RoboBoat 2024 - The Water Dogs

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***Abstract*—This document describes The Water Dogs' team entry in the RoboBoat competition. This design report analyzes the Water Dogs' strategic thinking for the competition season, and how their design and engineering decisions reflect and execute their game strategy. The unique circular architecture of the boat contributes to a highly stable, maneuverable and efficient system that can complete challenges with calculated control of various sensors and algorithms. In the past few years our team has primarily been comprised of high school students. However, this year we are excited that several engineering students from University of Central Florida (UCF) have joined our team and as a result, our team now has a stronger understanding of complex control theory. This document hopes to convey our excitement in working with this versatile platform.**

Fig. 1: Our boat: Astronautical!

I. Introduction

All members of the Water Dogs are part of a larger robotics program centered in Oviedo Florida, mainly the Hagerty Robotics High School Team partnered with the University of Central Florida Innovation Lab Team. The high school team also competes in the FIRST Tech Challenge where they develop an array of skills that are put to good use in the RoboBoat competition.

Fig. 2: The Water Dogs at Roboboat 2022

II. Competition Goals

The primary goals of the Water Dogs is to create a durable system design that is lightweight and designed with maneuverability, stability and high buoyancy in mind. We designed a platform that can be expanded on and used over a number of years. As a result, the Water Dogs chose to use proven boat building techniques. An assortment of materials were used with the hull being fabricated out of foam (cut with a CNC foam-cutter) and coated with epoxy and fiberglass protecting the outside of the hull. Carbon fiber was used to create high strength areas used for towing and pull testing. The boat is designed to cope with the extreme heat and rain in Florida by using active cooling and a highly insulating and waterproof hull.

In addition, as one of the main goals of the Water Dogs was maneuverability, a different hull design was explored than what is typically used. The Water Dogs decided to go with a rotating-spherical hull design which allows the boat to maneuver in any direction while keeping any target goals in view. To achieve this goal, three thrusters are placed strategically to drive our boat, allowing the boat to move in any direction. One drawback to our round boat idea is that the hull is not as streamlined as a traditional design. We understand this and are working long term to add hydrofoils to the thrusters to allow the boat to lift up and reduce drag. Because this is an out-of-the-box idea, it gives us an advantage over the competition in a number of areas that we hope to capitalize on.

Aside from our design, we noticed that as time was spent working on the hardware portion of the boat, testing time was sacrificed for software development and experimentation. As a result, the Water Dogs placed a strong emphasis on simulation testing to allow our software team to work efficiently. The decision to use simulation software allows for the hardware and software teams to work simultaneously and optimizes the limited number of working hours before competition.

Reliability is also a primary design goal. After competing in a number of competitions we have seen that a large impediment to success is the reliability of the design. At UCF we have a number of students that participate in internships at large defence contractors. Some of their duties are in the area of reliable wiring and testing. We have invited these students to become a part of our team. This has greatly reduced incidents of electrical noise, power glitches and signal loss in the boat. Component testing has also been introduced along with verification and qualification.

In summery, we plan on completing in all tasks (Follow The Path, Docking, Duck Wash, Speed Challenge, Collection Octagon, Delivery Octagon and Return To Home) and believe we have a strong platform to compete.

