Technical Design Report for Hope

Michael Lees	Bradford Creecy	Jake Spinnler	Sam Obhi
Software	Mechanical	Electrical	Mechanical
KSU AUV	KSU AUV	KSU AUV	KSU AUV
Acworth, GA, USA	Marietta, GA, USA	Braselton, GA, USA	Decatur, GA, USA
mlees@students.kennesaw.edu	bcreecy@students.kennesaw.edu	jspinnl1@students.kennesaw.edu	sobhi@students.kennesaw.edu

***Abstract*— With interdisciplinary cooperation between team members, the Kennesaw State University Autonomous Underwater Vehicle Team (KSU AUV) has built a new design from the ground up. The AUV Hopes And Dreams platform has been designed to allow new functionalities and behaviors for the 2024 RoboSub competition. The motor configuration and control systems of the AUV allows for maximum control and flexibility. This vehicle utilizes a custom electrical and software architecture to allow for ease of modifications and control of movements within the water. This paper discusses the 2024 KSU AUV competition strategy and highlights the technical attributes of Hope.**

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 2023-2024 competition season, KSU AUV has built a new design from the ground up. Hope is a versatile platform developed during the 2023 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 Hope are found in Sections II and III of this report in addition to the hardware and software specifications provided in the appendices. The team has collaborated for design work, integration, and testing while meeting appropriate safety guidelines.

B. Competition Strategy

Post-RoboSub 2022, the team identified numerous potential improvements from the Charybdis platform. Notable examples include an internal wiring overhaul, motor maintenance and replacement, killswitch redesign, overheating mitigation, chassis and fastener corrosion protection, accessibility, modularity, and numerous frame improvements. For the 2024 RoboSub competition, the team identified three primary challenges to pursue:

1. Open-Frame design

2. Design as much of the electrical system in-house as possible

3. Improved accuracy of autonomous control software

To meet these objectives, the team sub-groups focused efforts on improving movement-critical and task identification systems from the 2023-2024 season and developing a new AUV ground up.

II. Design Creativity

A. Mechanical Design

1) Outer Structure and Component Housing

After the 2022 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: limited space and difficulty accessing computer and electrical components, ease of adjusting weight distribution and external components, and lack of thruster positioning options. To address the first design concern, the mechanical team designed the main electrical housing to foremost allow easy access to internal components. To achieve this the housing is a rectangular prism with a removable bottom face. The second issue was solved by making the frame out of 1 Inch T-Slotted Aluminum Extrusion. This allowed for a highly adjustable frame with a high number of mounting options at a very low cost. 6105 Aluminum was the alloy chosen for the frame for its lower cost, while still greatly exceeding required strength. The frame design was modeled in SOLIDWORKS utilizing the weldments feature to create a highly accurate cut list to produce the frame with. Using the T-slot framing 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. For the third issue we incorporated eight thruster locations throughout the frame. All of the locations allow for quick and easy repositioning, which was invaluable during testing.

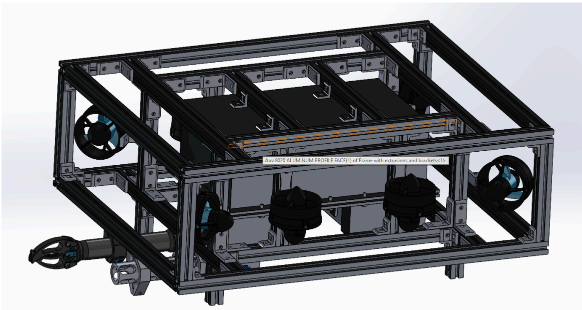

Figure 1. Hope Structural Assembly

2) Control Electronics Housing:

All of Hope's control electronics are located in the central housing. all of the components are mounted on a non conductive base plate that is mounted to the roof of the electrical housing. Mounting of components to the roof of the housing was chosen because when the AUV is being maintained it is upside down, allowing for easy access to all components. The electrical team worked on schematics and wire management which is discussed further in the *Electrical Design* section.

