UM::Autonomy - John Seana

Noah Ehmann, Edward Fenwick, Mario Galindez, Benjamin Johnson, Charlie Light, Rohan Mallya, Elliot Mueller, Rourke Pattullo, Alex Skillin, Gregory Su, Anthony Uytingco, Zachary Gordon

Abstract

UM::Autonomy's boat, John Seana, is a fully autonomous surface vehicle with a custom catamaran hull. Designed to compete in the 11th AUVSI Foundation RoboBoat competition, John Seana will need to navigate through buoy gates, find a path through a buoy field, select docks based on drone and hydrophone information, and follow a moving flag around a carousel. In designing our boat this year, we primarily focused on simplifying our hardware/software and build a more stable boat so as to reliably complete the autonomous task, speed gates, and docking challenges. This technical design report details the efforts we made to meet these goals and each individual challenge for the 2018 competition.

Figure 1: John Seana

Competition Strategy

Task Priorities

For this year, the team decided to focus primarily on completing the Autonomous Task and Speed Gates challenges reliably. Once these were completed, we planned to shift our focus to autonomously docking based on hydrophone data. Throughout our design cycle, each subteam used these goals to inform their decisions, allowing them to focus on the aspects of the boat that would actually be utilized. This led to an overall simplification of our boat in all subteams and helped us to build stronger fundamentals for this year and future years.

Software

Our team underwent a huge effort this year to simplify our code base, cutting out several years worth of legacy code that had become unmaintainable or unnecessary as the competition changed. This allowed us to focus all of our work in the areas we believe to be crucial to all aspects of the competition: buoy detection, localization, and route planning.

Hulls & Systems

Team boat designs in recent years have had issues with complexity, weight, and instability. Our strategy this year involved designing a hull that would best fit our needs while also reducing weight. We desired a design that was stable, maneuverable, and had adequate deck space for both an electrical box and a drone.

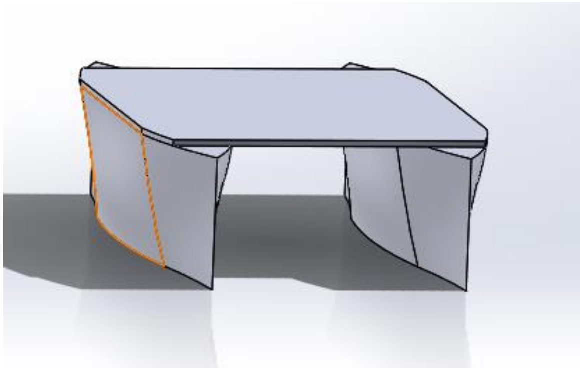

Figure 2: Early CAD model of John Seana

Electrical

Complications on the electrical and hardware side of the team prevented testing in previous years, both during the design process and at competition. Our design choices this year were focused on making a reliable system that was easily accessible and removable.

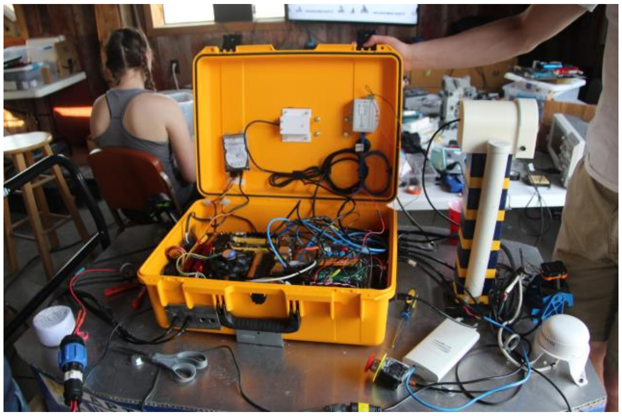

Figure 3: John Seana Electrical Box

Design Creativity

Overview

Our primary focus this year was on simplification and building a fundamentally strong platform for future members to build off of. Because of this, a lot of our effort was put towards simple, scalable projects rather than designing additional complex systems.

Software Simplification

In an effort to streamline our code base, we removed or replaced several outdated third-party libraries. Reducing our dependence on legacy code allowed us to upgrade our operating system to Ubuntu 16.04 LTS, enabling us to take advantage of new simulation software and well-maintained robotics tools.