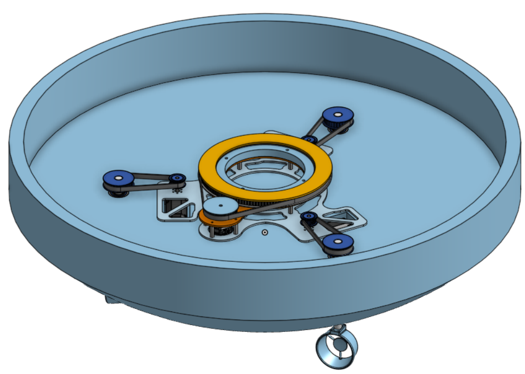


Fig. 3: Hull Design in CAD

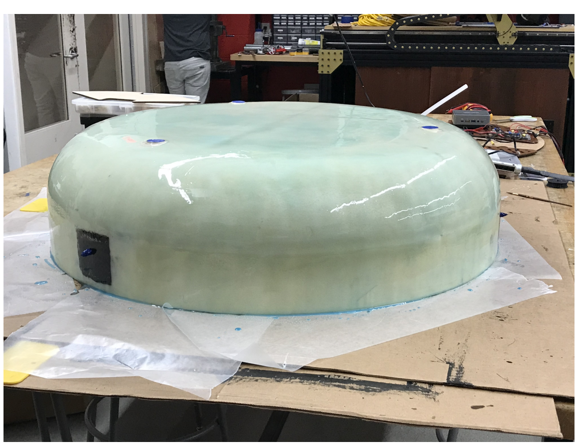


Fig. 4: Hull coated in Fiberglass

III. Design Strategy

A. 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 [1] 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 [2], smooth and lightweight structure.

Fig. 5: CNC Hot Wire Foam Cutter

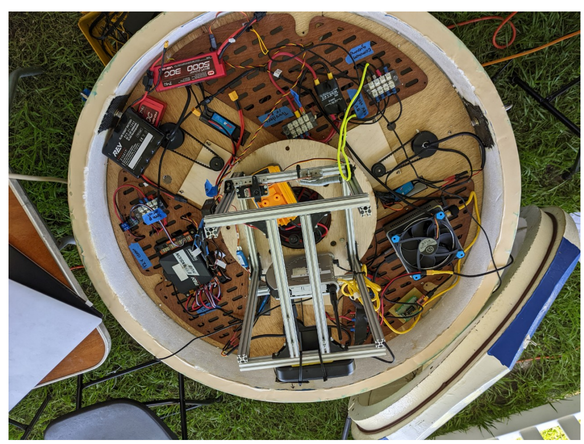


Fig. 6: Electronics in boat

B. Electronics Platform

The team used efficient design strategies in creating the electronics enclosure. We wanted to create a large compartment for electronics yet maintain a low profile. The boat also needed to have a low center of mass to avoid tipping. As a solution, we decided to put all of our electronics and batteries low inside the main hull. By creating a light weight cover we were able to keep our center of gravity low allowing the boat to withstand extream wind assocated with Florida thunderstorms. Everything was carefully designed in CAD to make sure our electronic components and batteries would fit. The result was an efficient design, using the space we have to its fullest extent.

C. Cooling System

The drawback to creating a water sealed electronics enclosure was the need for proper air circulation. With the perpetual thermal mass of the lake around the boat, the team devised a cooling system that pumps the lake water through a radiator. Fans circulate the air from the enclosure through the radiator to cool the electronics. This system is regulated by an on board temperature and humidity sensor.

D. Computer Systems

The Water Dog's approach for a robust control system is based around two main control computers. The first is a mini-pc x86 based computer that runs Ubuntu along with ROS. The second is a Nvidia Jetson Orin GPU accelerated computer that handles all of the computer vision and machine learning tasks. For low level control a Teensy micro-controller board is used to interface with the various hardware devices. Three brushless motor controllers power the thrusters using RC-PWM signals connected to the Teensy. The individual thrusters yaw control motors are controlled using a Rev Robotics Expansion hub that was repurposed from our FIRST robotics system. We had to reverse engineer the control protocol of the expansion hub to be able to use it on our boat. This has proved to be a robust solution as it has many sensor and control ports that we can use on the boat.

E. 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 mnini-pc using USB.

F. Fish Rescue Arm

We are working on a robotic arm that will have a rotating net attached. This arm will be stowed above the boat and extend during the rescue duck missions.

G. Safety

To safety handle the transition between manual and autonomous control we use a standard RC receiver connected to the Teensy using the sbus port. The Teensy is programmed to monitor one of the RC toggle switches and switch control of the thrusters from manual to auto. The RC receiver is also programmed in fail safe mode to automatically kill thruster poser on loss of signal.

