NaviGator AMS

***Abstract*—NaviGator ASV is a fully autonomous surface vehicle (ASV) built to compete in the Association for Unmanned Vehicle Systems International (AUVSI) Foundation's 2016 Maritime RobotX Challenge in Oahu, Hawaii. The NaviGator ASV is part of a larger group of collaborative autonomous aerial, surface, and subsurface vehicles known as the NaviGator Autonomous Maritime System (AMS). This paper describes the NaviGator ASV's structural design, propulsion, power system, electrical design, software infrastructure, outreach efforts, and approach to completing the challenges presented in the 2016 Maritime RobotX Challenge.**

I. Introduction

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II. Vehicle Design

This section of the paper will describe the hardware and software that was developed for this competition, as well as the motivations behind these choices. This will include descriptions of early iterations of hardware and software that may have failed, what was learned in that process, and how that knowledge was integrated to improve on the designs.

A. Mechanical Subsystems

The mechanical platform used for the NaviGator ASV is a modified WAM-V research vessel developed by Marine Advanced Research. Several of the mechanical modifications that the team has made will be detailed in this section. A computer-aided design (CAD) render of the NaviGator ASV is shown in Fig 1.

1) Propulsion: NaviGator ASV's propulsion system began as two forward-facing stern thrusters, providing the ASV with a skid-steer configuration. After a short time of testing, it became apparent that adding more thrusters and mounting them at an angle would simplify the vectoring of the thrust to achieve a desired motion, as well as adding the capability of lateral motion. The current configuration features two bow and two stern thrusters oriented at a fixed 45 degrees. This is a thruster configuration that the team used in the 2013 RoboBoat Competition with much success, earning first place. In addition to improved maneuverability, using four thrusters provides redundancy in the system, allowing the ASV to still have maneuverability even if either both bow thrusters or both stern thrusters fail. This feature was invaluable when a motor driver died minutes before a qualification run in the 2013 RoboBoat Competition. With a quick modification to the thruster mapper program, the ASV was able to operate with just three thrusters, saving the run. Moreover, during the 2016 RobotX Maritime Challenge, NaviGator was able to repeatedly and successfully station keep and maneuver the course despite rough currents and winds. The major disadvantage of this configuration is that the fixed angles of the thrusters means that it is not particularly efficient moving in any direction. However, as was demonstrated in 2016, for the tasks that the Navigator ASV is designed to perform, maneuverability is significantly more important than efficiency.

Mounting the thrusters posed many challenges and required several design iterations, especially for the bow thrusters. For the ASV to be deployed from a trailer, the bow thrusters had to be either removed or raised during deployment so they would not collide with the trailer structure. The transom clamps on the trolling motors accommodated this function. 3D printed polycarbonate clamping blocks that interfaced with the clamps on the trolling motors kept them fixed in place. While the mounts held the motors securely, the 3D printed parts began to crack and eventually failed. To solve this issue, the clamping blocks were machined from aluminum.

2) Sensor Mast: The need for a stable sensor platform is paramount in machine vision applications. The preliminary design utilized an 80/20 aluminum rail truss, which did not provide the required stiffness and resulted in smearing of the vessel's detection data. The initial sensor platform also did not raise the LIDAR system high enough to permit detection of obstacles in immediate proximity to the pontoons, a problem rectified in the final design.

As previously mentioned, the cameras, LIDAR, and GPS antenna require a rigid support. The need for an unobstructed GPS antenna guided the design towards a mast structure. For transport to the competition site, the assembly had to fit within the prescribed envelope of a Pelican Products transport case, requiring a modular assembly process. These target specifications led to a base-and-tree assembly, where the mast is simply welded to a plate that then fastens to the payload tray via a superstructure. For corrosion resistance and manufacturability, 6063 aluminum was chosen. To simplify the assembly process, fastener types were standardized. The mast is centered laterally on the ASV, which helps create a well-defined coordinate system that permits simpler software transformations. The sensor mast can be seen in Fig 2.

