The Water Dogs - RoboBoat 2019

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Abstract—**This design report analyzes the Water Dogs' strategic thinking in theory and in application, and how our engineering design decisions reflect the execution of our game strategy. This report will focus not only on the reasoning behind design and control decisions, but the execution of these decisions as well, analyzing and exploring the trials and tribulations that are ever-present with the engineering process.**

I. Introduction

The Water Dogs' 2019 RoboBoat entry, Sir Docks-A-Lot, utilizes a variety of sensors and vision software to accomplish the competition tasks. Our 2019 entry uses data gathered from the previous two years of competition to improve on past designs and software. Many of our members have past robotics experience, including RoboBoat, which allow the Water Dogs to retain a competitive edge. Our expansive knowledge in the greater robotics field acts as a precursor to our success in tackling challenges as novel as the RoboBoat competition.

II. Competition Strategy

The primary strategy of the Water Dogs was to create a durable yet lightweight system architecture with a focus on speed and mobility, customizing our design to our chosen tasks. As a result, we opted to optimize a catamaran hull that offered increased stability and mobility than a mono-hull design. In the previous years, the Water Dogs have focused heavily on the development on a reliable hull structure and propulsion system, with less emphasis on software experimentation throughout the season. In the 2019 RoboBoat competition, in order to tackle new tasks such as Find the Path and docking, we opted to experiment with a greater variety of software. To ensure this goal would be met, we decided to improve upon the existing catamaran design rather than renovating the entire boat to optimize working hours.

Fig. 1. The Water Dogs' Boat from the 2018 Season

After placing a strong emphasis on furthering sensor integration by developing the appropriate hardware base to create a well-linked system of sensors last season, the Water Dogs focused their efforts this year on using this sensor data to it's fullest through the creation of robust programs that were fine-tuned with the use of simulative testing, which was accomplished through the development of a customized virtual environment in ROS Gazebo. This virtual approach to experimentation and testing is meant as a dry-run of programs that saves time and increases productivity, allowing small bugs and problems in the code to be resolved before the in-water testing process, which is much more time intensive. Therefore, simulative testing and experimentation was a crucial step in the team's iterative process this year, and offered the potential to conquer new challenges much more easily (read more about simulative testing in Section IV).

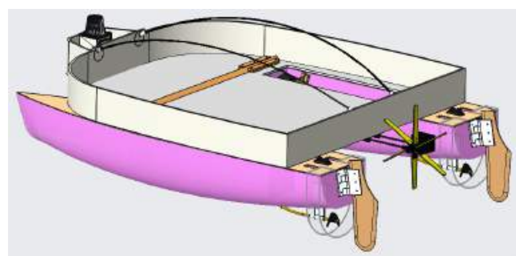

Fig. 2. Complete Boat Assembly in PTC Creo

III. Design Creativity

A. Fabrication

Sir Docks-A-Lot provides creative and innovative solutions to the various design challenges and objectives set out in the Competition Strategy section. The team opted to take an unique approach to fabricating their catamaran hulls. The two hulls were designed in Orca3D and later brought into Autodesk 123D, a slicer program, converting the geometry into templates able to be laser cut. One inch thick pink insulation foam was then sandwiched by two successive wooden templates, and a custom-made hot wire wand was constructed from a saw to cut the foam to the shape of the template. The foam slices were then adjoined by polyurethane glue and sanded down to create a smooth, uniform hull. Two supportive layers of fiberglass and epoxy were added to each hull, creating a hydrodynamic and lightweight structure capable of completing the RoboBoat challenges.

B. Electronics Platform

The team improved upon its arsenal of fabrication techniques in creating the electronics enclosure. In order to create a larger and more substantial electronics platform

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Fig. 3. Laser Cut Wood Templates

Fig. 4. Adjoined Layers of Pink Insulation Foam with Polyurethane Glue

Fig. 5. Fiberglass and Epoxy is Applied to the Hull

while maintaining a similar overall weight of 35lbs we utilized a lightweight honeycomb structure, Nida-Core to construct the platform's armature. The team then used vacuum bagging to create a lightweight sealing composite using fiberglass and epoxy.