(a) Drive Straight (b) Turning

Fig. 7: Actuator - Differential Drive

(a) Strafing (b) Station Keeping

Fig. 8: Actuator - Omni-directional Movement

H. Thruster Configuration

Our boat consists of three thrusters powered by propellers. These three thrusters help us steer and maneuver our boat effectively. The thrusters are also actuated axially to provide more control. We use two thruster configurations to provide our desired motion. Figure 7 shows the differential drive configuration we use to for simple path following. Figure 8 shows the omni-directional drive configuration used for station keeping.

I. Control - Station Keeping

Station keeping is an important aspect of our overall strategy. We have found that we need to reliably be able to keep the boat stationed at a fixed position before, during and after missions. To be able to do this in windy conditions was proven at last years competition. In our research we found a paper [3] on the control of an omni-directional ground robot using a Kiwi Drive configuration. In this robot, three special omni-directional wheels are placed 120 degrees apart. The resultant force vectors allow the robot to move in any direction. This is made possible because the wheels can slip in any direction. We were able to exactly translate this to our boat since the thrusters we use can also slip in any direction in the water.

1) Model Based Approach to Boat Control: Here the boat is designed to allow for "holonomic" control. That is to say the Water Dog can freely translate and rotate. It can also perform maneuvers that require the combination of translation and rotation simultaneously. This type of maneuverability allows for convenient and efficient optimization, way-point traversal and controls programming.

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 how is shown in figure 10 [3].

To derive the kinematics and then a simplified dynamics first we start with the free-body diagram and definition of key parameters:

Body Frame	World Frame	Constants
(ω) : $Body Ang.Vel.$	(x,y): Position	(m): Mass
(v_f) : $For.Vel.$	(ψ) : $Orientation$	(J_z) : $Moment$
(v_i) : $Wheel Vel.$		(r): Radius
(f_i) : $Force Of Wheel$		(R):BodyRadi
(ω_i) : $Wheel Ang.Vel.$		(n):GearRatio
(τ_i) : $Wheel Torq.$		
(V_i) : $Motor Volt.$		

Fig. 9: Boat Physical Parameters [3]

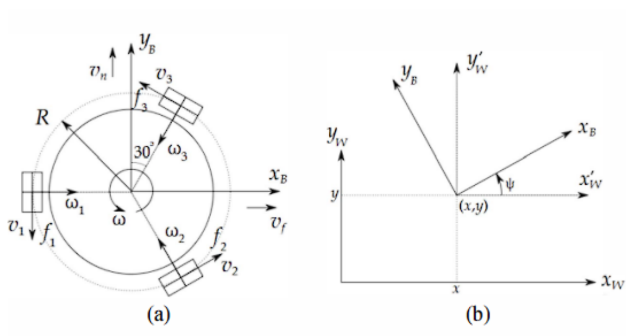


Fig. 10: Boat Free Body Diagram [3]

2) Kinematic Model: After defining the coordinate frames and physical parameters of the body, next we can explicitly define the boats kinematics derived from figure 3:

$$v_3 = -v_n + R\omega \tag{1}$$

$$v_2 = v_f * cos(\pi/6) + v_n * cos(\pi/3) + R\omega \tag{2}$$

$$v_1 = -v_f * cos(\pi/6) + v_n * cos(\pi/3) + R\omega \tag{3}$$

Here, for each motor shaft there is a reduction in the velocity according to the gear reduction. Therefore, we also know that:

$$v_i = r * \omega_i / n \tag{4}$$

Using this, we can simplify the constant terms above and explicitly write the matrix form of the robots Inverse Kinematics:

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} = r/n \begin{bmatrix} \sqrt{3}/2 & 1/2 & R \\ -\sqrt{3}/2 & 1/2 & R \\ 0 & -1 & R \end{bmatrix} \begin{bmatrix} v_f \\ v_n \\ \omega \end{bmatrix} \tag{5}$$

