# RoboBoat Technical Report

May 15, 2022

## I. Abstract

This is the technical report for Cornell AutoBoat's inaugural competition. We feature a catamaran style boat with carbon fiber hulls. The boat is equipped with a ZED 2i camera, Jetson, Nano, and Arduino Uno 3 to gather data, make computations, and receive signals and is powered by 14.8 V batteries. Our computer vision implementation and algorithms allow the boat to function fully autonomously, or via remote control.

## II. Competition Strategy

### General Strategy

With RoboBoat 2022 being Cornell AutoBoat's first-ever competition, the team's goal is to attempt and complete every competition challenge. Team success is defined as developing comprehensive and responsive mechanical, electrical, and computing systems that satisfy the testing procedures outlined in the team's Critical Design Review (CDR). Completion of all competition challenges serves as a catalyst for growth across research, design, and management strategies teamwide.

### Testing

The procedures of the testing phase were based on a rigorous approach to Design Failure Mode and Effect Analysis (DFMEA). As part of this analysis, failure modes of similar designs were researched, assessed, and ranked based on likelihood, severity, and detection. Specifically, the failure modes were assessed with a Risk Priority Number (RPN) matrix. This enabled us to target our testing procedures towards methods that mitigated the effects of failure modes that would be the most likely to occur, most damaging to our design goals, and most challenging to detect. The DFMEA assessment motivated the procedures outlined in the Design Verification Plan and Report (DVP&R), which aimed to ensure that the design met internal requirements and standards with a particular emphasis on mitigating the effects of failure modes that were assessed to be especially detrimental to competition success. Overall, the testing process encompassed all aspects of the design at the mechanical, electrical, software, and systems level, and it resulted in a robust design that met performance expectations.

### Safety

During the competition, several safety measures have been implemented in order to ensure the safety of our team and other participants in the competition. The most important is the remote and onboard emergency kill switch. This kill switch was designed to be independent of the onboard software, meaning any bugs in the software will not affect it. The onboard kill switch is large and easily reached by personnel.

A visual display system is also in place to depict which mode of operation the boat is in. The modes of operation and their corresponding colors are blue for autonomous, yellow for manual, and red for active emergency stop.

Additionally, all wires are properly covered in shrink tubing, so electrical shock is not possible when entering the electronics box. All electronics are fastened securely and positioned to decrease the risk of overheating.

Battery safety was a major concern of ours. Throughout the competition, all of our lithium-ion batteries will be properly stored in a fireproof LiPo bag at a suitable temperature. We have battery safety documentation on hand and protocols in place in case of an emergency.

# III. Design Motives & Process

## *Mechanical Aspects*

### Hulls

To maximize roll/yaw stability, a catamaran design was chosen. Carbon fiber was chosen as the hull material due its overall stiffness, durability, strength to weight ratio and structural integrity. The hulls were designed with flat bottoms for stability along with smooth curves at the front to maximize hydrodynamic flow separation. By making the hulls longer and using an optimal prismatic coefficient, the hulls were optimized to reduce drag while still displacing enough water to keep the boat afloat. Within each of the hulls, five laser-cut wooden frames were placed at equal intervals to ensure the structural integrity of the hulls. Additionally, silicone tips will be placed at the front of each of the hulls to protect the hulls in the case of a collision.

### Skeeball Launcher

For the skeeball task, a device was constructed that utilizes a system of gears that interact with a rack. As the rack moves back, a spring is compressed that will launch the ball towards the target. The spring was chosen over alternative designs such as compressed air and flywheel designs which would be difficult to design and add additional weight to the system. To launch the piston forward, the final gear will have missing teeth to propel the spring. To ensure that the mechanism will be able to shoot continuously, the system of gears will be powered by a motor. Spring loading will allow balls to fall freely in place into a feeder mechanism that blocks entry after being accessed. The ball feeder is placed on top of the main pipe at a slight angle to ensure the camera's field of view is not obstructed.

