MARC-I | 2017-2018 RoboBoat Competition

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***Abstract*—For IMARC's second year at the RoboBoat competition, the team redesigned the hulls, designed custom propellers and propulsion pods to produce 15 lbs of thrust, decreased the weight of the boat to around 30 lbs by using LiPo batteries, and wrote a software framework from scratch in Java. As a result of these changes, IMARC's latest boat is christened the MARC-I, a play on letters from IMARC and Iron Man's suit. IMARC has confidence in the MARC-I and the goal of this year's boat is to win the bollard pull and speed test, while also making a decent showing in the other competitions.**

Keywords—IMARC, MARC-I, autonomous, boat, Iowa, design

Figure 1: The current design of MARC-I as of May 20, 2018

I. INTRODUCTION

The Roboboat Competition is an annual autonomous vehicle competition in which student teams design and build fully autonomous boats to compete against teams from around the world. This year's competition is being held June 18-24th in Daytona Beach, Florida, and it will be IMARC second time in attendance. This paper details IMARC's design process, including the teams objectives, challenges, and design decisions for each part of the boat: hulls, propulsion system, hardware, and software.

II. COMPETITION STRATEGY

IMARC learned much at last year's competition and previous boat, Bare Necessities. It was too heavy, the car battery used was too heavy, the propulsion system was too heavy and just plain bad. Some of this was due to it being the first time competing, but a majority of the failure was due to the team focusing on too many aspects of the competition. This year, the MARC-I was built to win two parts of the competition: the speed test and bollard pull, therefore significant time was put into designing custom propulsion system.

III. DESIGN CREATIVITY

Although IMARC's main focus are the bollard pull and speed tests, a majority of the work done this year also works on the other tasks at the RoboBoat competition, such an the maneuverability due to the hull design. More detail will provided in the sections below.

A. Hull Design

Constraints are the limiting factor in a design and must be considered first. For the current hull design, the main constraints were time, money, geometric dimensions, along with weight. The geometric constraints were imposed by the team and included a length of 30", a width of 24" and a hull height of at most 12". Additionally, the boat needed to weigh less than 30 lbs therefore, the hull needed to weigh less than 10 lbs.

The next step in the design process is defining important criteria for which the design is geared towards. For this design the most important criteria are stability, maneuverability, as well as making the hulls hydrodynamically efficient. When considering the boat stability, the first consideration is how the boat will react in a turning maneuver. When the boat is turning, the rolling stability is the most important aspect of the design to consider. The most important parameters for stability are the metacenter, center of mass, moment of inertia at the waterline, submerged volume, and center of buoyancy. When the metacenter is above center of mass, the boat is stable. Analyzing general stability, the wider the boat is relative to the height, the more stable the boat becomes in the roll direction. An increase in width is beneficial for maneuverability, however, if the boat is too wide additional torque must be applied to attain a desirable angular velocity due to the additionally rotational inertia. Therefore, finding the optimal balance between stability and maneuverability is ideal.

A catamaran style was chosen for the design. The catamaran is a common design that is used for stability due to the width of the boat being large in comparison to the height of the boat. Additionally, the weight of the submerged volumes is located far from the center of gravity increasing the boats rotational inertia about the roll axis. Catamarans have thin demi-hulls making them streamline and reducing resistance.

The hull shape of the catamaran was inspired by existing designs in the field of naval architecture. The boat has a 7-inch width with curvature to add resistance to the weight. The boat needed to float which is calculated through a force balance between weight of boat and weight of water displaced. To assure the proper height for the sensor to receive information accurately, a height of 7.5 inches was chosen based off buoyancy testing. Wood was chosen as the hull material due to the natural buoyancy while still maintaining a rigid surface for attaching fasteners too.