All of the components are mounted onto a plastic plate which is then itself mounted to the roof of the main housing. Having all of the electronics located on one board allows for easy removal of all components for troubleshooting without a lengthy disassembly process. This mounting plate also helps to ensure all electrical components are electrically isolated from the metal housing.

3) External Battery Packs

The purpose of the External battery packs was to allow for more of the weight to be placed lower on the frame and to allow easy change out of low power batteries with fully charred batteries without needing to open the main electrical enclosure. This also isolates the heat the batteries produce during operation from the main electrical housing. Through several rounds of testing we have verified that the battery housing itself provides more than adequate cooling to all the batteries to prevent them from overheating during operation.

4*) Robotic Arm and Torpedo 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 and is visible from the front-facing camera.

Figure 2. Robotic Arm End Effector Testing

Multiple torpedo launcher and propulsion designs were considered and tested thoroughly leveraging the SolidWorks computational fluid dynamics (CFD) simulation package. Each torpedo design was run through a series of simulations in an attempt to evaluate the performance of the torpedo before production. The launching mechanism went through several revisions and the final launcher utilizes a piston and pull ring design. A single waterproof servo pushes on the back of the torpedo while also pulling the magnet ring back. The piston pushes the torpedo down the launch tube, getting it past the retaining o-ring. With the magnet ring pulled back the internal magnetic switch closes providing power to the internal motor. The combination of these two actions allows for the torpedo to propel itself out of the lunch tube and towards the target with accurate and repeatable results.

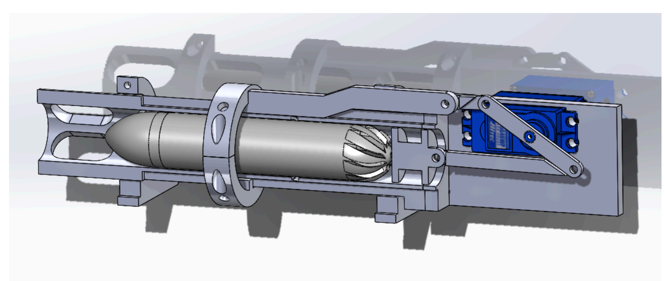

Figure 3. Torpedo Launching Mechanism

B. Electrical Design

1) *Custom Designed Electronics:* The electronics system is completely redesigned from the ground up. This allows for

complete customization over the system's functions to meet our needs. All designs were created in Altium software. Communication was standardized to cables that transmit I2C and power to all internal components. The electrical team worked with the mechanical team on the creation of 3D-printed mounts to provide stability for electrical components. This also allowed for better wire management to allow for easy debugging.

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

3) Power Distribution: Four lithium polymer batteries power the sub's motors, onboard computer, and sensors. Power distribution is managed through the battery monitor that was designed for sending power to the rest of the electrical system.

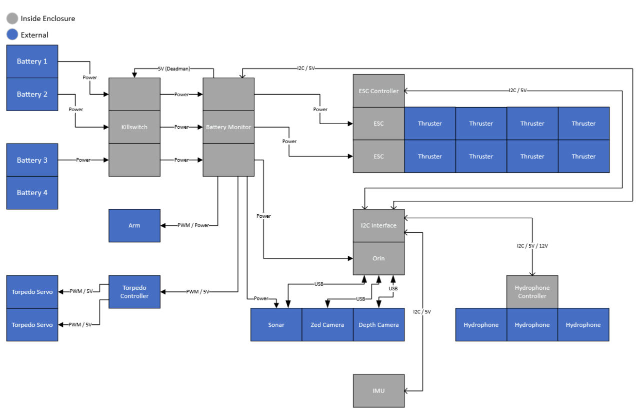

Figure 4. Electrical System Overview

4) Kill Switch: The kill switches control the flow of power from the batteries to the rest of the components. The killswitch will immediately kill all power when water is detected inside the housing, or if it is told to by the battery monitor.