3) Electronics Box: NaviGator ASV's electronics are housed in a Thule Sidekick cargo box. The team originally considered commercial waterproof boxes, but began looking for other options due to their high costs. One student suggested the idea of using a cargo box after being inspired by family road trips they had taken when they were younger. While traditionally used to mount on the top of cars to provide additional storage, the cargo box was an ideal electronics enclosure due to its watertight integrity, aerodynamic form factor, low cost, and a side-opening mechanism that makes it very easy to access all of the electronic components. The box's watertight integrity prevented the team from using air circulation for cooling. Instead, a combination of techniques are used to cool the box. First, an adhesive reflective covering was applied to the lid of the box to reflect heat generated by solar radiation. Second, the box has an active water cooling system that is used to remove the heat generated from the electronic components inside the box. Fiberglass inserts were used to mount all of the components inside of the box. These inserts add rigidity to the relatively flimsy box and make it easy to add or remove components from the box. The components that need to be frequently removed, e.g., the hard drives, are attached to the fiberglass with Velcro. The rest of the components are attached with traditional fasteners.

4) Racquetball Launcher: A system for delivering the racquetballs into the target for the Detect and Deliver task was developed by breaking the challenge into subtasks that were solved independently. The two main subtasks that were considered were moving the balls into the target and feeding the balls to the mover. Several ideas for moving the balls were considered, ranging from a catapult to a robotic arm that would drop the balls into the target. Prototypes of several designs were built and tested. One design featured two counter-rotating wheels attached to the trolling motors that were once part of PropaGator 1, the team's submission to the 2013 RoboBoat Competition. The trolling motors were originally used as part of an early prototype, but since they were already waterproof, were effective at launching the balls consistently, and were readily available, the trolling motors were incorporated into the final design. The ball launching mechanism was designed so that any type of ball feeder could be integrated into it. This allowed the team to test multiple types of ball feeder mechanisms, including a carousel and a linear actuator. A prototype of the linear actuator racquetball launcher can be seen in Fig 3. After the carousel mechanism was found to be prone to jamming, the linear actuator design was selected. Additional design criteria that were considered were the ease of loading balls and how quickly all four balls could be launched. Ball loading was addressed by designing a spring-loaded 3D printed ball magazine that is easily detachable. To achieve rapid-fire, the team developed a closed-bolt system. After a ball is loaded into the chamber, it is withheld at the minimum distance from the wheels to reduce the amount of time it takes to fire. In order to prevent premature firing, a retention lip is used.

5) Ring Challenge System:

B. Electrical System

Robustness and simplicity were the primary motivating factors behind the design of the NaviGator ASV's electrical system. The team focused on these aspects in order to get a testable system built quickly and minimize any downtime due to electrical failure.

1) Power System: The salient features of the power system are the dual battery power supply and the power merge board. The NaviGator ASV's power requirements surpassed those of

2) Power merge board: The power merge board is a student-designed printed circuit board assembly (PCBA). It uses two Texas Instruments LM5050 High Side OR-ing FET controllers as ideal diode rectifiers to balance and parallel the two batteries into one rail that supplies four output ports. This makes the system more fault tolerant to a failing battery, a feature used in normal operation to switch batteries out without turning the system off. One of the strengths of MIL is the ability to design hardware and software that can be reused on other projects and vehicles. This is the third vehicle for which this board design has been utilized. The design was originally created for PropaGator 1 and then used on PropaGator 2, both of which have competed in the RoboBoat Competition.

3) Passive sonar:

4) Kill system: The hardware kill system consists of two student-designed PCBAs and four off-the-shelf twist to detent kill switches. The kill system for the vehicle also has a software component. The kill board monitors the status of six kill sources. When any of the six sources request a kill, the kill board cuts power to the thruster motor controllers. The six kill sources are the four off-the-shelf switches that are mounted around the vehicle, a remote kill switch, and the computer. The remote kill switch operates over a 900 MHz radio link and displays the hardware kill status of the vehicle. The kill board is also used to control the NaviGator ASV's indicator lights and a siren used to ward off curious watercraft during testing.