From (5) we can write the form of the Forward Kinematics as well:

$$\begin{bmatrix} v_f \\ v_n \\ \omega \end{bmatrix} = r/3n \begin{bmatrix} \sqrt{3} & -\sqrt{3} & 0 \\ 1 & 1 & -2 \\ 1/R & 1/R & 1/R \end{bmatrix} \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \end{bmatrix} \tag{6}$$

After, we then express how to transform the robot's body speed into the world coordinate frame, thus giving the ability to track the boats world position and velocity during operation:

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} = \begin{bmatrix} cos(\psi) & -sin(\psi) & 0 \\ sin(\psi) & cos(\psi) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} v_f \\ v_n \\ \omega \end{bmatrix} \tag{7}$$

From these equations a simulation of the robot was made in MATLAB and Simulink to produce and visualization tool, allowing the team to see how the boat moves in relation to certain motor speed. The reverse was achieved as well, where we wanted a desired forward and normal velocity and are able to see what the desired motor speeds would be. This type of analytic relations allowed the team to perform sanity checks on the motors and explicitly define motor speeds to body transnational and rotational speeds.

After deriving the kinematics and simulating in an open looped fashion, the team then employed an LQR [https://www.mathworks.com/help/control/ref/lti.lqr.html] controller type to regulate the motor speeds and drive the boat to a desired trajectory. Again, here we wanted to be able visualize what types of motions were achievable. This type of simulation also helps collect data on how much power or speed you boat will need in order to achieve certain objectives, and gives the team an analytic way to validate later field experiments gauging the boats ability to maneuver. Shown in figures 11-15 we see a representation of what the system would look like while moving. In Figure 11 we see a visualization of the robot's position error when tracking a circular trajectory with radius equal to three meters over a thirty second interval. In Figure 12 we the robot's position and orientation over time, and in figure 13 we see the robot's motor speeds necessary to achieve the desired trajectory.

Figure 14 shows a Matlab simulation of the boat following a straight path with the starting position pointed twenty degrees off the path. In *position one* all three thrust vectors are equal, causing the boat to turn to the path. In *position 2* the boat has joined the path and only the front two thrusters are working to move the boat. Since the boat is not rotating, the thrust vectors must have a net zero torque on the rotation of the hull.

Figure 15 shows the simulation of the boat following a curved path. In *position one* the boat is executing a slight left turn. The thrust on the right thruster is shown to larger that the left thruster with the rear thruster helping with counter clockwise torque. *Position two* shows a much larger right thruster torque due to the larger curve of the path. In each case the three thrusters show a balance to achieve the correct rate of turn plus forward movement.

J. Control - Route Following

For simple way-point following we use a thruster configuration where all thrusters point forward. The two side thrusters act in a differential mode and the single trailing thruster rotates to help controls steering.

The PID control algorithm is used to keep the boat on a given path. An error signal is generated with deviations from the path and the PID is used to control the power and position of the thrusters.

