RoboBoat 2025 - The Water Dogs

Daniel Aguilar, Melanie Allen, Matthew Barrs, Jane Cichock, Nate Davis, Daniel De Allende Silva, Nathan Forrer, Angelina Garcia, Reagan Holmes, Ved Mahesh, Mohanashree Pamidimukkala, Jared Reid, Matthew Robert, Pranoy Roy, Samantha Semmel, Isabella Semmel, Dasha Pushkanova, Meghna Vikram

***Abstract*—**

The Water Dogs plan to improve performance in tasks by focusing on both basic and advanced challenges. This year, the team assigned new members to basic tasks and experienced members to advanced ones, emphasizing a solid foundation in the fundamentals to ensure reliable performance.

The team's design centers around a lightweight boat inspired by Vietnamese coracles. Its spherical hull, made from CNC-cut foam, fiberglass, and carbon fiber, allows for superior maneuverability and stability. The boat features a unique propulsion configuration with three strategically placed thrusters, each offering independent azimuth control. This setup provides omnidirectional control and precise movement, which is crucial for tasks such as docking and station keeping.

For software, the team uses advanced tools such as LiDAR for buoy detection, YOLO for computer vision, and ROS2 for overall control. They also conduct extensive component testing to ensure reliability. The team has incorporated simulation environments like Gazebo and VRX to test both hardware and software simultaneously, reducing development time.

In the lead-up to the competition, the Water Dogs plan rigorous in-water testing, along with high-resolution GPS sensors to validate boat positioning. With these improvements and a strong focus on reliability, the Water Dogs are excited for the upcoming RoboBoat competition.

Fig. 1: Our boat: Astronautical!

I. Competition Strategy

We plan on scoring points on all tasks, including Return to Home. We have grouped the tasks into two groups that represent the level of difficulty given our software and boat design.

- Core Tasks: Navigation Channel, Speed Challenge, Rescue Deliveries
- Advanced Tasks: Follow the Path, Docking, Return to Home

This year, we are assigning the many new members of our team to focus on the first group of tasks, while the more experienced members will handle the second group. Our most senior members will split between both groups.

In the past, one of our challenges was spending too much time on the more advanced tasks, leaving the basic tasks underdeveloped. As a result, we struggled to perform consistently when faced with less-than-ideal weather conditions during competition. This year, we are building a strong foundation to ensure we tackle the initial tasks effectively. We hope to ”get our feet wet” and have some wins during the first days.

Having participated in numerous competitions, we have come to understand the critical importance of robust software solutions that can adapt and recover from unexpected obstacles. Additionally, we have learned the value of situational awareness and the limitations of relying solely on dead reckoning for navigation.

Our strategy is to focus on developing strong fundamentals, outlined below:

- **Vehicle State Estimation:** Accurately tracking pose, location, and power consumption.
- **Vehicle Control:** Managing speed, heading, station keeping, and omnidirectional movement.
- **Game Element Recognition:** Identifying buoy types and docking structures.
- **Task Chaining:** Seamlessly linking multiple tasks during finals.
- **Error Recovery:** Skipping tasks, redoing tasks, and regaining situational awareness after a failure.

We have adopted several software tools and algorithms to address the fundamentals mentioned earlier. These include Kalman filters for state estimation, LiDAR (velodyne) point cloud clustering for buoy detection and classification, advanced control algorithms for omnidirectional vehicle control, AI vision algorithms (YOLO), and decision trees for error recovery.

As we brainstormed each task, we developed individual strategies that leverage the unique strengths of our boat, better navigation, and path planning. Common themes emerged in solving each task, as illustrated by the loop shown in Figure 2. These strategies are outlined below.

A. Task 1 - Navigation Channel

The objective of this task is to navigate through a channel marked by two sets of red and green buoys. To begin, we will use our station-keeping capability to position the boat at a safe standoff distance from the channel entrance.

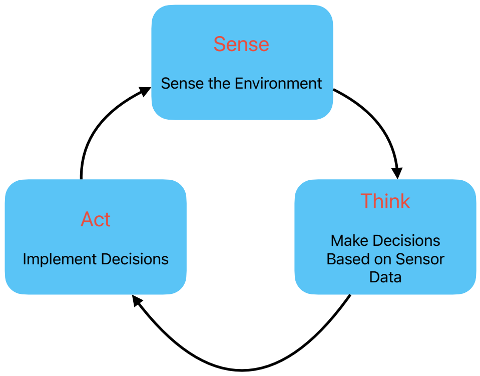


Fig. 2: Control Loop

Fig. 3: Pan/Tilt Camera

In autonomous mode, the LiDAR will detect the two closest buoys (1 and 2) and compute a path through their midpoint, extending perpendicular to the line connecting them for a predefined distance. The vehicle will then follow this path, scanning for the next pair of buoys (3 and 4). Once identified, a new path will be plotted to pass through their midpoint.