C. Software System

1) Object Detection and Classification: The lowest level perception service available on the NaviGator ASV is the Occupancy Grid Server. Occupancy grids are a twodimensional grid-like representation of the environment generated by the sensor suite available on the ASV. The generated map contains both the occupied and unoccupied regions in the environment. This information is provided to the server via any range-detecting sensor onboard. On the ASV, the primary range-detecting sensor is a Velodyne VLP16 LIDAR. A LIDAR uses lasers to provide relatively dense range information of the environment. This information is then segmented by regions containing dense clusters of relatively close points. These bounding regions are treated as obstacles, and are placed in the occupancy grid. This information is then provided to higher level services such as the motion planner and Classification Server. In the Classification Server, the points generated by the LIDAR are clustered into regions on the occupancy grid where it decides which of these distinct regions are objects. The ASV then looks at the bounding box of this object and classifies the object based on the dimensions of its bounding box. The software detects if the object has a prominent plane. If it does, then this information is attached to the object. These objects are then accessible to other programs through the use of a list of detected objects.

2) Motion Planning:

3) Motion Control:

4) Navigation and Odometry: The NaviGator ASV uses a student-developed Sylphase global positioning system (GPS) and inertial navigation system (INS) that is in the process of being commercialized by Forrest Voight, a UF student and member of Team NaviGator AMS. It primarily consists of a circuit board with a Spartan-6 field programmable gate array (FPGA), radio frequency (RF) frontend, inertial measurement unit (IMU), magnetometer, and a barometer. The FPGA performs the correlation operations that enable tracking of GPS satellites. All the sensor measurements and correlations are passed to a computer via USB, into a pipeline of software modules that track and decode the signals from the GPS satellites and then fuse measurements using an extended Kalman filter into an estimate of the ASV's pose in both absolute world and relative odometry coordinate frames. Last, the resulting odometry is transformed so that it describes the ASV's coordinate frame and it is then passed to ROS. By using the sensors to aid the GPS solution and taking advantage of GPS carrier phase measurements, extremely precise relative odometry is possible, with noise on the order of centimeters over periods of seconds to minutes. This is the result of years of work, during which several iterations of the hardware were produced. The initial version of the hardware was a Beaglebone cape, but quickly moved to the USB/FPGA approach for ease of development and reduced CPU load. The current revision of the hardware is shown in Fig 9.

5) State Machine:

III. Design Strategy

A. Find Totems and Avoid Obstacles

B. Identify Symbols and Dock

C. Scan The Code

IV. Experimental Results

A. Simulator

B. Field Testing

In addition to testing in the simulator, NaviGator ASV underwent significant lake testing. Over 130 hours of in-water testing were carried out in the form of day-long tests in the months leading up to the competition at a lake near UF. Lake testing offered real-life environmental factors that simulation cannot accurately provide, such as wind and current disturbances, various lighting conditions, and inclement weather. Field testing also offered a chance to test the mechanical systems of the ASV, such as actuators like the racquetball launcher, the strength of team-manufactured components, and the efficiency of the computer cooling system. The frequency and duration of testing helped to expose hardware failures that may have gone unnoticed until the competition. For example, the original sensor mast placed the Ubiquiti omnidirectional Wi-Fi antenna less than two inches away from the Velodyne LIDAR. During field testing, the team found that the LIDAR was returning noisy data. However, when testing in the lab, the LIDAR data looked fine. Eventually the team determined that the only difference was that a wired connection was used to connect to the ASV while working in the lab, as opposed to the Wi-Fi connection that was used while field testing. It turns out that the Wi-Fi signal from the antenna was adding noise to the LIDAR data. Moving the Wi-Fi antenna further from the LIDAR solved the problem. This kind of issue would never have arisen during simulation. The detection of this and other flaws during testing prevented what would have been catastrophic failures during the competition. C. Field Element Construction In order to take full advantage of the realistic testing environment that the lake provides, field elements similar to those that will be used in the competition were constructed. The field elements were designed to be simple in construction and easy to deploy. Many of the elements were made of a PVC pipe frame that allowed for modular construction and easy assembly and disassembly. Buoyancy was provided by foam sheets and pool noodles fitted around the PVC pipes. The simplicity and light weight of the course elements allowed for quick and easy setup and teardown of the course using only a few team members in a kayak. As an example, the Identify Symbols and Dock platform that the team constructed and used for testing can be seen in Fig 13.

V. Acknowledgement

VI. References