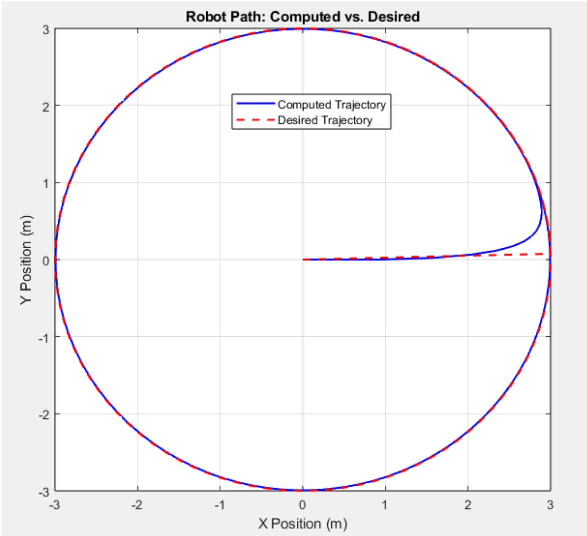


Fig. 11: Boat Position Tracking Error Visualized

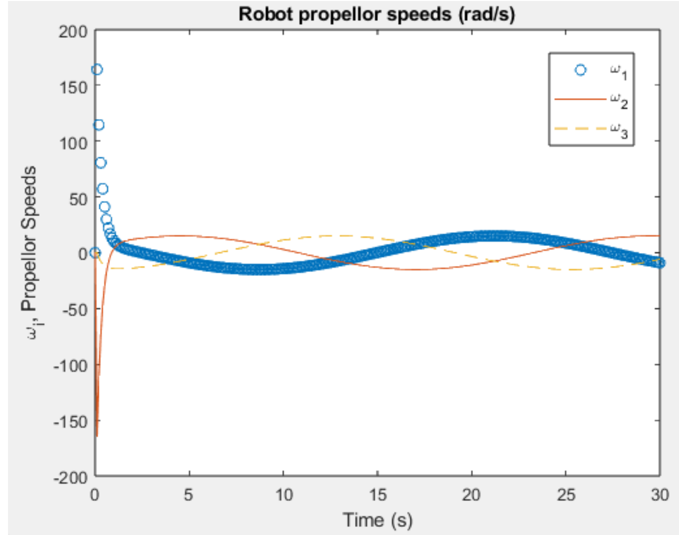


Fig. 13: Boat Motor Speeds over Time

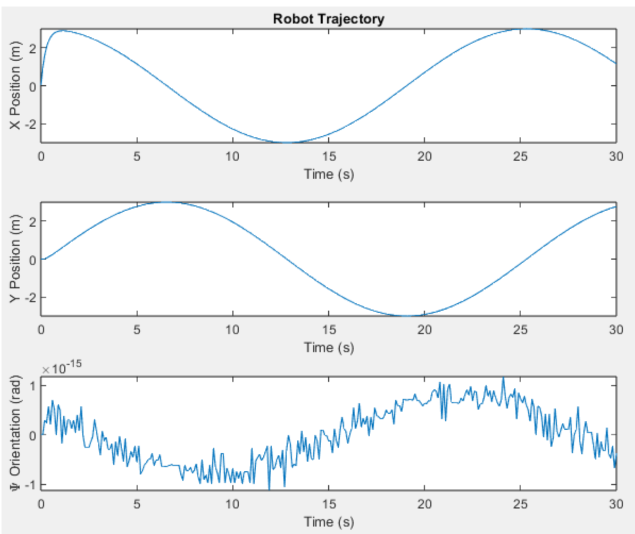


Fig. 12: Boat State over Time

(a) Straight - Position 1

(b) Straight - Position 2

Fig. 14: Actuator Thrust Vectors (Straight Path)

K. Software Development

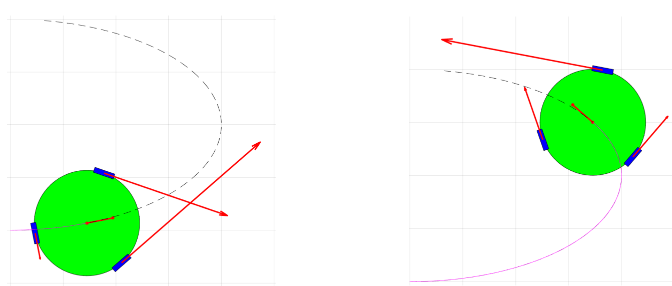
The Water Dogs utilize the Robot Operating System (ROS) as a skeleton for all of the team's software systems. Using ROS, nodes can be made for each boat subsystem. For example, the team is currently working on a ROS node that will interpret the images received from it's stereo camera using OpenCV software, and return data relevant to accomplishing certain goals. ROS also allows for synergy between sensors including a LiDAR, a Global Positioning System, and an Inertial Measurement Unit.

The software team also possesses a VLP-32 Velodyne LiDAR sensor. This small, compact LiDAR has a 100 meter range with a 360 horizontal field of view and 32 +/- vertical field of view.

Additionally, the team uses a ZED 2 stereo camera as a secondary measure of developing a view of our surroundings.

