RoboBoat 2022 - 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 architecture of the boat contributes to a fast and efficient system that can complete challenges with calculated control of various sensors and algorithms**

I. Introduction

All members of the Water Dogs are part of larger robotics clubs centered in Oviedo Florida, mainly Hagerty Robotics. The club competes in many robotics competitions including the VEX Robotics Competition and the FIRST Tech Challenge. The VEX Robotics Competition is a season long engineering challenge in which teams must build and program a robot which can compete and score points in a small-scale 2 minute game. FIRST Tech Challenge, a similar competition on a larger scale, is the club's most time consuming and successful event with a strong focus on outreach and documentation. The club recently went to the FIRST World Championship in Houston by being in the finals of the Florida State Championship and winning the "Think Award" which is an award based solely on documentation. Many of the members also have programming experience, an essential skill in the RoboBoat competition. These past experiences provide members with an intense robotics background that allows the Water Dogs to retain a competitive edge over their college competition. Their expanse of knowledge in the greater robotics field acts as a precursor to their success in tackling the RoboBoat competition.

Fig. 1. The team celebrating their achievements

II. Competition Strategy

The primary strategy of the Water Dogs was to create a durable system architecture that is lightweight and designed with speed, stability and high buoyancy in mind. As a result, the Water Dogs chose to use a diverse assortment of materials with the hull being cut out of foam with hardened Fiberglass coating the outside. In addition, as one of the main goals of the Water Dogs was stability, a different hull design was thought out than what is typically used. The Water Dogs decided to go with a rotating-spherical hull design which allows the boat to rise up and stay extremely stable, which is vital when shooting the pre-loaded balls and water. In order to increase versatility, a turret system was implemented on top of the hull, allowing the boat to have no real "front side," giving our software team as much control as possible. Additionally, three thrusters are placed to drive our boat, allowing the boat to have a strafing motion. Although this is an out-of-the-box idea, it gives us an advantage over the competition for those who have to turn around the buoys. Aside from our design, we noticed that as time was spent working on the hardware portion of the boat, 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 2 teams to work simultaneously and optimizes the limited number of working hours before competition.

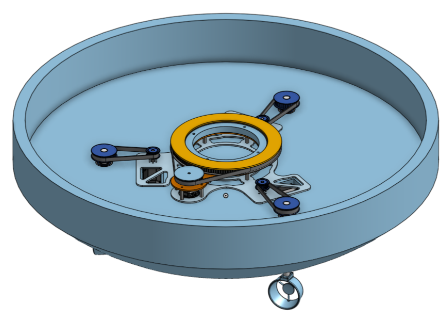

Fig. 2. Hull Design in CAD

III. Design Creativity

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 catamaran hulls, utilizing the machinery accessible to them. The hulls were designed in PTC Onshape CAD software. A custom-made hot wire wand was constructed from a hand-held saw and power supply to cut pink insulation foam to the shape of our design. With prior experience with vacuum bagging in the First Tech Challenge competition, the Water Dogs decided to place fiberglass cloth adjoined with epoxy resin over the insulated foam to create a hydrodynamic and lightweight structure.

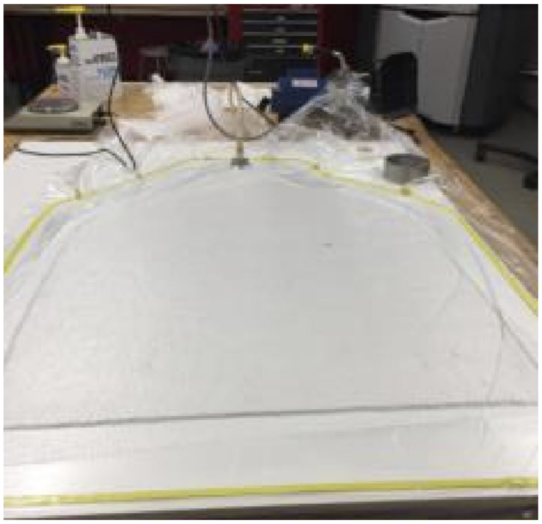

Fig. 3. Vacuum Sealing new Hull Design

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 Water Dogs also needed to have a low center of mass to avoid tipping. As a solution, we decided to put all of our electronics inside the turret as we would only need to unscrew a couple screws to get to them. This was carefully designed in PTC Onshape to make sure our electronics would fit. In addition, a water-resistant ”lid” was placed on top of the turret, allowing the turret to slide back down to prevent water from entering the boat. The result was an efficient design, using the space we have to its fullest extent.