The task is complete once the vehicle successfully navigates between buoys 3 and 4. The pure pursuit path-following algorithm will be used to follow the plotted paths accurately [1]

B. Task 2 - Mapping Migration Patterns (Follow the Path)

This challenge is another path-following task, similar to Task 1. However, the path is narrower, and the buoys are small spherical shapes — red on one side and green on the other. A key complication is the presence of small yellow buoys placed in the middle of the channel, which must be avoided and counted.

Our strategy for this task involves using computer vision (OpenCV) to identify and connect sequences of similarly colored buoys, creating continuous barriers on each side of the channel. A global path planner is then used to calculate a route to an arbitrary point beyond the channel. A local path planner handles the avoidance of yellow buoys, ensuring the vehicle navigates around them before merging back into the original global path.

C. Task 3 - Treacherous Waters (Docking)

This is one of our Advanced Tasks that we have not focused on extensively. Our plan involves using LiDAR to accurately locate the empty docking bay and employing a camera with YOLO (You Only Look Once) for identifying the correct color and shape.

We also intend to construct an external model of the dock and utilize SLAM (Simultaneous Localization and Mapping) algorithms to determine the boat's position relative to the dock after navigating to the general area. A key design feature of our boat is its round shape, which enables omnidirectional movement—an advantage that will be especially useful when docking in windy conditions.

D. Task 4 - Race Against Pollution (Speed Challenge)

In this task, we begin by applying some of the techniques from Task 1, followed by using our path-planning and LiDAR sensing capabilities to plot a path around the blue buoy.

To detect the color beacon, we purchased a pan-and-tilt camera, Figure 3, equipped with optical zoom, allowing it to track the beacon and accurately determine its color. Green means go!

E. Task 5 - Rescue Deliveries (Object and Water Delivery)

This task involves locating and targeting stationary vessels with water or balls, depending on a specific shape attached to their sails.

We developed a model of the target vessel and trained a YOLO AI model using approximately 5,000 images captured on our lake. The results have been very promising. Using our pan-and-tilt camera, we continuously scan the area around our vehicle to locate the target vessel. The optical zoom is particularly useful, allowing us to identify and track the vessel at varying distances.

F. Task 6 - Return To Home

In this task, we must navigate back to an area near the starting location and pass through two black buoys. Our strategy is to set a waypoint at the starting location at the beginning of the run and plot a path back to this point, ensuring we pass near the exit gate.

We have not attempted this task yet.

II. Design Strategy

A. Design Goals

The strategic goal of the Water Dogs' ASV is to create a lightweight, durable system with exceptional maneuverability, stability, and buoyancy. Our versatile platform, built using proven boat-building techniques, adapts to various tasks over time.

The hull, constructed from CNC-cut foam coated with epoxy and fiberglass, is reinforced with carbon fiber in high-stress areas for towing and pulling. Designed for Florida's

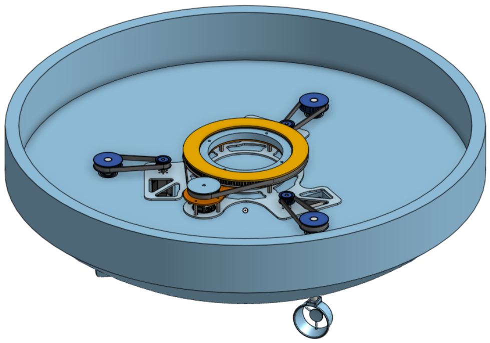


Fig. 4: Hull Design in CAD

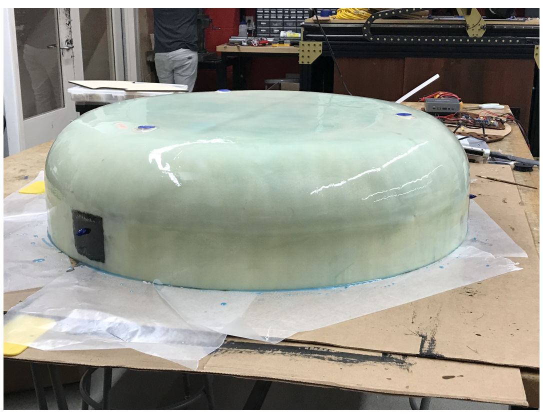


Fig. 5: Hull coated in Fiberglass

extreme weather, it features a waterproof shell, foam insulation for thermal protection, and active water-cooling radiators.

Inspired by Vietnamese coracles, our unique spherical hull design allows omnidirectional movement, powered by three strategically placed thrusters. While less streamlined than traditional hulls, we plan to incorporate hydrofoils to reduce drag. This innovative approach gives us a distinct edge in competition.