### Water Gun

To complete the water jet task a device was constructed that siphons water from the surrounding body of water and ejects that water toward the target. This is a simple design with a straightforward execution and provides flexible positioning on the boat. Siphoning is facilitated by a diaphragm pump capable of pulling water without being in the water itself, therefore not comprising efforts of hydrodynamic drag reduction and eliminates the need for pump priming. The pump provides sufficient flow rate at two gallons/min, ensuring the ejected water can reach the target. The other components of the water gun include the tubing, which serves as the connection from the pump to the water. The tubing is ⅜" in diameter. The hose and the tubing both serve as mediums to transport the water, while also allowing the pump to be installed on the boat's bridgeside towards the left hull. The nozzle focuses the flow of water from the pump and is attached at the end of the hose.

### Cooling System

The cooling system exists to ensure all electronics remain at or below operating temperatures, protecting the health and functionality of all electrical components within the electronics bay. The boat uses a combined forced convection solution utilizing a fan and non-sweat ice packs to reject heat into a pre-cooled reservoir. Preliminary analysis of high heat generating components projects 15 Watts of heat generation. Forced convection via fan and ice pack was chosen over alternative solutions such as heat exchanging and conduction rods due to ease of implementation/testing and time constraints.

### Propulsion

After the research phase, it was observed that T200 Thrusters were a common design choice for similar applications. The design decision to select the T200 Thrusters was verified by evaluating the BlueRobotics website, where thruster spec sheets confirmed that they could be supplied with enough power to move the boat at a predetermined speed. Mounting brackets were bought separately and used to attach the thrusters to the bottom of the hulls. When mounting the thrusters onto the hulls, caution was used to ensure that they were assembled 1-2 inches away from the stern of the boat, allowing for effective rotation. One thruster is attached to the bottom of each of the two hulls.

To determine the input power into each thrusters, Nomoto's model [1]. The model creates an arbitrary rudder input with two state variables, sway and yaw. Through zigzag testing, constants in the state matrix are to be determined.

## *Electrical Aspects*

### Sensor Hardware

Our sensor hardware exclusively features Stereolabs' ZED 2i camera. This camera provides us with all of the necessary environmental information while remaining durable, water-resistant, and equipped to handle challenging outdoor environments. Key features include its dual, wide-angle cameras with polarizing filter and built-in 9-DoF IMU. Combined with the provided SDK, these features all result in depth perception from 0.2 meters to 20 meters, 3D position tracking and mapping, and object detection. This environmental awareness is necessary for the boat to make decisions during challenges.

### Computer Hardware

The main computer used on our boat is a Jetson Nano, where all the sensor and control information is received and processed. This computer has advanced AI performance (472 GFLOPS), detailed graphics rendering (128 core GPU), 4GB of RAM, and impressive computing power (quad-core ARM Cortex-A57), which means it is perfect for interfacing with the ZED 2i and to support all of our CV and AI needs. The Jetson directly controls both T200 thrusters, "water gun," and visual display LEDs. It also works in conjunction with an Arduino Uno R3, which receives RC receiver signals and controls our three stepper motors.

### Power System

The boat and its electrical components are powered by two 14.8V, 15.6Ah lithium-ion batteries. These high-capacity batteries will provide more than enough power for the boat to operate throughout the competition and hours of testing. The power system also includes a series of voltage and current regulators to deliver power to our 12V, 5V, and 3.3V subsystems. Additionally, a kill switch circuit has been implemented to disconnect power from the thrusters in situations where the boat acts unexpectedly. All the relays and regulators featured are rated for their respective voltages and maximum currents that each electrical component draws upon.

## *Software Aspects*

### General Overview

The design's software consists of two major systems: the computer vision system and the motor control system. The computer vision system is responsible for detecting objects in the competition and extracting their position information. The motor control system consists of the algorithms that control the motors on the boat, which are used for navigation/propulsion and operating the water gun and skeeball cannon. These two systems communicate using the ROS framework. The core of the software is the Main Control Loop, which continuously runs as long as the onboard computer is on. The behavior of the loop each iteration may differ from the one before depending on the state of the boat and its surroundings. However, at a high level overview, the general process of each loop is as follows: the boat observes its surroundings, makes a decision based on the current objective, and writes the appropriate signals to its motors.

