RoboBoat 2023: Technical Design Report
Iceberg ASV - Lukey’s Boat

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Abstract

This report outlines the competition strategy and development of Iceberg ASV’s vessel - Lukey’s Boat. Iceberg ASV’s strategy focused on an iterative design approach which allowed for improvements on each prototype until the finalized design for Lukey’s Boat was achieved. All systems were tested independently in a simulation environment before integration to ensure a simple yet robust design.

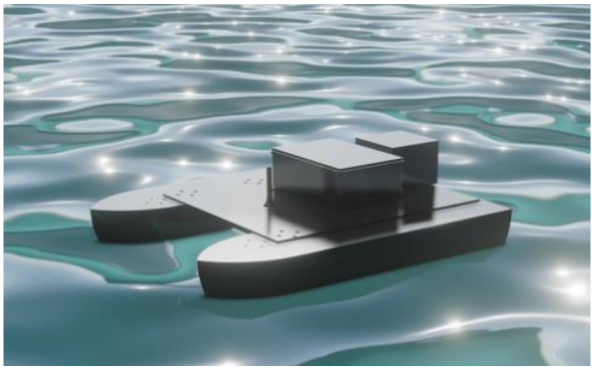

Figure 1 – Lukey’s Boat

Competition Goals

Iceberg ASV approached this year’s competition with an iterative design process. The mindset behind this approach was to stay consistent and aim for improvements in small, manageable steps. This concept allowed the team to learn, create, and solve problems encountered in an efficient manner, while also making consistent progress on Lukey’s Boat.

The team’s initial design was a small remote controlled boat, which was scaled up during each testing phase, going from semi-autonomous, to fully autonomous as the final result. Each testing phase iterated on the previous design, with improvements on hull design or additional technology until the final design was fulfilled.

The ASV design was created with the intention of successfully completing three competition tasks: Navigate The Panama Canal, Magellan’s Route, and Northern Passage Challenge [1]. These tasks are the least complex and allow the team to design a simple yet structurally sound vessel that aligns with the teams skill set and experience.

Design Strategy

Hull and Mounting

The design teams’ main task was to design a simple but reliable hull. Using a simple vessel will allow flexibility when improving the team's design for future projects. With this in mind, the team constructed a catamaran vessel with a bridge connecting the two pontoons. The hulls were constructed using three layers of rigid foam (Figure 2) that were carved, sanded, and secured with flex seal.

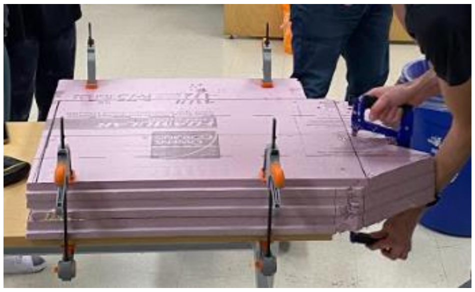

Figure 2 – Construction process of foam hull

The main challenge was reducing the buoyancy of the model. To reduce buoyancy and achieve the desired draft, the solution was to reduce the amount of buoyant material used in the model. This was achieved by improving the geometry of the hulls and decreasing the overall beam and length.

The bridge attaches to the ASV's hull and supports the electrical housing. During the iterative design process, the bridge has undergone several prototyping phases to arrive at the final design. In the initial prototype, the bridge was made by gluing popsicle sticks to miniature foam hulls. The next prototype featured a 3D printed bridge with a custom design for inserting the motor mounts and securing the electrical components. Lastly, the final bridge design was made with a sheet of HDPE and was machined to the desired dimensions using a CNC machine. The bridge is mounted to the foam hulls using 3D printed inserts, allowing for modular disassembly during shipment and on-the-fly modifications.

The electrical integration was a key consideration when designing the bridge. On the bottom face of the bridge, there are two cutouts where the motor mounts are secured. On the top face, there are holes for mounting two electrical housing boxes, one camera mount, and the LiDAR. The camera mount and LiDAR mount were designed and 3D printed in house.