Fig. 6. Electronics enclosure design

The result was a rigid, waterproof compartment. The entire platform is covered by a fiberglass lid modeled in PTC Creo.

C. Cooling System

In order to maintain a sealed electronics enclosure, the team designed a system for proper air circulation and cooling. With the perpetual thermal mass of the lake around the boat in mind, the team devised a cooling system that pumps the lake water through a radiator. Fans then circulate

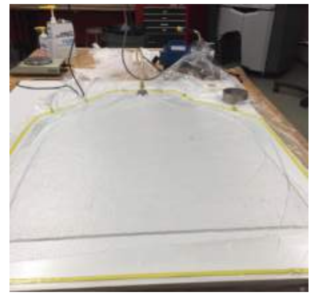

Fig. 7. Vacuum Bagging the New Catamaran Center

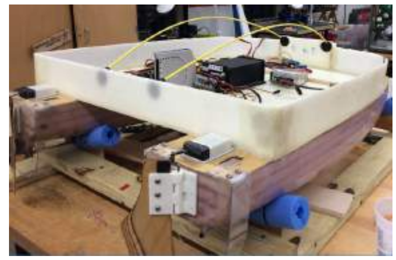

Fig. 8. New Catamaran Center with two pole Framework

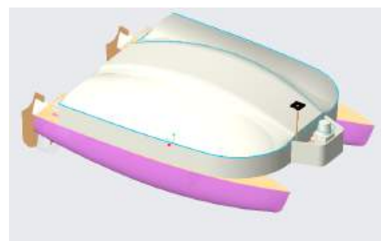

Fig. 9. Electronics Compartment Cover Modeled in PTC Creo

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. Modular Hull

With a focus on continual in-water testing in the latter half of our season, the team desired a way to fight fast battery drainage without having to take the boat out of the water. Their solution was a modular third hull that can hold batteries. The hull is smaller than the two main hulls and can be attached to the underside of the electronics enclosure. This hull provides added buoyancy equivalent to the weight of the batteries it contains, ensuring that the water line on the boat remains consistent throughout the run.

E. Self-Leveling Lidar

While performing in-water tests, the Lidar returned inaccurate readings due to unpredictable wind conditions and throttle. 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 and accurate.

F. Control System

The Water Dogs' approach for a robust control system was to use an 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 also implemented on the boat. Each board can read sensors 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.

G. Paddle Wheel Encoder

The team has continued experimenting with an AMT 102-V encoder attached to a paddle wheel as a method of measuring displacement and velocity. For the 2019 season, using the data we were able to collect from last year, we opted to prioritize readings from other sensors (such as the IMU and GPS) over the paddle wheel to avoid reliability issues. The Water Dogs designed the entire paddle wheel assembly and encoder housing in PTC Creo, and created a motion skeleton to accurately simulate the paddle wheel's rotation before manufacturing its components. The encoder data is received by a Texas Instruments micro-controller, and the calculated distance and velocity is published for other nodes to subscribe to it.

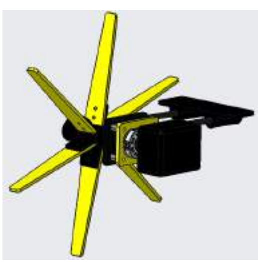

Fig. 10. Paddle wheel assembly

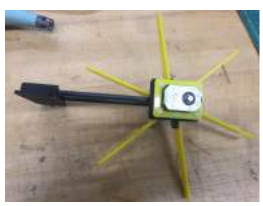

Fig. 11. Fully constructed paddle wheel assembly

IV. Experimental Results

The Water Dogs have always encouraged the physical and virtual testing of new ideas and concepts as a way of training members in the process of engineering design. Although a majority of experimentation took place in the early stages of hardware development, in determining whether the use of a catamaran hull would continue to be optimal in a competition that prioritized speed, stability, and load-bearing capabilities, it took on a huge role once again in this season with the introduction and development of simulative testing. Throughout this season, the team prioritized continual experimentation and testing in regards to software development, primarily through the newly discovered facet of virtual simulation in ROS Gazebo.