Localization

In last year's competition, we found our SLAM system unreliable due to its reliance on sparse LiDAR data from nearby buoys. To remedy this, we converted our Simultaneous Localization and Mapping (SLAM) system into a pure localization system using a particle filter to combine the measurements of a GPS and an IMU into a pose in the global reference frame. By eliminating LiDAR and FOG from our SLAM system, we were able to shift our focus to a much simpler problem without having to worry about maintaining a consistent map of the entire world. This will make the code easier to debug this year and simpler to understand for future members of the team.

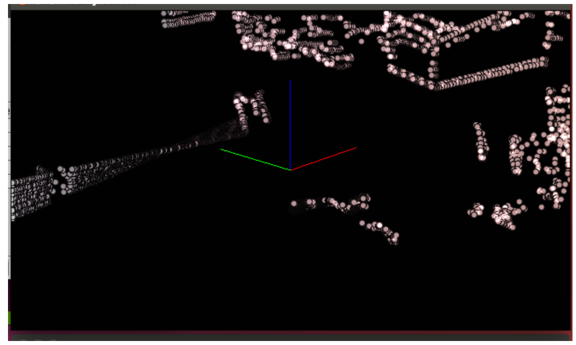

Figure 4: Lidar Point Cloud

The team determined that the mapping capabilities of our prior implementation were excessive; most challenges do not require awareness of every buoy on the course at once. To replace this system, we combined our global pose with our perception stack to find the global position, color, and shape of buoys that we can currently see. Another system allows these buoys to persist briefly in memory after leaving our sight, giving us a more detailed view in dense buoy fields like *Find the Path*. We believe that this new system will lead to less technical complexity throughout the boat while still giving us the necessary information to complete the challenges of the current competition.

Perception

The most computationally expensive area of our boat code is our camera-based buoy detection algorithm. In an effort to reduce this computation time, we group nearby lidar points into clusters and overlay them on our camera images. Our camera buoy detection code only runs on the parts of the image which overlap this clustered lidar data. This also reduces the number of false positives caused by reflections on the water or other background objects. With this algorithm, the boat can reliably find buoys in its field of view and assign colors to them.

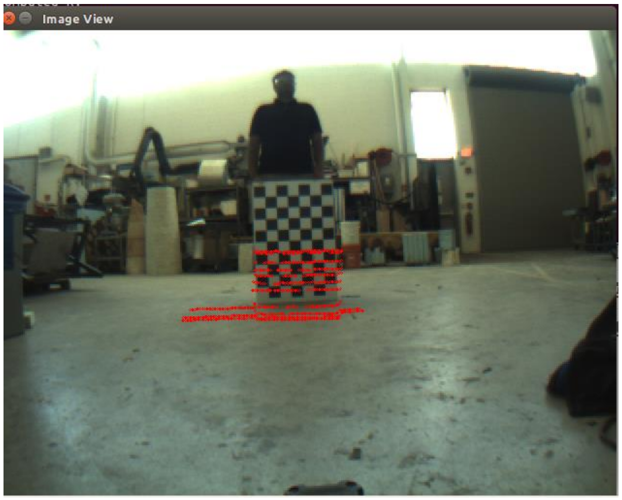

Figure 5: Camera Calibration

Simulation

Previously, we performed simulation at a high level, sufficient for testing route planning and obstacle avoidance. In Fall 2017 we decided to integrate our boat with the Gazebo open-source robotics simulator, allowing full 3D physics simulation of the boat. The primary motive this year was testing the boat's localization methods. Custom Gazebo plugins publish sensor readings for FOG, IMU, and GPS with similar frequencies and noise distributions to the physical sensors used on the boat. Another plugin accepts thruster control messages from the boat's control system and applies the thrust onto the simulated boat. The localization system receives them just as it would data from real sensors, and the difference between calculated pose and the actual pose within the simulation can be directly visualized.

As more sensors are simulated, such as LiDAR and vision, Gazebo should be able to provide a year-round platform on which to test nearly all boat subsystems.