5) Hydrophones: The RESON TC4013 are the hydrophones that were chosen for detecting the varying frequencies of the 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 its 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: We had the opportunity to utilize the Nvidia AGX Orin 32 GB Developer Model as the core processing unit of this year's build. This model boasts much greater performance over the Nvidia TX2 that was used previously and allows our newly developed software architecture to run at full speed and efficiency in comparison to last year's board.

We are also utilizing the original ZED stereographic camera used by our Camera Package and the Anker Power Conf C200 2k camera. These cameras allow us to get both front facing and bottom facing views.

2) Software Architecture: The software architecture of Hope is built upon the Python Programming language (version 3.10.2). We decided to remove the Robot Operating System (ROS) code that was developed by our alumni members and replaced it with a purely Python implementation. The architecture consists of one main process with four sub processes linked together with multiple relational databases. The four sub processes are as follows:

- Hardware Interface
- Movement Package

- Neural Network Package
- State Machine Package

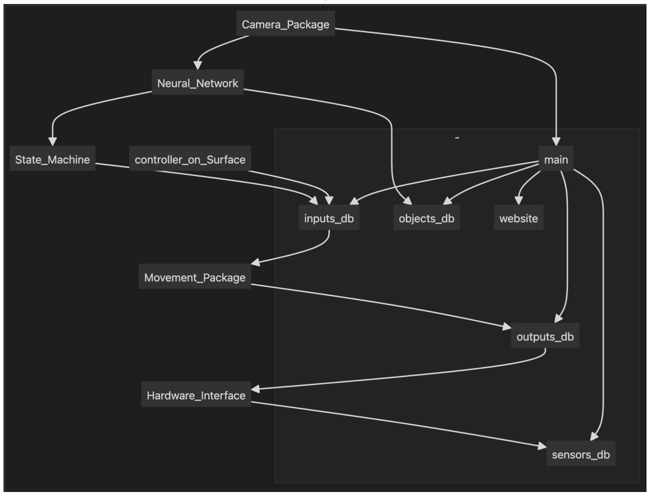

Figure 5. Software Architecture

3) High-level Control: Hope is controlled by the State Machine created with the python state machine library. This state machine framework acts as the brains of Hope and can complete simulated qualification runs at thirty percent completion but we have plans to increase the completed percentage to one hundred percent before the actual competition.

4) Cameras: Hope utilizes one original ZED depth sensing camera and one Anker Power Conference C200 camera. The ZED camera provides Hope with the front facing view and distance measurements to detected objects in front of Hope.

5) Hardware Interface: The hardware interface sub process handles all communication between the electrical system and the Orin. Written in Python, the sub process communicates with the electrical system over I2C communication lines, ensuring accurate and fast communications between them. All sensor data is stored within the relational database and all of the movement data is queried from the same database and sent to the necessary electrical hardware.

7) Simulation: Using the Unity game engine allowed our team to create the simulated environment in which Hope can practice competition runs without the need to build expensive (for our team) mission props. Our simulation is built with two levels, the first level includes the pre-qualification run and the second level includes the main qualification run. Our simulation allows for our Orin to communicate directly utilizing the already developed database structure within the main process.

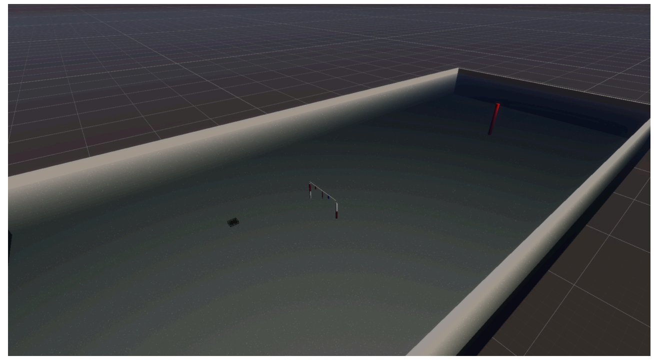

Figure 6. Prequalification Simulation

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 Hope platform a reality.