B. This Year's Updates

This year, we have introduced several updates to enhance the competitiveness of our boat.

- **High-speed WiFI** - Ubiquiti Rocket Airmax high speed point to point router
- **Azimuth brushless motors (3)** - that control the azimuth of the three thrusters
- **CAN bus** - network daisy chained to motor controllers
- **Added 4th thruster** - Flipsky Amphibious Fully Waterproof Motor 65111
- **Epoxy** - stronger coating on hull

C. Fabrication

The Water Dogs' boat offers creative and innovative solutions to the various design challenges and the objectives set out in the Competition Strategy section. The team took a unique approach to fabricating their Vietnamese coracle-inspired [2] hulls, utilizing the machinery accessible to them. The hulls were designed using the PTC Onshape CAD software. A custom-made 4 axis (3+1 rotating) CNC hot wire cutter was used to shape the large foam blocks used in the hull. With prior experience with vacuum bagging in the First Tech Challenge competition, the Water Dogs decided to place fiberglass cloth infused with epoxy resin over the polyurethane foam to create a hydrodynamic [3], smooth and lightweight structure.

Fig. 6: 4th Thruster

Fig. 7: CNC Hot Wire Foam Cutter

Reliability is a key design goal. Through past competitions, we've identified unreliable systems as a major obstacle to success. To address this, we've involved UCF students with internship experience at large defense contractors, particularly in reliable wiring and testing. Their expertise has significantly reduced issues like electrical noise, power glitches, and signal loss. Additionally, we've implemented component testing, verification, and qualification processes to enhance system reliability.

D. Electronics Platform

The team employed efficient design strategies to create a large, low-profile electronics compartment. By placing all electronics and batteries low in the main hull and using a lightweight cover, they lowered the center of gravity and ensured the boat could withstand extreme winds. Every component was carefully modeled in CAD to maximize space usage, resulting in an efficient, streamlined enclosure. Figure 8 shows a top view of the electronics bay.

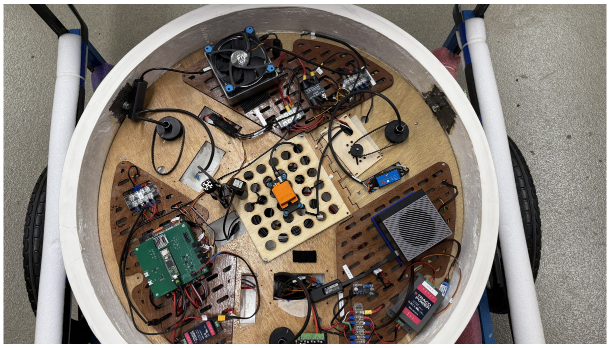


Fig. 8: Electronics in boat

E. Computer Systems

The Water Dog's control system relies on two primary computers. The first is an x86-based mini-PC running Ubuntu with ROS2, and the second is an Nvidia Jetson Orin, handling computer vision, machine learning, and Lidar processing. A Teensy microcontroller manages low-level hardware interfacing.

F. Sensors

Our two main sensors are a Velodyne Lidar and a ZED stereo camera. The Velodyne Lidar is connected using Ethernet to a shared hub and the ZED stereo camera is attached using USB to the mini-pc. An Xsens GNSS/INS MTI-G-710-6A8G4 sensor is used to track the boat position and orientation. The Xsens is connected to the mini-pc using USB.

G. Safety

To ensure safe transitions between manual and autonomous control, we use a standard RC receiver connected to the Teensy via the SBUS port. The Teensy monitors an RC toggle switch to switch thruster control between manual and autonomous modes. Additionally, the RC receiver's fail-safe mode automatically cuts thruster power if the signal is lost.

H. Thruster Configuration

Our boat features a unique three-thruster configuration. This year, we enhanced our understanding of control theory and completely overhauled the control system. Previously, we used a differential drive strategy with fixed thruster azimuths for path-following maneuvers, but this often resulted in instability.

Now, we are dynamically adjusting the azimuth of all three thrusters to steer the boat, with promising results as each thruster effectively acts as a rudder. To enable rapid, precise adjustments, we replaced the previous geared motors with brushless motors, offering significantly faster response times.

This year we have added a forth stationary high speed thruster to help in the speed challenge and thrust to weight ratio test. We also added a trim tab to help counteract the hull rising due to the low center of force the thruster provides.