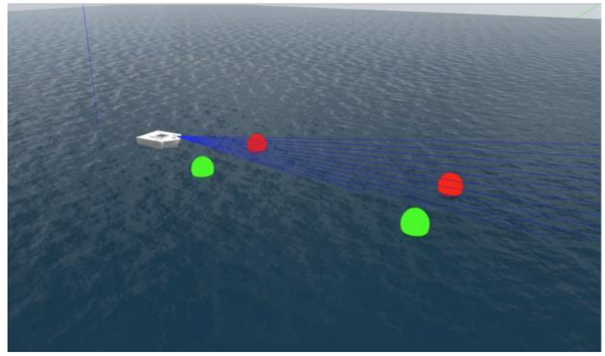

Figure 6: Simulation of Autonomous Task

Hulls & Systems

After reviewing previous designs, we decided that a Catamaran best fit our needs for this year. Its sleek design allows for smooth movement and turns through the water. To alleviate trimming due to boat acceleration, a small sheet of metal was installed parallel to the surface of the water with negligible effects on drag.

In addition, we created new 3D printed housings for our compass and camera. The camera 'bottle' in particular was designed to allow for easier removal and customization of the camera and its lenses.

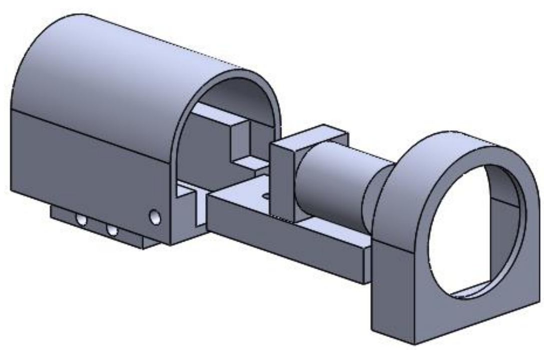

Figure 7: Custom Camera Bottle

Electrical

The previous two boats both used internal, fixed (permanent) electrical boxes embedded within the hulls. These proved to be difficult to work with and led to significant electrical failures. This year, we moved to an external, on-deck Pelican case. This case housed all nonperception sensors and electrical equipment on two layers to reduce box size. In addition, new fabricated waterproof connectors were chosen to reduce possible fail points.

The other major design change was to our power distribution PCB. Our battery does not have built in protection and previous versions of this board had significant flaws and errors. This year's version fixed many of those flaws and introduced protection circuitry for reverse biasing, over-current, and under-voltage. In addition, groundwork was laid for future versions and additional safety protocols.

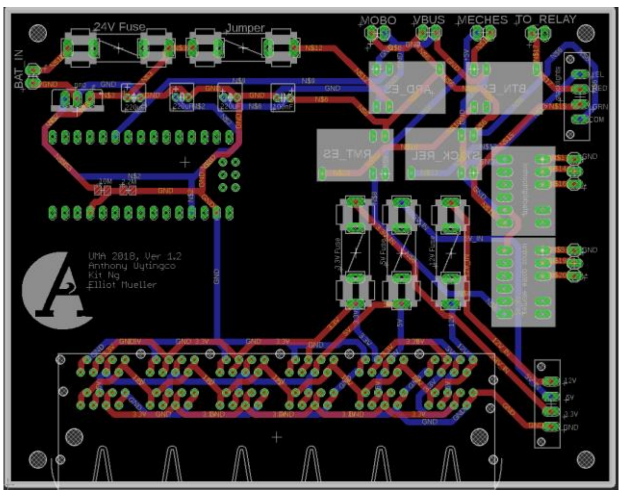

Figure 8: Custom PCB Schematic of Traces

Experimental Results

Testing with Simulation

Since most water near our team is frozen during the school year, weather often limits the amount of time spent testing. To remedy this, we implemented a simulator which would allow us to test the competition logic, PID, and localization systems of our boat without needing to put the boat in the water. This was immensely helpful in allowing our team to make progress during the winter where we would normally have nothing but data logs to test with.

