The Water Dogs - RoboBoat 2018

Zach Irving, Nicholas Injo, Jared Reid, Edgar Madruga, Haven Carter,
Sachin Shah, Asheya Naik, Katherine Guise, Neel Maity, Aashni Patel, and Jolie Miller

***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 where they placed second in their division and won the Design Award. Many of the members 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. Their expanse of knowledge in the greater robotics field acts as a precursor to their success in tackling the RoboBoat competition.

II. COMPETITION STRATEGY

The primary strategy of the Water Dogs was to create a durable system architecture that is lightweight and designed with speed and high buoyancy in mind. Given that the main focus of the competition is on autonomous software development, a balanced platform is integral to the design in order to support sensors and other electronics. Therefore, the Water Dogs chose a catamaran hull over a mono-hull design due to its stability and mobility through the water.

In the previous year, the Water Dogs focused heavily on the development of a reliable hull structure and propulsion system. In turn, they sacrificed time for software development and experimentation. This year a strong emphasis was placed on in-water testing in order to give the Water Dogs a more competitive edge. The decision to improve upon the existing catamaran design instead of a complete redesign was chosen in order to optimize the limited number of working hours before competition.

Fig. 1. The Team's Boat from the 2017 Season

Sensor integration was a central focus to the improvements made upon last year's design. In order to approach more of the course challenges, proper sensor housing and placement was necessary. A new electronics and sensor enclosure was designed and fabricated providing a larger surface area for components and added water proofing. This versatile platform supports hardware and software synergy, opening up a new potential to score higher points.

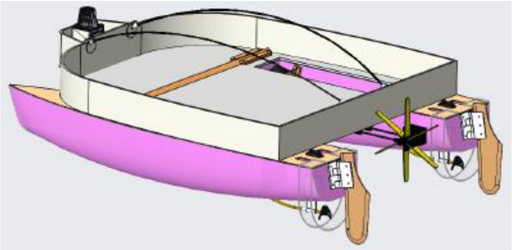

Fig. 2. Complete Boat Assembly in PTC Creo

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 Orca3D and later brought into Autodesk 123D, a slicer program, converting the geometry into templates able to be laser cut. One inch pink insulation foam was sandwiched by two successive wooden templates. A custom-made hot wire wand was constructed from a hand-held saw and power supply, in order to cut the pink insulation 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 geometry. Two layers of fiberglass and epoxy were added to each hull, creating a hydrodynamic and lightweight structure.

B. Electronics Platform

The team improved upon its arsenal of fabrication techniques in creating the electronics enclosure. They wanted to

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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

create a larger platform while maintaining the same overall weight of 35 lbs. The Water Dogs utilized a lightweight honeycomb structure, Nida-Core, to create the enclosure. The team used vacuum bagging for the very first time to create a lightweight composite of Nida-Core, fiberglass, and epoxy.

Fig. 6. Electronics enclosure design

The result was a rigid, waterproof compartment. The entire compartment is currently covered by a water resistant fabric and supported by a two-pole framework, keeping the electronics dry. The Water Dogs plan on creating a fiberglass shell from a mold to replace the fabric cover in the future.

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.

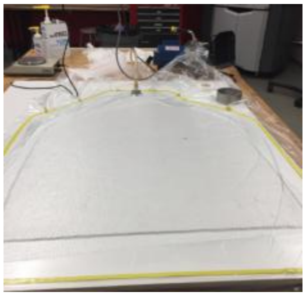

Fig. 7. Vacuum Bagging the New Catamaran Center

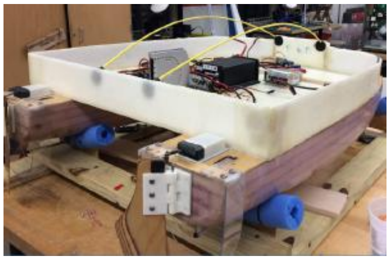

Fig. 8. New Catamaran Center with two pole Framework

Fig. 9. Water Resistant Fabric Covering the Electronics Enclosure

D. Modular Hull

With a focus on continual in-water testing, 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, that way the water line on the boat stays the same.

E. 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.

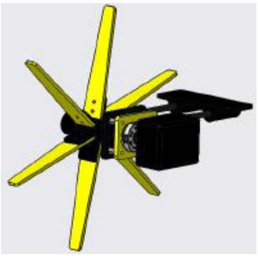

Fig. 10. Paddle wheel assembly

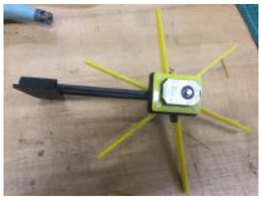

Fig. 11. Fully constructed paddle wheel assembly

F. 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.

G. Paddle Wheel Encoder

The team is currently experimenting with an AMT 102-V encoder attached to a paddle wheel as a method of measuring displacement and velocity. The paddle wheel spins as the boat moves through the water. The Water Dogs designed the entire paddle wheel assembly and encoder housing in PTC Creo. They created a motion skeleton to accurately simulate the paddle wheel's rotation before actually 3D printing and laser cutting its components. The encoder data is received by a Texas Instruments microcontroller, and the calculated distance and velocity is published for other nodes to subscribe to it.