The fixed thruster mounts connect the twin Blue Robotics T200 thrusters to the bridge of the model, see Figure 3. The mounts were 3D printed with high quality PETG filament and designed to handle the power of the T200 thrusters. The shaft length was designed to allow the T200's to be fully submerged with adequate clearance from the hull. The mount itself consists of a shaft with flanges on the top and bottom, these flanges will be used to fasten the mounts to the thrusters and bridge. The flanges have a wide diameter with enough clearance between them to allow for easy access to the fasteners. The mounts are designed to be modular for easy maintenance and storage. The thrusters, mounts, and bridge can be removed from the hulls.

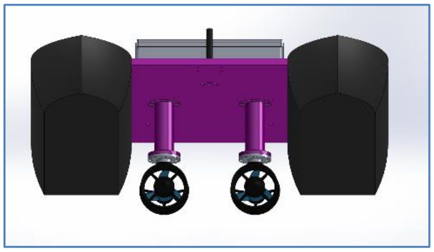

Figure 3 – Finalized CAD mode of bridge, motor mounts and hull design.

The iterative design process allowed for improvements based on issues encountered on the previous model. Initially, the thruster mounts were to be rotating mounts powered by a stepper motor, this however increased the difficulty of coding the navigation algorithms as well as the challenge of waterproofing. The T200 thrusters are capable of reverse thrust and therefore provided the option of skid steering if used with fixed mounts. Additionally, the initial design of the mount was not secure enough to withstand the vibrations caused by the T200 thrusters and detached from the model during testing. Initial designs also faced challenges with access to fasteners that made assembly difficult. These mistakes ultimately allowed for the final hull design to be robust and modular.

Controls

The heart of the electrical controls is the Pixhawk 6C flight controller. The Pixhawk 6C model was chosen because it is afforable, designed for use in small scale autonomous systems, and has significant resources. It performs a variety of tasks, including communication with the receiver for radio control and monitoring battery health by connection to the power distribution board [2]. The Pixhawk is contained in the electrical housing on the ASV and can transfer operational status wirelessly by means of telemetry radio. This data can be viewed using mission planner software, QGroundControl.

The remote kill switch is a required safety feature [1]. When activated, the Electronic Speed Controller (ESC) circuits must physically disconnect and must also provide a failsafe shut-off when battery power is disconnected. The kill switch is activated when a remote signal is sent through the transceiver, or when the physical kill switch button is pressed. The lack of relays on the market with a 5V signal voltage rated for the current draw from the thrusters presented a significant design challenge. To resolve this, a DC-DC boost converter was implemented to increase the rated signal voltage to 12V, and a standard automotive relay with a suitable current rating could be used [3].

The ASV can operate autonomously or using radio control (RC). The early iterations of control system development were focused on RC. The original control system consisted of a controller from a toy RC boat and an Arduino to receive the control signal and operate the thrusters. To improve, the FlySky-i6X controller and receiver combination was selected as an economical and effective upgrade to control the ASV via radio. The FlySky-i6x is compatible with the Pixhawk 6C flight controller [2], therefore the vessel controls can seamlessly transition from autonomous to remote controlled operation.

Power Distribution

A Holybro PM07 power distribution board (PDB) is used on the ASV. To ensure voltage requirements are satisfied, information from manufacturer datasheets were evaluated to guarantee compatibility between the PDB and the ASV components. Two LiPo batteries are used to power the hardware. To distribute appropriate power across the system, one battery powers the TX2 while the other distributes power across the remaining components using the aforementioned PBD.

The electrical system is housed in two junction boxes. The primary housing contains two LiPo batteries and larger hardware components including the Pixhawk. The secondary housing contains smaller hardware, notably the relay circuit for the kill switch. Junction boxes were selected as they are widely available, easy to modify and water-resistant making them ideal for the competition. Cable glands were installed on the boxes to provide an air-tight transfer of electrical wiring. Additionally, junction boxes allow for easy access and fast assembly, prioritizing on the fly adjustments and troubleshooting.