## Computer Vision

The boat uses an object detection model that is trained to detect the components of the competition course in a live video input. This model is produced by selecting a neural network architecture from the TensorFlow 2 Model Zoo, using the TensorFlow 2 library and a custom dataset for training, and then deploying as a TFLite model. A TFLite model is lighter computationally than a standard TensorFlow model. This version was selected because it can run more efficiently on the onboard computer. Also, a computationally heavy model is unnecessary because the objects that need to be detected look exactly like the objects in the training dataset. This model will then be used with the ZED Camera SDK, which provides an API that can extract the positional information of the detected objects. A position is given by the X, Y, Z vectors of the target object relative to the camera.

## Motor Control

The ZED SDK produces an array of the detected objects. Each element has a class label and the relative distance to the object in the form of X, Y, and Z vectors. See Figure 1 below:

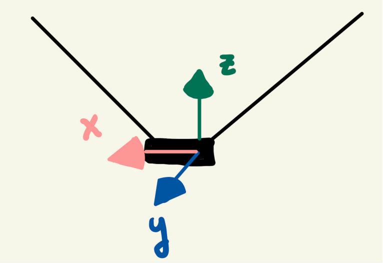

**Figure 1.** The ZED provides the component vectors to detect objects along the above axes.

When executing a specific competition objective, this array is filtered based on the distances and type of objects that are expected to be seen for each course.

For movement, the boat makes navigational decisions by maintaining positional vectors. The following is how the boat is designed to traverse between two buoys. Every iteration of the Main Control Loop, the horizontal X vectors from the boat to the two buoys are measured. The motors will be powered to move the boat forward while ensuring that the two vectors are as equal as possible so that the boat will pass through the middle. Without loss of generality, say for one iteration the left vector is greater than the right. Then, the right motor will produce more thrust than the left so that the boat will "veer" left back on course to maintain the equidistance. Figure 2 below shows this example:

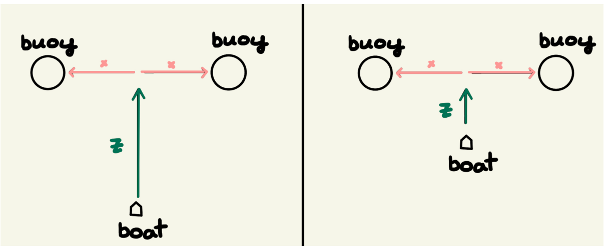

**Figure 2.** The boat traverses between two buoys with the horizontal positional vectors shown.

As the boat approaches the two buoys, it checks that both X vectors are equal and powers the motors accordingly to stay on course. More generally, the boat will pick a point relative to a buoy (or multiple) to "approach." Then, as the boat advances, the navigation software continuously checks that the X vector(s) values remain within a certain threshold and makes slight adjustments so that the boat reaches the selected point.

There are two instances when the boat may not find the objects it would expect to see when completing an objective. The first is during an obstacle avoidance task when the boat is reaching the finishing point and the last set of buoys of the course has fallen past the camera’s field of view. In this case, the boat will continue traversing for a short set duration before marking the current objective as complete. The second case is where the boat has veered completely off-course, in which case the boat will pivot in place until it is back in the correct orientation and sees the objects it expects to see for the current objective.

The procedure for aiming and firing the water gun and skeeball cannon are the same. Both shooters are mounted on the same rotating platform and their angle of elevation is controlled by the same motor. The position of the target is given by the computer vision system. Using this position, the shooters will be adjusted in a turret-like fashion (left-right rotation first to align orientation, then elevation adjustment based on the distance). When the shooters are in place, the motors for the firing mechanisms of each shooter will be triggered.

Transitioning between objectives relies on knowledge of the overall course layout. The order of completing objectives is pre-determined and pre-programmed based on the relative starting and finishing locations of each task.

# IV. Results

Hull manufacturing processes are still underway and independent assembly processes are ongoing. Independent testing setups are also a work in progress, and testing with the fully integrated design is scheduled to begin in early June. It is anticipated that slight changes to software will be implemented throughout the full-assembly testing process, and so frequent repetitions and iterations of certain trials are scheduled.

# V. References

[1] Mishra, Pradeep & Panigrah, S & Das, Swarup & Dept, Mechanical & Milit, Pune & Email,. (2015). Ships Steering Autopilot Design by Nomoto Model. International Journal of Mechanical Engineering and Robotics (IJMER). 3. 2321-5747.