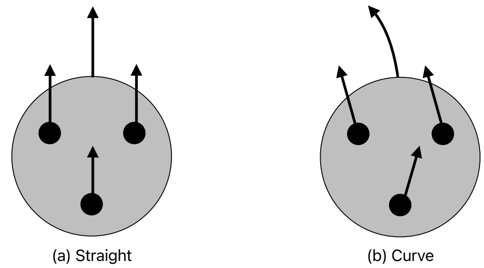


Fig. 9: Control - Route Following

I. Two Modes of Control

We employ two distinct thruster configurations depending on the situation.

1) Control - Route Following: For simple way-point following we use a thruster configuration where all thrusters point forward. To command a yaw, the front two thrusters rotate in the direction of the turn and the single rear thruster rotates in the opposite direction. This control strategy is coupled with the path following algorithm, Adaptive Pure Pursuit [1]. This has proven to be a huge improvement over our previous year's differential steering by eliminating oscillation in yaw. Figure 9 shows the thruster configuration.

2) Control - Station Keeping: Station keeping is a critical part of our strategy, ensuring the boat can maintain a fixed position reliably before, during, and after missions. This was evidenced last year when there were days with extremely strong winds.

In our research, we discovered a paper [4] on controlling an omni-directional ground robot using a Kiwi Drive configuration. This robot uses three omni-directional wheels spaced 120 degrees apart, allowing movement in any direction through resultant force vectors. The wheels achieve this by slipping freely in any direction. We successfully adapted this concept to our boat, as our thrusters can similarly "slip" in any direction in the water, enabling precise and omni-directional station keeping.

To achieve this, the three thrusters used to propel the boat will each be mounted such that the propelling force, and therefore its velocity, produced by the motors and props will be tangent to the circular hull, similar to what is shown in figure 10. Figure 11 and 12 show simulations of the boat following straight and curved paths.

J. Software Development

The Water Dogs use the Robot Operating System (ROS2) as a scaffolding for all of the team's software systems. The ROS2 package allows small independent nodes to be programmed for specific tasks. These nodes can then communicate with other nodes to form a complete system. This compartmentalization is invaluable when working with a large team. It allows tasks to be broken down into smaller, manageable sub-tasks, which can then be assigned to individual team members. Each member can independently develop and test their assigned

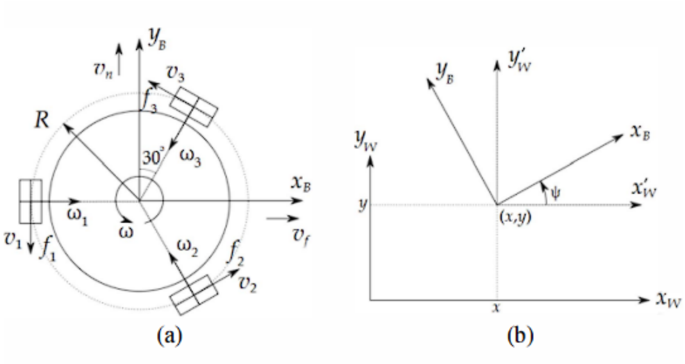
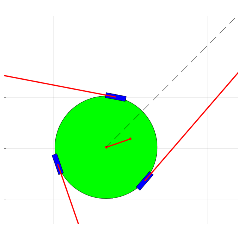
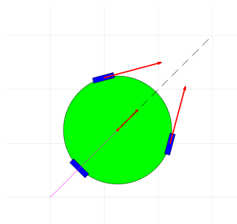


Fig. 10: Boat Free Body Diagram [4]



(a) Straight - Position 1



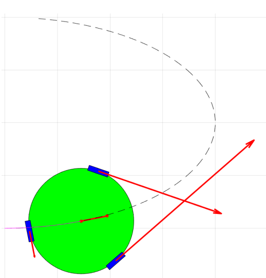
(b) Straight - Position 2

Fig. 11: Actuator Thrust Vectors (Straight Path)

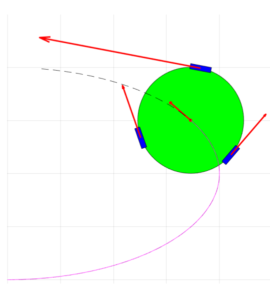
node, streamlining collaboration and ensuring efficiency in the development process.

The team also makes use of a variety of image processing tools found in the ROS2 and PCL (PointCloud) libraries. Incoming data from both LiDAR and camera sources is sent through a node which converts it to simple PointClouds, giving us 3D points which we can work with. These points can be filtered to eliminate outliers and reduce error, and are then segmented into clusters using the PCL library's Euclidean Cluster Extraction. We can treat these clusters as our obstacles and analyze them further if needed. For example, we might look for the distance between them or their height to width ratio to determine if they are the buoys.