For effective use of the inertial measurement unit in the Pixhawk, centering this component to a sturdy base was prioritized. To ensure this, the team placed Velcro at the bottom of the box and shelving supports were placed on the corners to aid in accessibility.

Software Development

To complete the Navigate The Panama Canal, Magellan's Route, and Northern Passage Challenge tasks, the ASV must identify buoys on the course and navigate accordingly. The depth camera identifies buoys, then the LiDAR dictates navigation with respect to them. Collecting and storing sensor data at the 2023 competition can also be used for future work within simulators like Gazebo [4]. The LiDAR and depth camera data can be used to enhance the autonomous performance of the vessel outside of the competition and during the winter months while the water sources are frozen over.

Lukey's Boat uses a Remote Operating System (ROS) navigation stack to drive autonomously. This involves mapping environments, localizing within the environment, and navigating to desired positions without hitting obstacles. ROS allows for easy configuration of an autonomous system as it reads globalized setpoints and performs obstacle avoidance to react to immediate obstruction while remaining on course for the intended location.

Iceberg ASV chose to implement SLAM (Simultaneous Localization and Mapping) for the 2023 competition. SLAM allows the ASV to navigate throughout an environment in real time [5]. SLAM was selected for navigation as it is native to ROS, and quick to configure. From this, the team could begin iterating and tuning the navigation system immediately.

Testing Strategy and Outcomes

RC Testing

An initial testing procedure was to ensure proper controller and receiver calibration for skid-steering. Skid steering requires the propellers to rotate clockwise and counterclockwise. To test the bi-directional capability of the thrusters, the receiver's PWM signals were observed. Prior to connecting the thrusters to the receiver output, oscilloscope testing was used to safely ensure that the PWM signal behaved as expected.

To activate the relay of the remote kill switch, a DC signal is required to activate the coil and switch the relay position. The receiver sends PWM signals, therefore an Arduino Uno is employed to read the PWM signal and output the corresponding DC coil voltage. First, code was written to observe the PWM signal read by the Arduino. This code was run, and the serial monitor observed an inaccurate signal with distortion.

To compensate for the Arduino's inaccuracy, the accepted bandwidth for the PWM signals would need to be expanded. The code was improved to then send a 5V DC output after a PWM signal within the expected bandwidth is detected. Once testing confirmed safe and accurate operation of the kill switch, it was implemented in the final design.

Simulation Environment

Gazebo simulation allowed for software testing without using hardware. Gazebo was selected for available online resources and easy integration with ROS and the sensors. The simulation proved to be an effective software verification prior to implementation with hardware systems.

The first simulation involved 3-wheeled robot models and implementing the ROS navigation stack. The robots were then modified to create a model of the ASV and simulation environment (Figure 4). Gazebo uses a physics engine [4], simulating the dynamics of a boat in the water, which further aids in tuning sensors and algorithm parameters. All software was tested in Gazebo before in-water testing to ensure the safety of the ASV and to speed up development time.

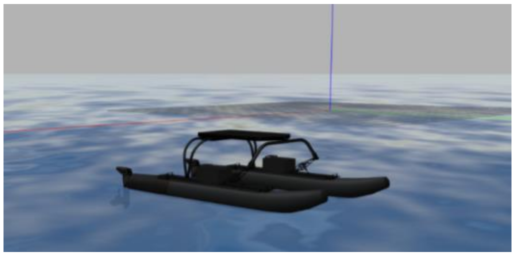

Figure 4 – Gazebo Simulation Environment

In-Water Testing

The first iteration, named Scrappy, was to get the initial conditions of the design so the team could begin iteration process, see Figure 5. The test resulted in low propulsion, unreliable construction, and a low operational life which provided a variety of areas for the team to improve on while working towards the next boat iteration.