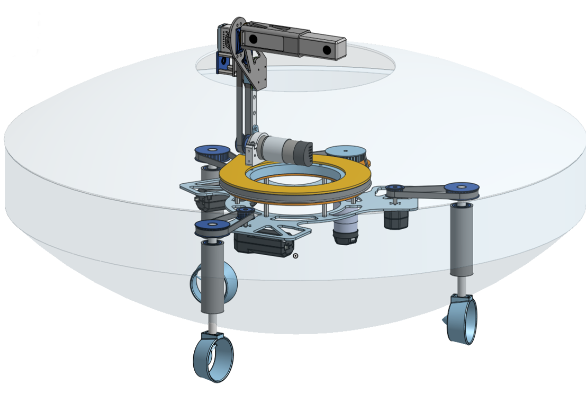

Fig. 4. Electronics will be stored at bottom through turret

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. Self-Leveling Lidar

While performing in-water tests, the Lidar returned inaccurate readings because the boat shook with increased throttle and windy conditions. To account for this error, the team designed a self-leveling Lidar gimbal. This device uses sensor data from an IMU and a PID control algorithm to keep it balanced.

E. Control System

The Water Dog’s approach for a robust control system was to use a RC multiplexer to shift from manual to autonomous control. This switches between an RC receiver and an Arduino microcontroller board that controls the throttle and steering. A number of microcontroller boards that connect through USB to the main computer are implemented on the boat. Each board can read sensor and write to actuators. This division of labor improves reliability and allows different members of the team to participate in building and debugging individual sensor/actuator subsystems, or nodes. The team’s creative use of ROS to create a skeleton of nodes is further explained in Section V.

IV. Experimental Results

Throughout the season, the team prioritized experimental design in order to encourage members to learn the engineering design process. A majority of experimentation took place in the early stages of development, in determining whether the use of a spherical hull would be optimal due to possible issues with stability. With the limited number of working hours, we used Physics and CAD to determine what type of Hull design to go with. First, we brought our initial spherical design to CAD and decided to compare it with a donut-shaped hull design. We realized quickly that a donut-shaped design would have a big force upwards when the boat is under water due to the fact that more of the boat is underwater, providing a bigger force upwards. However a drawback with this design is it would perhaps be slow compared to something that curves more naturally such as a sphere. As we weighed the pros and cons of each design we found that we could actually spin the sphere and it would cause the boat to rise up and stay extremely stable, which is vital when shooting the water and pre-loaded balls. As of now, we are still deciding between a donut-shaped design and a spherical design and will experiment with real designs rather than basic physics to figure out which design is most optimal.

A. 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. This form of testing is indeed valuable as it provides the software teams to work on a boat while the hardware team is making changes to the boat.

Fig. 5. Experimenting with Gazebo

B. Future Testing

The Water Dogs plan on quickly creating different hull designs in which we believe are optimal. 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 other day. The team has access to similar buoys used in competition thanks to the University of Central Florida Robotics Club RoboBoat team. This will allow them to be better prepared for the competition course.

V. 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 SICK TIM5512050001. This is an infrared sensor with a scanning angle of 270 degrees at 15 Hz. The angular resolution of one degree should make sure the team has a number of returns from the fixed buoys.

Additionally, the team uses a stereo camera, the MYNT EYE S1030, as a secondary measure of developing a view of our surroundings. The dual cameras provide 752x480 60fps resolution and a 140 degree field of view, with frame synchronization and a 6-axis IMU providing accuracy within 1 millisecond. The result is a depth map with a flexible range between half a meter to 20 meters that the team can use to find different obstacles and objects.