The team also makes use of dynamic path planning to navigate the boat through the course. Using ROS2's NAV2 [5], the team can input data sources from the LiDAR and camera as obstacles, and the robots true position found from the filtering of the IMU, GPS, and encoder odometer to create a costmap of the area around the robot. This costmap assigns weights to obstacles based on how close they are and can navigate the robot by keeping to its path towards its goal, but also avoiding high cost, dangerous areas.



(a) Curve - Position 1



(b) Curve - Position 2

Fig. 12: Actuator Thrust Vectors (Curve Path)

K. Simulation

The Water Dogs have utilized the simulation environment, Gazebo to aid in parallel software and hardware development. Gazebo connects with ROS2 to perform simulations of the course challenges. We also use the VRX simulation environment [6]. This form of testing is indeed valuable as it allows the software teams to work on a virtual boat while the hardware team is making changes to the boat.

For 2025, we have started using new major upgrades in the simulation environment. We are now using Gazebo Garden, ROS2 Humble and VRX 2.0. It has been a steep learning curve to understand the new interfaces and explore the new capabilities.

One large effort this year was porting our simulated boat from Gazebo Classic to Gazebo Garden. Gazebo Garden uses a completely different approach to software plugins. These plugins enable us to simulate the buoyancy and thrust characteristics of our boat.

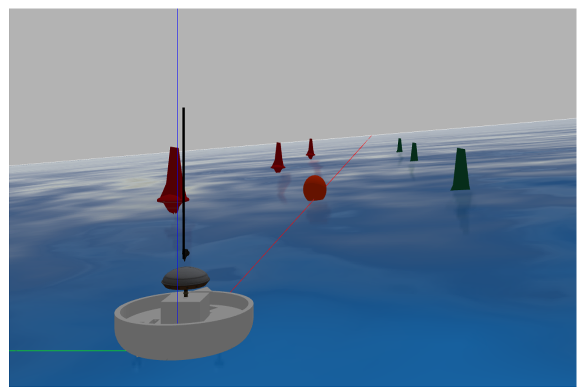


Fig. 13: Experimenting with Gazebo

III. Testing Strategy

A. Component Testing

One valuable lesson we learned while competing in RoboBoat is the importance of independent component testing when developing a complex robotic system. In the past, we would integrate components directly into the system, only to encounter inaccurate results during testing. Often, the software team would assume the issue stemmed from newly introduced code, only to later discover that a critical hardware component had failed unnoticed. This reactive approach wasted time and effort, underscoring the need for thorough testing of individual components before full system integration.

Another benefit of independent component testing is that it allows us to engage new team members with testing tasks. Performing these tests allows them to become familiar with the inner workings of the boat.

This year we have instituted a program where critical components have separate acceptance tests that will validate their specifications under controlled conditions. For example we discovered our Lidar had developed a defect on the lens that reduced the reflected beam, creating a blind spot. We found this by setting up the Lidar in a controlled room and comparing the point cloud with previous tests in the same room.

We have developed a suite of tests that we can run each day before launching the boat to quickly determine if any components have deviated from the known standard.

1) Test: Actuator Test: At system startup, we perform an actuator test by commanding each of the three actuators with a predetermined power and measuring the RPM against a known value. If any data is out of range, an alarm is triggered. Testing data is stored in a file, creating a historical database that helps identify performance trends, such as detecting underperformance caused by algae buildup on a motor shaft. This routine testing ensures confidence in the system when implementing and evaluating new algorithms.

2) Test: IMU/Magnetometer: Another component we test is the Xsens IMU/Magnetometer. As we add metal components to the boat the magnetometer needs to be calibrated. We follow the manufacturer's recommended calibration procedures but the method is time consuming and subject to errors. To overcome this, we created a turntable in the lab that is fixed to a know location. We have software that will read the magnetic sensor as the boat is rotated 360 degrees. We can then compare that against our known calibration data. The IMU/Gyro is also tested in the same manner.

3) Test: Pan and Tilt Camera: To test the camera and YOLO image recognition system, we placed target images around the lab. During testing, the camera is programmed to locate and report all identified target images, ensuring accurate detection and recognition functionality.

B. Dry Testing

Due to the unavailability of the lake during some weeks, alternative testing methods were employed through dry testing. This approach involved placing buoys and task-related objects on land to simulate the operational environment. The boat was manually maneuvered using our custom cart on the ground, figure 14, allowing the collection of data from the LiDAR and the camera systems. This method ensured continued progress in data acquisition and system validation despite the constraints.

Fig. 14: Testing on land

C. Simulation

We observed that hardware work often reduced testing time for software development. To address this, the Water Dogs prioritized simulation testing, enabling the hardware and software teams to work simultaneously and maximizing limited pre-competition hours.

D. Future Testing

The Water Dogs plan on using newly borrowed high resolution survey accurate GPS sensors to allow us to have a ground truth while the boat is navigating in the lake. We will only use this for testing, not in the actual contest since they rely on external data connections to the boat.