Figure 5 – Iceberg ASV’s first prototype, Scrappy

Scrappy V2 was the first boat that included parts the team purchased with intentions of using at the competition. This iteration included a new hull design and T200 thrusters. The in-water testing on this iteration was to verify the thrusters were powerful enough for competition use, and to analyze the robustness of the new hull design. This testing resulted in the hull and thrusters performing well, but the thruster mounts and controller signals provided areas of improvement. The thruster mounts had difficulty securing the thrusters during operation. As well, the control signals for the thruster required tuning as they were too sensitive for the receiver that was employed for the Scrappy V2 iteration.

The next iteration, as seen in Figure 6, included considerable upgrades to the communication systems of the boat, thruster mounts, and electrical housing. The upgraded communication systems include increased operating range for remote controlling and telemetry radios to monitor the boats power performance.

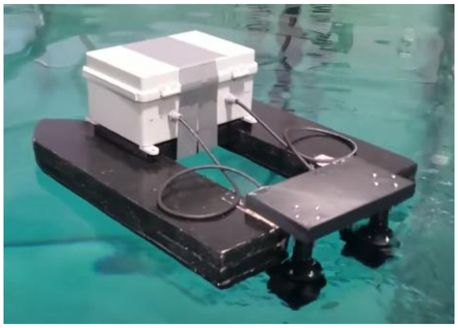

Figure 6 – Upgraded semi-autonomous prototype

Multiple distance tests were performed by sending signals through our transceiver to our receiver in the university parking lot. Each signal was tested in increments of 10 meters to ensure that the communication range is strong within 100 meters.

The thruster mounts were upgraded and refined to extend the motor depth and the infill density of the 3D printed filament. The thruster mounts were tested by repeatedly testing the extremes of the thrusters, each iteration can be seen in Figure 7. The electrical housing was upgraded to outdoor rated junction boxes with cable glands to allow the cables through. To test the water and dust resistance the housing was thoroughly checked after in water runs for water intake.

Figure 7 – Thruster mount prototypes from oldest (left) to newest attached to bridge (right)

The overall in-water testing results showed the increased strength in thruster mount design, communication signals, and electrical component protection. The in-water tests of this iteration presented an issue with the sensitivity of the remote controls as the thrusters accelerated the vessel aggressively that may result in damaging our sensors.

Lukey's Boat is the final iteration for Iceberg ASV for the 2023 competition, see Figure 8. The in-water testing for the final iteration focused on meeting competition requirements, specifically the kill switch. The competition handbook outlines that the physical kill switch must be large enough and placed such that it can be activated with a canoe paddle [1]. The kill switch functionality for both physical and remote-control activation was tested to ensure it works correctly.

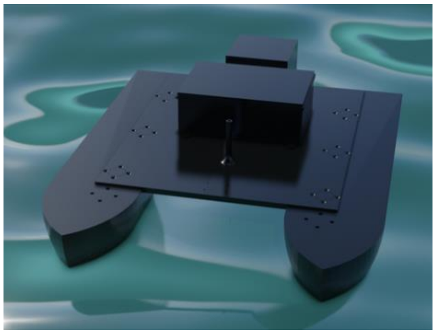

Figure 8 - Finalized Rendering of Lukey's Boat

The in-water testing included data collection from LiDAR, depth camera and GPS systems to allow the software team to view the collected data to study and implement within the simulations built to train the boat and allow for testing of competition tasks to success.