To find the location and orientation of the boat, the Water Dogs are experimenting with two sensors. The first is a NAVCOM GPS with Starfire Precise Point Positioning. This

Fig. 6. The SICK TIM5512050001

Fig. 7. The MYNT EYE S1030 Stereo Camera

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 will allow for higher accuracy in traversing towards the start of a course challenge. 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 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 odometry 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.

VI. Conclusion

The fourth 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 weeks prior to the competition, the team will continue to experiment with their software to ensure dependable control. The team will also work on assembling the rest of the boat. The Water Dogs are proud to be competing in yet another season of RoboBoat, and can't wait for competition week!

VII. 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 aren't 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 coaches, Mr. Stefan Ibarguen and Mrs. Po Dickison, who work hard to organize meetings and keep the team focused and on track. Mr. Ibarguen is a retired teacher and software engineer, and also assists in the software and programming of the boat. 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. In addition we have 3 mentors, Mr. Don Harper, Mr. Steven Yun and Mrs. Jaynelle Miller who all provide mentorship and assistance and facilitate team meetings. In addition, Mr. Don Harper is the director of the Texas Instruments Innovation Lab at the University of Central Florida, and has an immense 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.

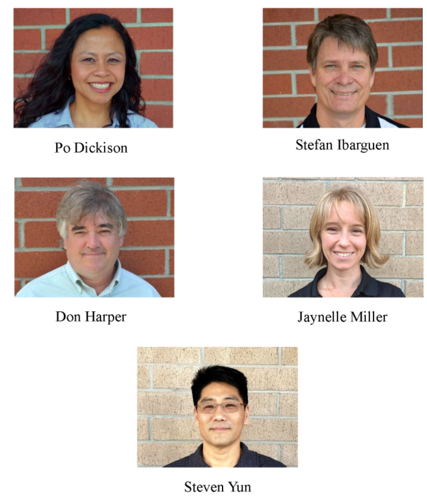

Fig. 8. Our wonderful mentors!

B. Sponsorships

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

Fig. 9. 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, lathe, or the drill press.

Fig. 10. Texas Instruments Innovation Lab

Appendix A: Component Specifications

Since the Water Dogs work out of a university maker space and in close relation with Mr. Harper, who has an immense background in robotics and computer science at the University of Central Florida, 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.

Component	Vendor	Model/Type	Specs	Unit Cost	Quantity	Total Cost
Pink Insulation Foam (hull)	Home Depot	FOAMULAR 1.2inx4ftx8ft		$10.00	1	$10.00
NidaCore Honeycomb Sheets	Florida Fiberglass	.25inx4ftx4ftx8ft		$50.00	1	$50.00
Fiberglass Cloth	Florida Fiberglass	4OZ E-glass Yd		$4.33	5	$21.65
Servos	HiTec	HS-645HB		$25.00	2	$50.00
Brushless Motors	Alien Power System	6355 Outrunner brushless 230KV 2400W		$200.00	2	$400.00
Encoder	CUI Inc	AMT102-V		$23.53	1	$23.53
Lidar	SICK	TIM551201000 1		$2,000.00	1	$2,000.00
GPS with Correction	NAVCOM	SF-2050M	Starfire PPP Correction	$300.00	1	$300.00
Microcontroller Board	Arduino	UNO		$15.00	1	$15.00
CPU	Gigabyte	GB-BSSA-6100		$200.00	1	$200.00
Wireless Router	Buffalo Technology	WHR-HP-G54		$79.00	1	$79.00
Receiver	Spektrum	AR7000 2.4ghz DSM2		$45.00	1	$45.00
Solid State Relay	Crydom	D1D40		$25.00	1	$25.00
Motor Controller	DIY Electric Skateboard	VESC 50A PWM		$89.00	2	$178.00
IMU/AHRS	XSENS	MTi-G-710		$5,000.00	1	$5,000.00
Batteries	Tattu	450mAh 14.8V 75C 4S1P Lipo Battery		$15.00	2	$30.00
Operating System	ROS			$0.00	1	$0.00
Team Size: 11						
Expertise Ratio: 8:3						
Testing Time (Simulation): 5 hours						
Testing Time (Simulation): 10 hours						
Inter-vehicle communication: N/A						
Programming Language: ROS						