With the software and hardware teams working simultaneously, the Water Dogs plan to dedicate the remaining time before the competition to in-water testing. Weather permitting, the team will follow a strict schedule, testing at our on-campus lake every three days. We are fortunate to have the exact buoys used in the competition, ensuring thorough preparation for the course.

IV. Acknowledgments

As a multi-year endeavor, the Water Dogs team owes much of its success to the contributions of former teammates and mentors. We gratefully acknowledge their guidance and support, even as we look forward to competing against some of them this year — a testament to the enduring bonds and friendly rivalry fostered by RoboBoat.

None of the Water Dogs' achievements would have been possible without the unwavering guidance and support of our mentors, who dedicate countless hours to the team and are always willing to sacrifice a few nights of sleep.

Our hardware and software teams would like to thank Don Harper, the director of the Texas Instruments Innovation Lab at the University of Central Florida. His extensive background in computer science and robotics makes him an invaluable asset to the team, providing guidance and support. He also provides the team access to the Innovation Lab which includes a plethora of tools and resources, such as 3D printers, CNC machines and a laser cutter.

Our multimedia and outreach teams would also like to thank Ms. Po Dickison, the sponsor for the Hagerty Robotics Program. She manages the high school workspace and facilitates after-school meetings, ensuring that the team has the resources and space necessary for their work.

We also thank our sponsors UCF, Lockheed Martin, DoD STEM, Alaka'ina Foundation, and more, who generously provide funding and equipment to the Water Dogs. Their contributions are essential to sustaining the program.

References

[1] S. Macenski, S. Singh, F. Martin, and J. Gines, “Regulated pure pursuit for robot path tracking,” *Autonomous Robots*, 2023.

[2] R. F. Cairo, “A note on south vietnamese basket boats,” *The Mariner’s Mirror*, vol. 58, no. 2, pp. 135–153, 1972.

[3] T. I. Fossen, *Handbook of Marine Craft Hydrodynamics and Motion Control*. John Wiley Sons, Ltd, 2021.

[4] I. Galgamuwa, L. Samaranayake, M. P. Ekanayake, and K. Liyanage, “Simplified controller for a three wheeled omni directional mobile robot,” *Control and Intelligent Systems*, vol. 44, 01 2016.

[5] S. Macenski, F. Martin, R. White, and J. Ginés Clavero, “The marathon 2: A navigation system,” in *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2020.

[6] B. Bingham, C. Aguero, M. McCarrin, J. Klamo, J. Malia, K. Allen, T. Lum, M. Rawson, and R. Waqar, “Toward maritime robotic simulation in gazebo,” in *Proceedings of MTS/IEEE OCEANS Conference*, Seattle, WA, October 2019.

APPENDIX A: TESTING PLAN

A. Safety Kill Switch Testing Plan

This is an example of one of our testing plans. This plan tests the physical, radio communication loss and wireless kill switch.

1) Place the boat on test stand
2) Turn on the RC transmitter
3) Place the RC transmitter ”enable” switch in the on position
4) Place the RC transmitter ”auto/manual” switch in manual
5) Turn on the the main boat power
6) Using the RC transmitter joystick, give half power to the thrusters
7) Place the RC transmitter ”enable” switch in the off position
8) Note: the thrusters should go to zero power in at most 2 seconds
9) Place the RC transmitter ”enable” switch in the on position
10) Press the manual kill switch on the boat hull
11) Note: the thrusters should go to zero power in at most 2 seconds
12) Place the RC transmitter ”enable” switch in the on position
13) Turn off the RC transmitter
14) Note: the thruster should go to zero power in at most 3 seconds

B. Hull Building Testing

Our initial hull was made of a single layer of 4oz fiberglass covering a foam core. After a year of in water use, we found the fiberglass covering was too thin to withstand the constant use. Also as we fixed dings, we found that the hull thickness was less than the initial 4oz fiberglass. We attribute this to the sanding that was done to fair the hull during construction. Over the Summer we decided to completely re-cover the hull using two layers of 4oz fiberglass and use faring compound to get rid of any imperfections in the hull that would cause drag. Figure 15 and 16 show some of the process in creating the new hull.