Acknowledgements

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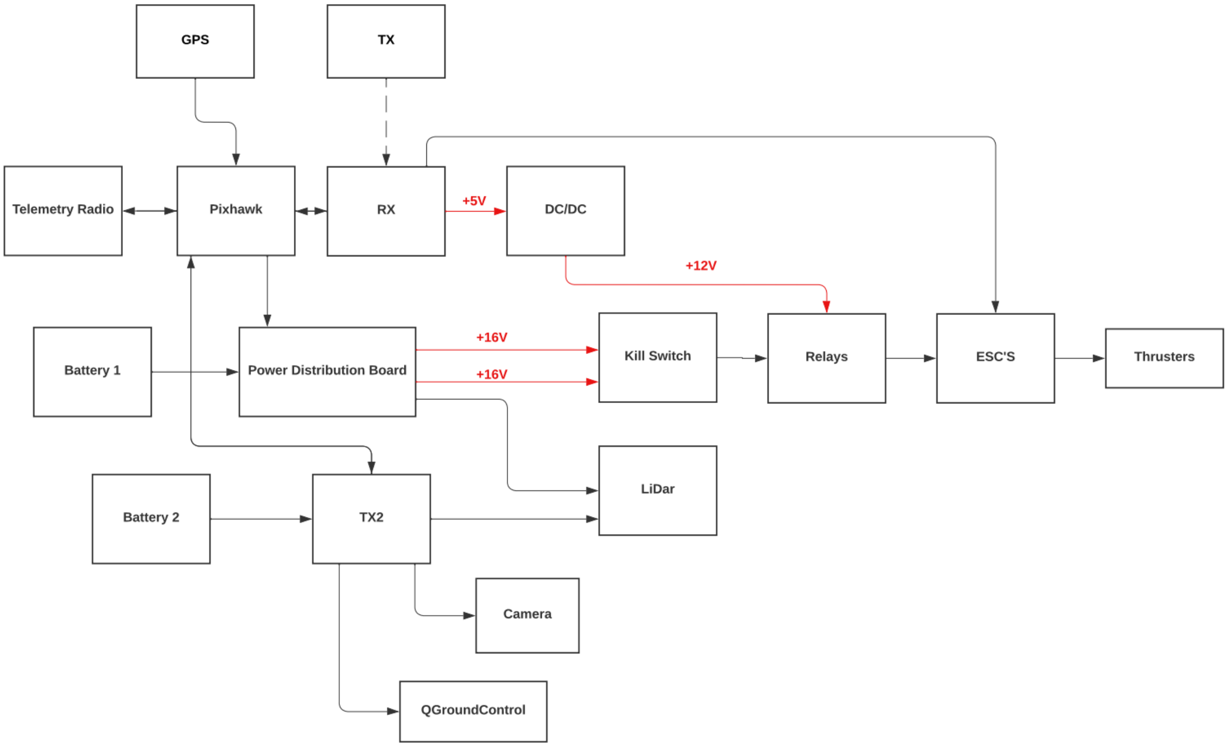
APPENDIX A: COMPONENT LIST

Component	Vendor	Model/Type	Specs	Custom/ Purchased	Cost (USD)	Year of Purchase
ASV Hull	Custom	-	~ 32.75” x 7.75” x 4.25”	Custom	$100	2022
Waterproof Connectors	Leviton	O-Ring 0.5” PVC	PVC, Threaded w/ locknut, 0.5”	Purchased	$6	2023
Propulsion	Blue Robotics	T200 Thruster	https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster-r2-rp/	Purchased	$382	2022
Motor Controls	Blue Robotics	Basic EESC R3	https://bluerobotics.com/store/thrusters/speed-controllers/besc30-r3/	Purchased	$84	2022
Power System	Youme Power	4S 50C LiPo Battery	4S, 50C, 14.8V, 6200mAh	Purchased	$80	2022
GPU	Nvidia	Jetson TX2	https://developer.nvidia.com/embedded/jetson-tx2	Donated	$0	2023
Teleoperation	Flysky	FS-i6X	https://www.flysky-cn.com/fsi6x	Purchased	$84	2022
Inertal Measurement Unit	HolyBro	Pixhawk 6C	http://www.holybro.com/product/pixhawk-6c/	Purchased	$333	2022
Camera	Intel	RealSense D435	https://www.intelrealsense.com/depth-camera-d435/	Purchased	$338	2022
Algorithms	Custom	-	-	Custom	-	2023
Vision	Open CV	-	-	Custom	-	2023
Localization & Mapping	Custom	-	-	Custom	-	2023
Autonomy	Custom	-	-	Custom	-	2023
Open Source Software	ROS	-	-	Custom	-	2023

APPENDIX B: ELECTRICAL DIAGRAM



APPENDIX C: SOFTWARE DIAGRAM