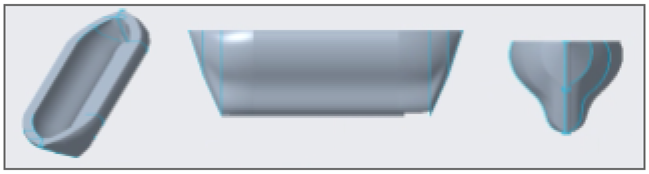


Figure 2: Multiple perspectives of hull design

B. Propulsion System

Some members of IMARC were chosen, along with several naval hydrodynamic students, to have their senior design project be designing a propulsion system for this year's boat. This project had two parts: the propeller and the shroud/supports. Overall, the goal was to achieve 15 lbs of thrust at bollard from one propeller and pod. For the propeller, the team started off with a MARIN Ka4-70 standard propeller series. After performing several rounds of CFD, the team designed a propeller that produced 15 lbs of force at bollard. The shroud was also selected from a standard series. The MARIN Type 37 shroud was selected over the Type 19 shroud due to its increased performance in the reverse direction. The supports that connected the motor and shroud to the board were designed such that the propeller could be angled slightly upwards to prevent pitch. Unfortunately, with the selected angle of around 20 deg, the boat currently feels about 2 in of heave on startup. That slight change in elevation was deemed acceptable due to the dramatic change in pitch.

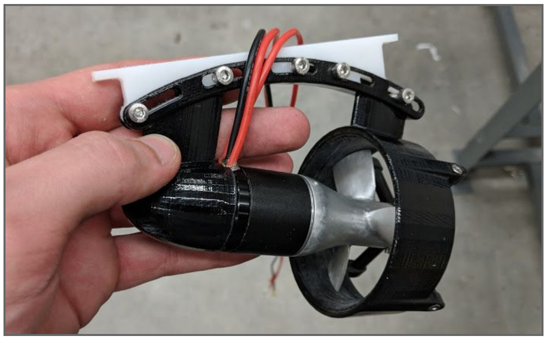


Figure 3: Final propulsion system pod

C. Hardware

Last year's boat used extremely heavy lead acid car batteries. To keep the weight down this year, the onboard electronics are powered by a system of 5 LiPo batteries. Each motor will two 5000mAh 5S LiPos connected in parallel to provide. This setup will provide around 25 minutes of operational time. All other electronics will be powered by a single 5000mAh 4S LiPo battery. It will provide around 30 minutes of power.

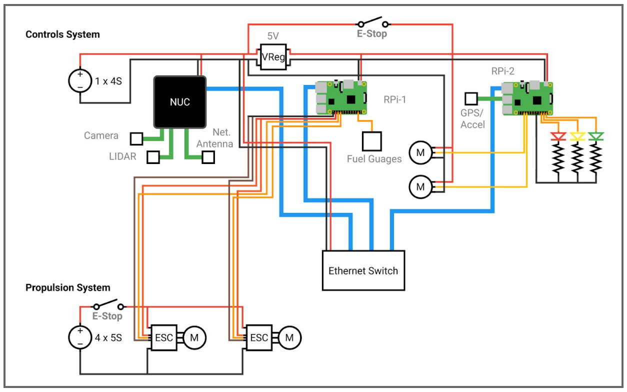


Figure 4: An initial design for the electronics.

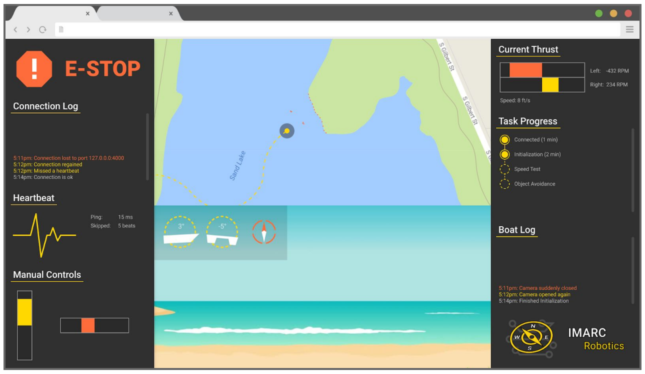
Networking and communication with the onshore computer is accomplished over WiFi. Any other form of communication cannot carry the necessary amount of data to communicate with and be controlled from the on shore computer. The major downside to this was the poor range, which was solved by a long range WiFi antenna.

D. Software

Last year's team used ROS as the main framework for the boat. This was not the direction the team took this year. ROS is a powerful tool, but it is quite problematic for our team. Instead, the team wrote their own framework in Java. Most members of the Software team were much more familiar with Java than C++, and a gradle based project is much easier to start working on than installing a VM and working with Linux for the first time, especially for new members.

Network communication with the onshore dashboard is done via HTTP requests. This is one of the easiest and most simple ways to communicate over the Internet. Much like any other API, the boat acts as a server, and the dashboard makes requests to get the boats GPS location, the motor speeds, and other stats. It is also used for manual controls and emergency stopping the boat. Internal communication between processing units is done through sockets.