Fig. 15: Sanding New Hull

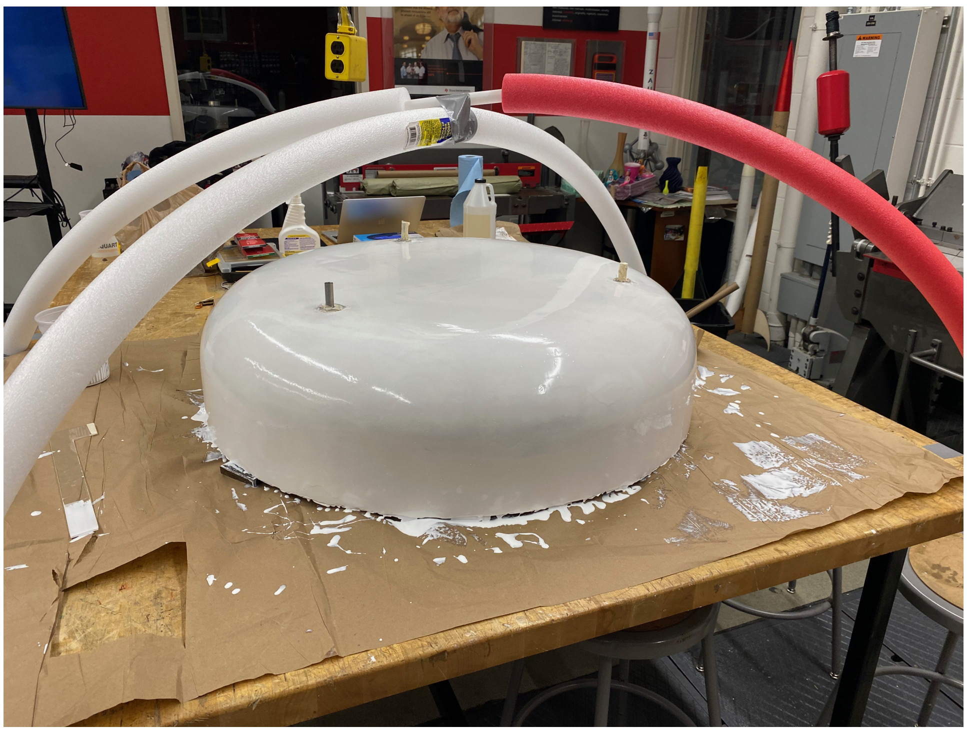


Fig. 16: After Final Epoxy Coat

APPENDIX B: ELECTRICAL SCHEMATICS