A. Hull Design Experimentation

This season, the team chose to stick with the catamaran design that the team has been using over the past two years due to the clear advantages it offers over other boat designs, as proven by the results of an experiment that the team conducted in it's first season to decide which boat design would be best to construct. In order to test how quickly each boat design could travel through the water, we designed a controlled experiment. An indoor pool contained the experiment, so as to eliminate weather and current effects. The same motor and battery was connected to each boat in order to maintain consistency. We then timed each boat as it traversed the length of the pool. We repeated the process three times and took an average. The times were recorded in the table below. Then, the team calculated the speed of each boat during each trial, in centimeters per second, by dividing 1000cm by each time trial.

Speed Experiment - Boat Design Versus Time Taken to Cross 10m			
Trial	V-Hull Boat Time	Barge Boat Time	Catamaran Boat Time
1	24	42	32
2	23	40	34
3	25	42	33

Fig. 12. 10 meter Speed Experiment Results Table

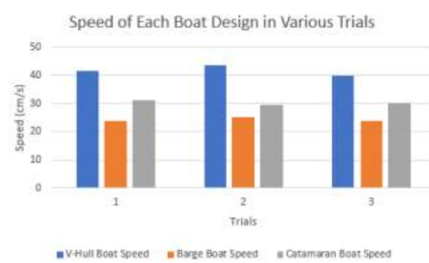

Fig. 13. Speeds of Various Hull Designs Within Each Trial

B. Simulative Testing

At the beginning of the 2019 season, we understood that using a collaborative platform to facilitate testing of our design and programming iterations would be a big priority, since our team's traditional method of constantly wet-testing our newest implementations at a real lake was incredibly inefficient and resulted in lost time and productivity. Thus, we focused our efforts on developing an accurate and reliable virtual simulation of the boat within ROS Gazebo, a set of ROS packages that allow the creation of a simulated environment complete with variables such as waves and weather in addition to permitting fluent communication with our control system, ROS.

Initially, we used the software repository provided by the Virtual RobotX competition, which furnished us with a base environment which we could then use and customize specifically for Sir Docks-A-Lot. We edited the visual and collision parameters of the boat in-simulation and tailored it towards it's real-life counterpart. We supplied the CAD model of our boat in PTC Creo with material specifications and generated estimates of the mass and moments of inertia for specific parts of our boat, which we could then input into the simulation for further accuracy.

In addition, we integrated our sensors into the simulation as well, such as the Lidar, GPS and the stereo camera. Not only are these sensors simulated, but their output data are as well, facilitating testing with these sensors to be done

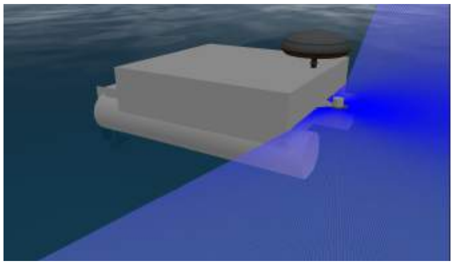

Fig. 14. Simulated Boat in the Gazebo Virtual Environment

completely virtually. This allowed us to experiment with these sensors in-simulation, such as the Lidar, and receive real-time data from them.

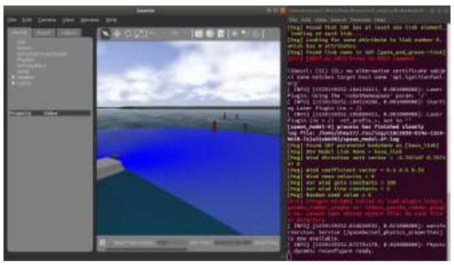

Fig. 15. Using Lidar Input from the Simulator to Detect Buoys

Furthermore, to communicate with the boat, there is a router on the boat bridged to a router on the shore. This onshore router is then connected to the University's network. The team uses the VPN service, Hamachi, which allows them to set up a VPN and go through the university's firewall to access the boat. Since ROS allows the work to be split up among multiple computers/nodes, team members unable to go to the lake for testing can work on the boat and perform experiments from home. Having the boat always connected to the internet improves collaboration between the programmers on the team, such as the use of the source code repository, GitHub.