To find the location and orientation of the boat, the Water Dogs are experimenting with two sensors. The first is a NAV-COM GPS with Starfire Precise Point Positioning. This GPS Correction program is renewed by the team every month of operation, and allows a margin of error shorter than 5cm. This precision tracking sensor is only used for ground truth testing. The second is a Xsens MTi-G-710 Inertial Measurement Unit. This sensor can provide high-quality position, velocity, acceleration and orientation of the boat.

Using ROS as a development environment provides the team with many software tools to aid in autonomous navigation. The team makes use of the inbuilt communication features in the ROS environment to receive data and output commands to the variety of sensors and motors. ROS uses a network of nodes that publish messages known as topics, which allow



(a) Curve - Position 1

(b) Curve - Position 2

Fig. 15: Actuator Thrust Vectors (Curve Path)

Fig. 16: The Velodyne VLP-32 LiDAR Sensor

Fig. 17: The ZED 2 Stereo Camera

for one node to subscribe to or publish multiple sources of data or commands. For example, various sensor data, including velocity from an encoder, IMU readings, and GPS position can be subscribed to by one node which can acts as a Kalman filter to produce a reliable position of the robot. A Kalman filter is tool used to merge sensor data, assigning inputs different probabilities based on their error, in order to form an accurate conclusion about the position of the boat.

The team also makes use of a variety of image processing tools found in the ROS 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 to determine if they are the buoys.

The team also makes use of dynamic path planning to navigate the boat through the course. Using ROS's Move Base package, 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 cost map of the area around the robot. This cost map 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.

L. Simulation

The Water Dogs have utilized the simulation environment, Gazebo to aid in parallel software hardware development. Gazebo connects with ROS to perform simulations of the course challenges. We also use the VRX simulation environment [4]. 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 2024, 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.

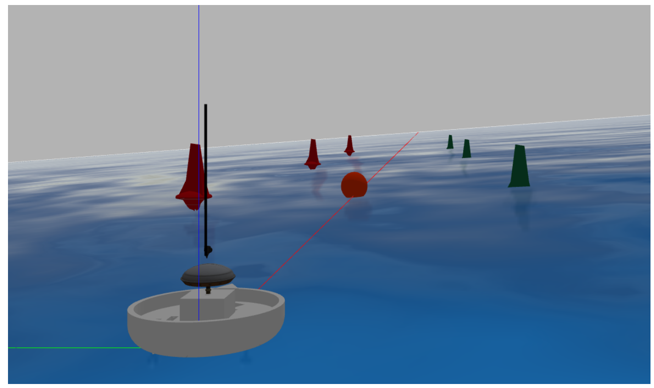


Fig. 18: Experimenting with Gazebo

IV. Testing Plan

A. Component Testing

One valuable lessons we learned while competing in Roboboat is that independent component testing is critical in developing a complex robotic system. In the past we would install components in the system and then chase our tails when the software team would get inaccurate results, only to find that a critical component had failed. This would go unnoticed as the team would blame it on the new software just introduced.

Another benefit of independent component testing is that it allows us to engage new team members with testing tasks. Preforming the test allow them to become familiar with the workings of the boat.

This year we have instituted a program where critical components have separate tests that will validate their specifications under controlled conditions. For example we discovered our Lidar had a defect on the lens that reduced 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 our simulated Lidar in the same virtual room.

1) Test: Actuator Test: At system startup we always perform an actuator test. Each of the three actuators is commanded with a predetermined power and the RPM is measured and compared to a know value. An alarm is given when any data is out of range. We also store the testing data in a file to build a historical database that can help us spot trends in the performance of the thrusters. We have a few examples where one thruster is under preforming and found an algae buildup on the motor shaft. This startup testing really helps us have confidence when testing 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 know calibration data. The IMU/Gyro is also tested in the same manner.

These tests are always performed each time we take the boat out in the water.