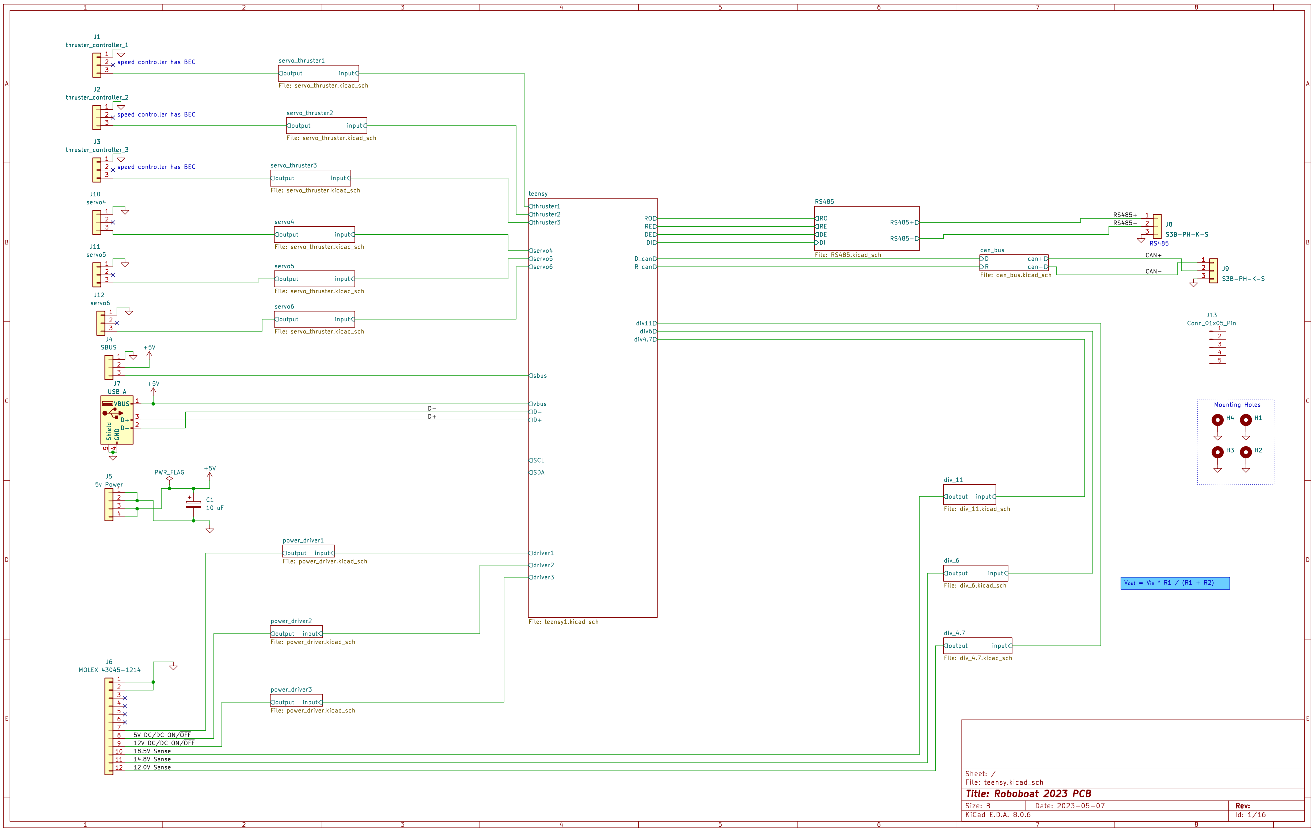


Fig. 17: Schematic of low-level control PCB

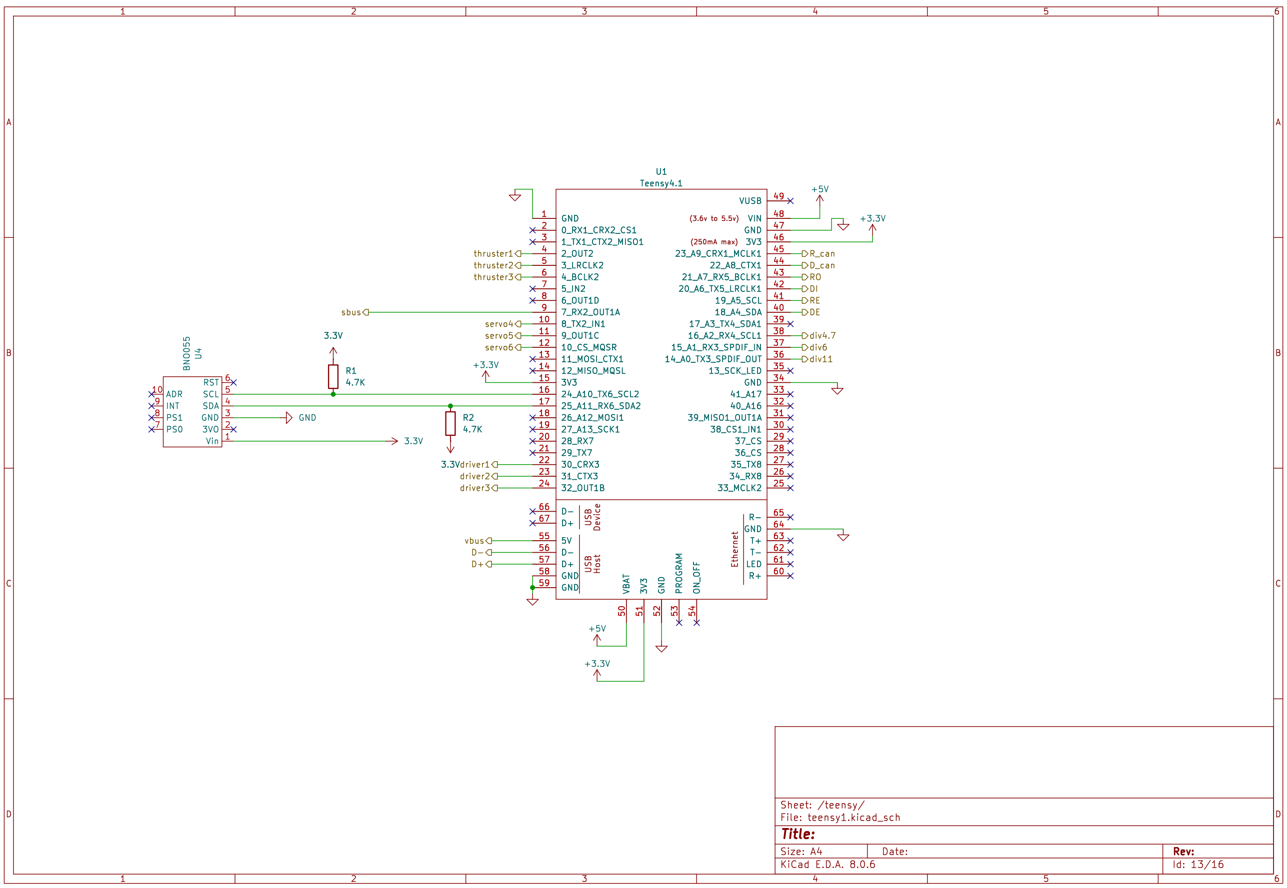


Fig. 18: Schematic of Teensy 4.1 Microcontroller