The onshore dashboard is written using HTML, CSS, and JS. It is written using ReactJS to make it easier to develop, and it run using Electron, a web framework that compiles and run the application natively on all OS's, rather than as a webpage in a web browser.



5:11pm: Connection lost to port 127.0.0.0:4000
5:12pm: Connection regained
5:12pm: Missed a heartbeat
5:14pm: Connection is ok

5:11pm: Camera suddenly closed
5:12pm: Camera opened again
5:14pm: Finished Initialization

Figure 5: MARC-I Dashboard initial design

Mapping and navigation are accomplished through a LIDAR, GPS, and the CV discussed above. Each object/buoy that is found has a probability associated with the likelihood it is really there. This probability is determined by the frequency in which the LIDAR or CV find an object in the same area. Each of these objects is then used as input into a navigation field. This field is made up of vector's whose size range from -1 to 1 representing the speed and direction the boat should head in. The vectors are then turned into a set of percentages that each motor should rotate at to achieve the desired heading.

IV. EXPERIMENTAL RESULTS

IMARC performed 3 sets of experiments on the MARC-I. The first of which were during the development of the propulsion system. To verify the CFD results, the team tested the thrust output of one of the prototype propellers in a towing tank at the University of Iowa's new fluids facility. Figure 6 shows the results of these tests. The experiments verified our CFD results, actually showing the the CFD results were underperforming.

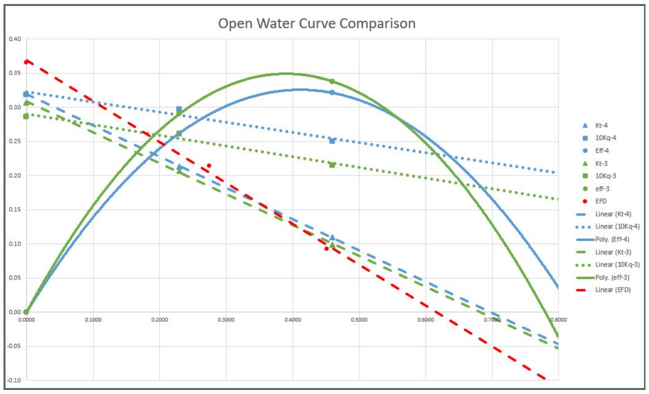


Figure 6: Open water curves for CFD and experimental tests of the propeller prototype. 3 blade (green), 4 blade (blue), 4 blade experimental thrust (red)

The second experiments ran were on the hull. CFD was performed on it to find an angle for the propellers that would minimize pitching when the motors started and stopped. Figure 7 contains some of the results that lead us to choose 20 deg. While 20 deg was not the best (30 deg showed less pitching), it was a good middle ground between minimal pitching and minimal heave due to the upwards force.

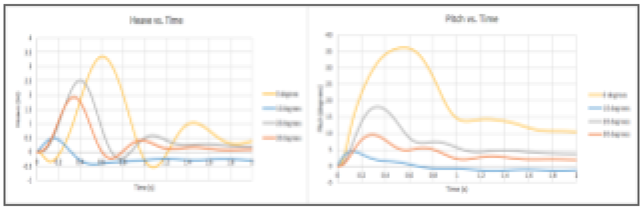


Figure 7: Pitch (left) and Heave (right) for different propeller angles. 20 deg is the grey line.

The final experiments performed were the overall performance of the boat. This includes a simulation written to work with the software framework, as well as physical testing in a nearby lake in Iowa City. The simulation was a simple physics simulator used for figuring out autonomous navigation, and the lake was used to test out manual controls and the wifi antenna's actual range. Future tests involve setting up a course in the same lake using balloons and rope to act as buoys to test out the controls for the speed test.

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Appendix A: Component Specifications

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- Raspberry Pi 3B: https://www.raspberrypi.org/products/raspberry-pi-3-model-b/
- Arduino Mega 2560: https://store.arduino.cc/usa/arduino-mega-2560-rev3
- BrosTrend 1200Mbps Long Range USB WiFi Adapter: https://www.trendtechcn.com/Product.aspx?ProductId=325&TypeId=1
- 2-8S LiPo Battery Checker: https://www.amazon.com/gp/product/B01LQ1HL94/ref=ox_sc_act_title_2?smid=A1VCJ11DLIX7DF&psc=1
- 8mm Silent CPU Fan: https://www.newegg.com/Product/Product.aspx?Item=N82E16835103025
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