N/A | | | |
| Regulator | Amazon | KNACRO | AC/DC to DC 20W Converter | $11.20 |
| Embedded System | Nvidia | Jetson Nano | Quad-core ARM Cortex-A57 MPCore processor (1.43 GHz) | $99 |
| Internal Comm Network | N/A | N/A | USB cables | N/A |
| External Comm Interface | Blue Robotics | | Ethernet tether cable | N/A |
| Programming Language 1 | Python | | | |
| Programming Language 2 | C++ | | | |
| Compass | Amazon | Pixhawk 3 | | N/A |
| Inertial Measurement Unit (IMU) | Amazon | Pixhawk 3 | | N/A |
| Doppler Velocity Log (DVL) | N/A | | | |
| Camera(s) | Logitech | C930E and C270 | C930E: 1080p/30 FPS, 90° FOV<br>C720: 720p /30 FPS, 60° FOV | N/A |
| Hydrophones | Teledyne Marine | RESON TC4013 | N/A | $1500 |
| Manipulator | N/A | | | |
| Algorithms: vision | Tensorflow | SSD MobileNet v2 | N/A | $0 |
| Algorithms: acoustics | N/A | | | |
| Algorithms: localization and mapping | N/A | | | |
| Algorithms: autonomy | KSU AUV | Custom | N/A | $0 |
| Open source software | ArduSub, Ubuntu, ROS, MavROS, OpenCV, SMACH, Tensorflow | | | |
| Team size (number of people) | 32 | | | |
| HW/SW expertise ratio | 2 HW : 1 SW | | | |
| Testing time: simulation | 2 hrs. | | | |
| Testing time: in-water | 15 hrs. | | | |