V. References

[1] A. Graves, A. Hagle, C. McDermitt, C. Meier, E. Neleski, B.Sailor "*Technical Design Report for Via Maris*," RoboNation, https://robonation.org/sites/default/files/Kennesaw_TDR_RS18.pdf [Accessed on July 1, 2019]

[2] A. Cheng, H. Evans, J. Gragg, A. Graves, A. Hagle, C. Meier, J. Nguessan, V. Nguyen, B. Sailor. "Design rationale for Leviathan autonomous underwater vehicle." RoboNation, http://robonation.org/sites/default/files/RS17_KennesawState_Paper.pdf

[Accessed on May 15, 2021]

[3] R. Panez. "Simplified method for obtaining navigational information from hydrophone arrays". University of Florida, 2004, https://www.mil.ufl.edu/publications/thes_diss/Rolando_Panez_thesis.pdf [Accessed on 5 January, 2021]

[4] "LT1097 - Low Cost, Low Power Precision Op-Amp", Linear Technology Corporation, https://www.analog.com/media/en/technical-documentation/data-sheets/1097fas.pdf [Accessed on March 25, 2021]

[5] "RESON TC4013 - hydrophone", Teledyne Marine, http://www.teledynemarine.com/reson-tc4013?ProductLineID=48 [Accessed on March 30, 2021]

[6] "MID-FREQUENCY PINGERS", JW Fishers, http://www.jwfishers.com/products/pingers-mid.html [Accessed on April 25, 2021]

Appendix A: Component Specifications

Component	Vendor	Model/Type	Specs	Cost (if new)
Buoyancy Control	N/A			
Frame	KSU AUV	Custom	23in x 13 in x 35in	$250
Waterproof Housing	KSU AUV	Custom	5 in x 9 in x 15 in	$300
Waterproof Penetrators	Blue Robotics	Red/Black Wetlink Penetrators	N/A	$150
Waterproof Connectors	Amazon	SP29	IP68	$10
Thrusters	Blue Robotics	T200	17 A @ 12 v	$ 1600
Motor Control	GetFPV	Xilo Stax V2 F4	45A	$55
High Level Control	Nvidia	Jetson AGX Orin	Quad-core ARM Cortex-A57 MPCore processor (1.43 GHz)	$1,248.75
Propellers	Blue Robotics	T200	N/A	$8
Battery	HobbyKing	Turnigy High Capacity	10000mAh, 4S	$72
Embedded System	Nvidia	Jetson AGX Orin	Quad-core ARM Cortex-A57 MPCore processor (1.43 GHz)	$99
Internal Comm Network	N/A	N/A	I2C	$10
External Comm Interface	Blue Robotics	Fathom Tether	Ethernet Tether Cable	$235
Programming Language 1	Python			
Programming Language 2	C++			
Inertial Measurement Unit (IMU)	N/A	Custom	MPU-6050	N/A
Camera(s)	ZED Amazon	Original ZED C200	Dual 1080p @ 60fps Single 2k @ 60fps	$300 $59.99
Hydrophones	Teledyne Marine	RESON TC4013	N/A	$1500
Manipulator	Blue Robotics	Newton Subsea Gripper	6.2cm capacity	$640
Algorithms: vision	Tensorflow	Custom	N/A	$0
Algorithms: autonomy	KSU AUV	Custom	N/A	$0
Open source software	Python, Flask, Flask SQLAlchemy, Python State Machine, Tensorflow			
Team size (number of people)	14			
HW/SW expertise ratio	2 HW : 1 SW			
Testing time: simulation	2 hrs.			
Testing time: in-water	15 hrs.			