B. *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 thest for testing, not in the actual contest since they relay on external data connections to the boat. Additionally, as the software team is working simultaneously with the hardware team, the Water Dogs will be able to use the remaining time before competition for in-water testing. So long as weather permits it, the team will maintain a strict testing schedule, going out to a nearby lake every three days. The team has access to a on campus lake and the exact buoys used in competition. This will allow them to be better prepared for the competition course.

V. CONCLUSION

The fifth season of the Water Dogs was one of growth and improvement through critical error analysis and discovering solutions through innovation. The team learned from past designs and worked towards a new goal of speed, lightness and stability . In the upcoming month prior to the competition, the team will continue to experiment with their software to ensure dependable control. The team will also work on iterating and testing the actuators for this year's challenges. The Water Dogs are proud to be competing in yet another season of Roboboat, and can't wait for competition week!

VI. ACKNOWLEDGMENTS

None of the Water Dogs' accomplishments would've been possible without the endless guidance and support of our mentors, who spend countless hours with the team and are not afraid to sacrifice a few nights of sleep. Without them, our members would be far less successful and our team would amount to nothing. The Water Dogs are also immensely grateful for the generous contributions of their sponsors, who provide funding and technical support to the team.

A. *Mentoring*

The Water Dogs have an intensive group of mentors and coaches that contribute not only to the team's success, but also to the education and skill-building of each of its members. The team has two mentors, Mr. Don Harper and Mrs. Po Dickison, who work hard to organize meetings and keep the team focused and on track. Mr. Don Harper is the director of the Texas Instruments Innovation Lab at the University of Central Florida, and has extensive knowledge of computer science and robotics. He is also fond of sailing, giving him the nautical experience to lead the Water Dogs into this competition. Mrs. Dickison is the school sponsor of the Hagerty Robotics program, and manages our school workspace and allows the team to conduct after school meetings.

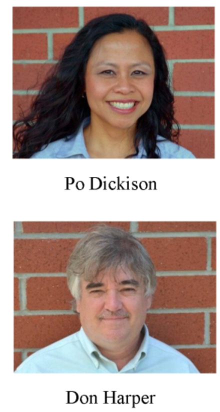


Fig. 19: Our wonderful mentors!

B. *Sponsorships*

The Hagerty Robotics program has a large base of sponsors that provide funding and equipment to the Water Dogs through their generous contributions, sustaining the program and our participation within this competition. Nothing would be possible without their support.

Fig. 20: Thank you to our sponsors!

C. *Workspaces*

The primary workspace of the Water Dogs is the Texas Instruments Innovation Lab in Engineering Building II of the University of Central Florida. This is a maker space that has a variety of tools and equipment for builders and designers, equipped with all that is needed to design, build, and prototype. The lab provides several methods of fabrication, including 3D printers and a laser cutter, allowing the Water Dogs to easily make and manufacture parts. The lab also has CAD/CAM software and simulation software like ANSYS, which allows the team to model and simulate designs and mechanisms for real life application and enhancement. Neighboring the Innovation Lab is the Manufacturing Center, which has various heavy duty equipment such as the CNC Mill, CNC lathe and wire EDM machine.

Fig. 21: Texas Instruments Innovation Lab

Appendix A: Component Specifications

The team is very resourceful and economic in its use of materials and application of store-bought components. In addition, a majority of the components on the boat were reused from last year. This allowed us to lower our overall costs and preserve time to work on the boat.

The most notable additions this year are:

- Blue Robotics T200 thrusters (two were donated to us at the Roboboat 2022 competition
- Nvidia Jetson AGX Orin CPU
- Xsens GNNS/INS Mti-g-710 IMU system
- Velodyne VLP-32 LIDAR

We would like to thank UCF's Center for Research in Computer Vision (CRCV) for allowing us the use of the Jetson, Xsens and LIDAR.