As an example, the first iteration of our SLAM algorithm was tested exclusively on real boat logs. This made it very difficult to objectively prove that our localization was accurate because we could never accurately measure the difference between the boat's true position and the position estimated by SLAM. Using the simulator, we have been able to rigorously test various parts of our algorithm, including the transformation of the IMU into global coordinates, the double integration of the IMU, and the particle filtering algorithm used to combine the IMU data with the GPS. This has allowed us to get objective data on how well our overall system is approximating true position based on noisy sensor data.

Testing Plans

Coming into competition, the team has a functional perception stack, localization system, and route planning system. Given these building blocks, we hope to spend most of our time at competition testing and redesigning the challenge logic that we had tested last year within a simulation. We are capable of doing this testing in our new simulator, but our primary goal is to get as much practice time as possible on the actual competition courses.

Our first order of business upon arriving at competition is to test and tune our new PID system to ensure that the boat will reliably be able to drive straight. We'll then run some basic tests on our waypoint system to confirm that the boat's navigation systems are still working correctly. After these two systems have been tuned, we will be prepared to start doing mock competition runs, focusing first on the autonomous task and speed gates. When we get these challenges to a point where we can complete them reliably within the same run, we will shift our focus to autonomously docking based on our hydrophone algorithm. If we complete all of these tasks, the remainder of our time will be dedicated to tuning these challenges even further and potentially attempting the Find the Path challenge.

Acknowledgments

Every year our success is dependent on the generous support of our sponsors and University resources. First and foremost our thanks to the University of Michigan, the Wilson Student Team Project Center and the College of Engineering for providing facilities, testing ground and equipment for our day-to-day operations. Without their backing, our participation and development would not be possible. Similarly, we would like to thank Professor David Singer for his help in the design of our hull and his continued departmental sponsorship of the team. In addition to our academic resources we have made huge strides this year thanks to the continued backing of corporate sponsors. Ford, Aptiv/Delphi, Raytheon have all provided technical, financial and professional development support to the team and our members. A special thanks to Boeing for their extremely generous contribution to the team and their technical guidance with the development of the boat. We also wish to express our continued appreciation towards PNI and Sparton for our compass and IMU. Lastly, we would like to thank the Fein family for housing the team during our end of year testing, this being the fifth year. Without all of the contributions of time and resources from our sponsors and mentors, our project would not be possible.

Figures 9: Team Sponsors on the port (top) and starboard (bottom) sides of John Seana

Appendix A: Component Specifications

Note: Legacy refers to an item being used across multiple years previous to 2018

Component	**Vendor**	**Model/Type**	**Specs**	**Cost (if new)**
Hull form/platform	Custom	Catamaran	Fiberglass	-
Waterproof connectors	AliExpress	Generic Waterproof	8-pin, pre-constructed	$20, 15 total
Propulsion	SeaBotix	BTD150	24 V, 4.25 A	Legacy
Power System	Pulse Battery	LiPo Battery	16 Ah, 6s, 15C	Legacy
Motor Controls	Vex Pro	Talon SRX	24V, PWM	Legacy
Motherboard	ASRock	Z97 OC Formula	8 USB, 32GB ram, SATA	Legacy
CPU	Intel	i7-4770	3.4 GHz, 4 Cores	Legacy
IMU	Sparton	AHRS-8	16g, 5V, 1.0º RMS	Sponsor Gift
LiDAR	Hokuyo	UTM-30LX/LN	12V, 30 m, 2D	Legacy
Camera	Point Grey	Firefly MV Color	1.3 MP, 23FPS	Legacy
Hydrophone (s)	Aquarian	H2a	-180 dB, 10-100 kHz	Legacy
GPS	Garmin	19x HVS	<3 meter, 0.1 knot RMS	Legacy
FOG	KVH	DSP-3000	375º/s, 100hz	Legacy
Compass	PNI	Prime Module	3-axis, 1.0º RMS	Legacy
Team Size	-	-	32 Members	Priceless
Expertise Ratio (hardware v. Software)	AI team 18 members	Business 5 members	Electrical 9 members	H&S 4 members
Testing Time: Simulation	>120 Hours (January - Present)	-	-	-
Testing Time: in-water	~4 Hours (Hull testing)	~10 Hours (Mock Comp, w/Software)	-	-
Programming Languages	C++ C Python Java	-	-	-