Fig. 11. Component Specifications

Appendix B: Movement Methods

Our boat consists of three propellers. These three propellers help us steer and maneuver our boat effectively. In the first image, all propellers are powered, facing forward, moving the entire boat forward. As seen in the second image, our boat uses a differential drive, where one back propeller is given more power that the other, allowing the boat to move in a curved path. Using our omnidirectional drive system, we are able to rotate all of our propellers and strafe, moving our boat diagonally, without having to turn our entire boat. Sometimes this method of driving can be unreliable because the power from the three propellers is not equally balanced on all sides. This is why, as seen in our fifth image, we don't power one propeller and rotate the other two propellers to drive in certain directions, represented by vectors a and b, which result in vector c, which is the same direction our boat would have driven with the strafing method. To keep our boat stationary in the water, we rotate the propellers to opposite directions, and power them equally, which allows the forces caused by the propellers to cancel out, keeping the boat stationary.

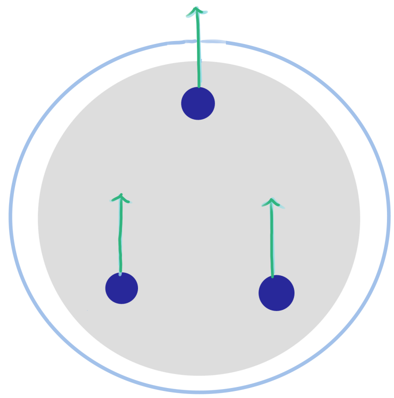

Fig. 12. Differential Drive Straight

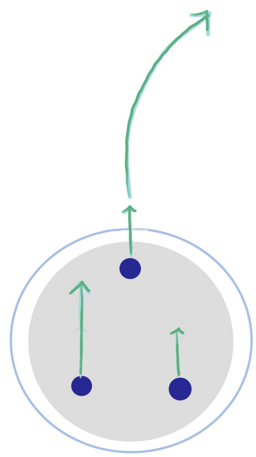

Fig. 13. Differential Drive Turning

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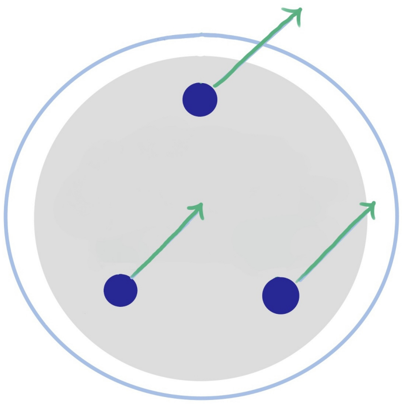

Fig. 14. Strafing Motion

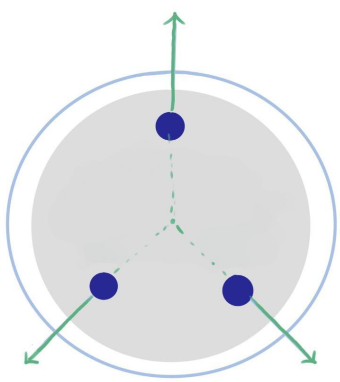

Fig. 15. Station-Keeping

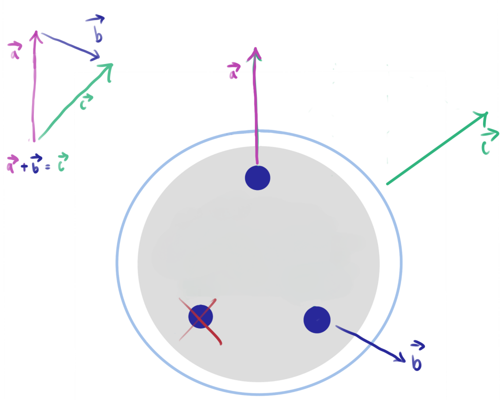

Fig. 16. Station-Keeping Resultant Vectors