C. Kalman Filter Integration

Another

D. Future Testing

The Water Dogs plan on using the majority of the remaining time before competition for in-water testing. So long as the 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 node that will interpret the images received from it's stereo camera using OpenCV software, and return data relevant to accomplishing certain goals. Nodes communicate on topics using messages, and nodes can publish data as well as subscribe to other data. ROS allows for synergy between sensors including a Lidar, Stereo Camera, a Global Positioning System, and an Inertial Measurement Unit.

The Lidar the team uses is a SICK TIM5512050001, as seen in Figure 16. 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.

Fig. 16. The SICK TIM5512050001 Lidar

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.

Fig. 17. The MYNT EYE S1030 Stereo Camera

To find the location and orientation of the boat, the Water Dogs experiment with two sensors. The first is a NAVCOM 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 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 acts as a Kalman filter to produce a reliable position of the robot. The Kalman filter merges 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.

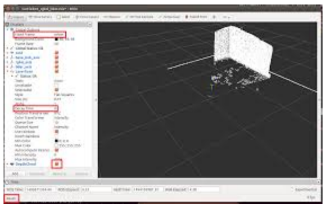

Fig. 18. Example PointCloud data displayed in the RVIZ visualizer

In addition, the team utilizes 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 third season of the Water Dogs was one of growth and improvement through critical error analysis and discovering solutions through innovation. The team learned from its past mistakes and worked towards design improvement by keeping the main objectives of speed and lightness. 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 towards accurately simulating the boat for continued testing and improvement. The Water Dogs are proud to be competing in yet another season of the RoboBoat competition, and can't wait for competition week.

VII. Acknowledgements

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 unafraid to sacrifice a few nights of sleep. zThe 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

Fig. 19. Mrs. Po

Fig. 20. Mr. Harper

Fig. 21. Mr. Ibarguen

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, manages our school workspace and allows the team to conduct after school meetings. Our mentor, Mr. Don Harper, provides technical mentor-ship and assistance, and facilitates the team's use of his workspace and professional equipment. He 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.

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. 22. Thank You to Our Generous 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 such as ANSYS or Orca3D, 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.

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. The component specifications are listed underneath.

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		$23.63	1	$23.63
Lidar	SICK	TiM55120050001		$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-BSBA-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. 23. Component Specifications

Appendix B
Outreach Activities

While participating in both RoboBoat and other robotics competitions, the members of the Water Dogs have accumulated over 500 hours of outreach. All team members are required to fulfill a minimum of 15 outreach hours each year. Before each event, the team meets to discuss and review the content being presented so that each member understands the material and is able to educate others. This season, the Water Dogs placed a heavy emphasis on regular outreach activities to spread the word about STEM within the community and to encourage our youth to pursue careers in engineering. We achieved this goal through regular mentorship of FIRST Lego League teams at local elementary schools and founded 2 Junior FIRST Lego League teams to spread STEM to the youngest generation of future innovators. The team also reached out to the community through team showcases and expositions at the Maker Faire in Orlando and the Mini Maker Faire at a Barnes&Noble to get parents and students excited in STEM and interested in joining the team. In addition, the team interacts with professionals in engineering by attending events like I/ITSEC, and Women in Engineering.

Fig. 24. The Water Dogs attending I/ITSEC

Fig. 25. The Water Dogs Mentoring Robotics Students at Midway Elementary

Fig. 26. The Water Dogs Mentoring an FLL Team at Evans Elementary

Fig. 27. Members Teaching Students about STEM at One of their Three Summer Camps

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