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 catamaran hull would be optimal in a competition that prioritized speed, stability, and load-bearing capabilities.To test the different boat hull designs that could be used, several foam prototypes were made. First, three small scale boats were constructed using insulation foam. The first design was a V-hull design meant to reflect most modern day speed boats. The V-hull provided the most speed, but offered the least load-bearing capabilities with the least stability. The second design was a barge, with a flat bottom. It placed first in its load-bearing capabilities, but last in speed and second in stability. The third design consisted of a catamaran hull. It seemed to perform the best in categories most crucial to the competition, which is the balance between stability and speed, placing first and second in those categories respectively. It also placed second in load-bearing capabilities, making it the most desirable design overall.

A. Speed Experiment

In order to test how quickly each boat 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

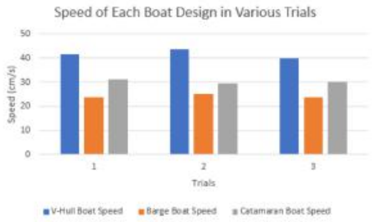

Fig. 13. Speeds of Various Hull Designs Within Each Trial

B. Load Bearing Capabilities

Using the same setting as the speed experiment, each of the boats were placed in the water and weights were added to the middle of each boat until it was submerged. The data is represented in the table below.

Load Bearing Capabilities

Trial	V-hull Boat Max Weight (grams)	Barge Boat Max Weight (grams)	Catamaran Boat Max Weight (grams)
1	54	102	79
2	57	101	81

Fig. 14. Load Bearing Experiment Results Table

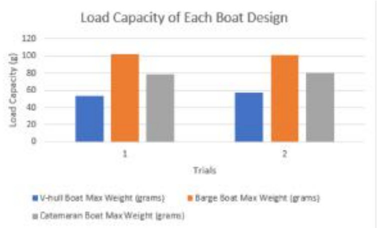

Fig. 15. Load Bearing Capabilities of Each Hull Design Within Each Trial

C. Stability Experiment

Within this experiment, we utilized the same boats, weights, and the same setting as the load bearing capabilities experiment. This time, the weights from the previous experiments were stacked on one at a time on the far side of the boat until each boat capsized. The experiment was repeated three times, and the data was recorded in the table below.

Stability Experiment - Boat Design Versus Weight Required to Capsize

Trial	Max Weight to Tip a V-Hull	Max Weight to Tip a Barge Boat	Max Weight to Tip a Catamaran Boat
1	33	45	59
2	32	44	58
3	34	46	61

Fig. 16. Stability Experiment Results Table

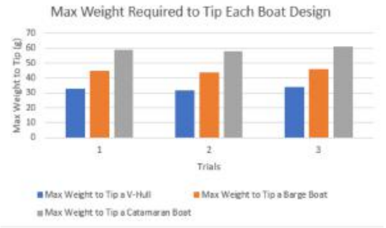

Fig. 17. Stability of Various Hull Designs Within Each Trial

D. *Collaborative Testing*

To communicate with the boat, there is a router on the boat bridged to a router on the shore. The router on the shore is also 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.

E. *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, though nothing beats the accurate conditions of in-water testing.

F. *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 ROS node that will publish the boat's displacement and velocity from a paddle wheel encoder. ROS also allows for synergy between sensors including a Lidar, a Global Positioning System, and an Inertial Measurement Unit.

The Lidar the team possesses is a SICK TIM5512050001, as seen in Figure 18. 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. 18. The SICK TIM5512050001 Lidar

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 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.

Fig. 19. Mrs. Po

Fig. 20. Mr. Harper

Fig. 21. Mr. Ibarguen

VI. CONCLUSION

The second 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 creating an efficient cooling system for the interior of the electronics enclosure. The Water Dogs are proud to be competing in yet another season of RoboBoat, 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 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. 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 like 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.

APPENDIX B
OUTREACH ACTIVITIES

Between all of the other robotics competitions our members have participated in, the Water Dogs have done over 350 hours of outreach this season. All team members are required to fulfill a set quota of outreach hours each year. Before each event, the team meets to discuss and review the content being presented so that each member

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 1yd		$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	TIM5512050001		$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-BSi3A-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	850mAh 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

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. This was done through season-long member mentorship at an FLL team at Evans Elementary School, as well as STEM education and curriculum based teaching at Midway Elementary. 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, Lockheed Martin's eWeek, 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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