RoboBoat 2024 Parts List						
Component	Vendor	Model/Type	Description	Unit Cost	Quantity	Total Cost
Lidar	Velodyne (ebay)	VLP-32	16 beam 360 degree Lidar	$ 1,500.00	1	$ 1,500.00
Fiberglass Cloth	Florida Fiberglass	4 oz plain weave	Lightweight fiberglass cloth	$ 4.85	8	$ 38.80
Plain weave carbon fiber tape	Florida Fiberglass	6 oz	4" cloth tape	$ 4.00	2	$ 8.00
West Systems Epoxy Hardner	West Marine	205 Hardner	32 oz fast epoxy hardner	$ 33.99	1	$ 33.99
West Systems Epoxy	West Marine	105 Epoxy	1 gallon epoxy resin	$ 110.78	1	$ 110.78
Polyurethane foam	Deno's Prop Studio	1 pound foam	1 pound polyurethana foam 2' x 6' x 6'	$ 400.00	1	$ 400.00
RC Servo Motor	Grave's RC	Hitec 485	RC Hitec 485 servo used in camera pan	$ 34.00	2	$ 68.00
Thruster	BlueRobotics	T200	Brushless underwater thruster	$ 200.00	3	$ 600.00
CPU1	Gigabyte	GB-BEi7HS-1260	Ultra Compact PC	$ 400.00	1	$ 400.00
CPU2	Nvidia Jetson	Orin AGX 64 Gb	Nvidia powered single board coputer	$ 1,999.00	1	$ 1,999.00
Solid State Relay	Amazon	SSR-25DD	DC to DC Solid state relay (safety)	$ 9.90	1	$ 9.90
E-Stop switch	Amazon	mxuteuk 2NC	Emergency stop push button mushroom switch	$ 10.99	1	$ 10.99
RC Receiver	FrSky	Taranis X8R	RC receiver used for manual override	$ 35.99	1	$ 35.99
RC Transmitter	FrSky	Taranis X9D Plus	RC transmitter used for manual override	$ 229.00	1	$ 229.00
20v Battery	Dewalt	20V MAX XR	Computer battery, 20V 5Ah	$ 72.90	1	$ 72.90
LiPo battery	Amazon	Zeee 7.4V Lipo	Thruster Lipo Battery 2S 50C 5200mAh	$ 38.00	2	$ 76.00
IMU/GPS	Xsens (ebay)	Xsens Mti-G-710	Imu + Gps filtered	$ 800.00	1	$ 800.00
Motor/Servo/ADC controller	RevRobotics	Expanson Hub	Reversed engineered FTC Expansion Hub	$ 250.00	1	$ 250.00
Thruster rotation motor	RevRobotics	Core Hex Motor	Drive motor used to rotate thrusters	$ 28.50	3	$ 85.50
						$ 6,728.85

Fig. 22: Component Specifications

Appendix B: Testing Plan

D. *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

E. *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 23 and 24 show some of the process in creating the new hull.

Fig. 23: Sanding New Hull

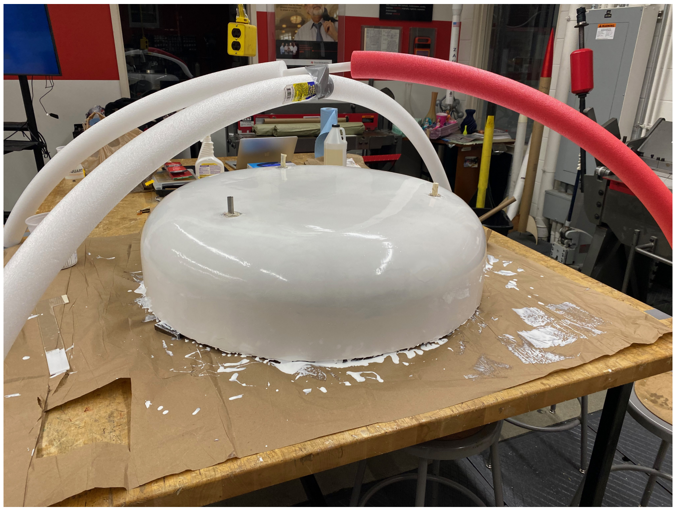


Fig. 24: After Final Epoxy Coat

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