# PropaGator 2014: UF Autonomous Surface Vehicle

Daniel Frank, Andrew Gray, Dr. Eric Schwartz

Machine Intelligence Lab (MIL),

University of Florida, U.S.A

email: dzf209@gmail.com,

andygrayia@gmail.com,

and ems@mil.ufl.edu.

***Abstract*—PropaGator is a fully autonomous surface vehicle built to participate in the Association for Unmanned Vehicle Systems International Foundation's 2014 RoboBoat Competition. This year's event will be held in Virginia Beach, Virginia. This paper describes the hull design, propulsion design, electrical design, software infrastructure, and PropaGator's approach to completing the challenges presented in the RoboBoat 2014 competition.**

***Index Terms*—Autonomous Surface Vehicle, Azimuth Thruster, Hubless Propeller, Kort Nozzle, Robot Operating System**


Figure 1. CAD render of PropaGator 2

## I. Introduction

PropaGator is an autonomous surface vehicle (ASV) designed and built by students in the Machine Intelligence Lab (MIL) at the University of Florida. This is the second year that the University of Florida will participate in the Association for Unmanned Vehicle Systems International (AUVSI) Foundation's surface vehicle competition. Last year the team had an exciting rookie season where PropaGator took first place in the 2013 RoboBoat Competition. This year the PropaGator team is back and ready to compete with an entirely new ASV, PropaGator 2, shown in Fig. 1. The PropaGator team is comprised of undergraduate and graduate students from the departments of Electrical and Computer Engineering, Mechanical and Aerospace Engineering, and Computer and Information Science and Engineering.

## II. Mechanical

Last year, the team's strategy was to build a mechanical platform as quickly as possible so that the team could focus on developing software. While PropaGator 1 was a seaworthy platform and performed well at the competition, there were certainly areas for improvement. One of the major flaws with the design of PropaGator 1 was its weight. With the quadcopter and landing pad mounted onto the top of PropaGator 1, the ASV was very close to being penalized for being too heavy. Without these components, the ASV would not be penalized for its weight. The biggest contributors to the weight were the commercial pontoons and aluminum superstructure that acted as the exoskeleton [1].

The second biggest area for improvement was the ASV's overall speed. PropaGator 1 featured a displacement type hull, thus its theoretical maximum velocity is determined by its hull speed. At hull speed, the ASV becomes trapped behind its own bow wave and is no longer able to increase its velocity. Hull speed can be estimated using the following formula [2],

$$v_{hull} \approx 1.34\sqrt{L_{wl}}, \quad (1)$$

where $v_{hull}$ is the hull speed measured in $kts$ and $L_{wl}$ is the length of the waterline measured in $ft$. Using this formula, the maximum top speed of PropaGator 1 was predicted to be 3.14 $kts$. The goal of this year's mechanical team was to design and build a boat hull from scratch that weighed less than 100 $lbs$ and could travel at a velocity of 10 $kts$.

### A. Hydrofoil Research

As shown in Equation 1, the maximum speed for displacement vessels is dictated by a single geometric parameter, the length of the water line. Since the competition imposes a constraint of a maximum ASV length of 6 $ft$, the team decided to design a displacement hull that featured hydrofoils. Like an aircraft wing, hydrofoils produce lift as the ASV moves through the water. By raising the ASV out of the water, the ASV is allowed to ride over its bow wave and reach velocities greater than those determined by the hull speed. The hydrofoils were designed using an Eppler 817 hydrofoil cross section [3], and an image of the foil shape can be seen in Fig 2.

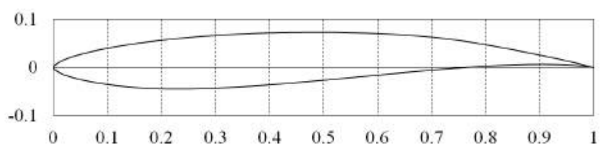


Figure 2. Eppler 817 cross section used for the hydrofoil design

This cross section was chosen for its minimal disposition towards cavitation and its ease of manufacturing. The foil was cut using a 4-axis CNC mill and tested for its lift and drag characteristics in a wind tunnel shown in Fig. 3.

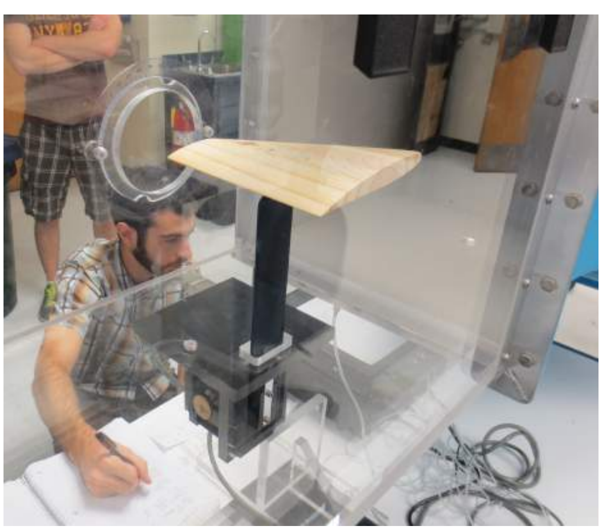

Figure 3. Hydrofoil mounted in the wind tunnel for testing

The goal of the test was to determine the angle of attack that produced the greatest lift-to-drag ratio as well as the maximum lift force that the hydrofoil could generate while moving in the water at 10 $kts$. The air in the wind tunnel had a Mach number of approximately .2, therefore no significant effects due to compressibility were present. Water, under the ASV's normal operating conditions, may also be assumed to be incompressible. Since both fluids were incompressible and the Reynolds number of the ASV's top speed was matched with the wind tunnel's Reynolds number, the data collected in the test estimated that one hydrofoil, with an angle of attack of 5°, can produce 25.62 $lbf$ of lift when the ASV is traveling at 10 $kts$ with a lift-to-drag ratio of 6.55. This would allow a 100 $lbs$ ASV to completely lift out of the water when moving with a velocity of 10 $kts$.

After the wind tunnel results were analyzed, a wooden prototype hull with hydrofoils was constructed as shown in Fig. 4. Two fixed 80 $lbf$ thrust trolling motors were installed onto the prototype and a number of speed tests were conducted in order to determine its maximum velocity. The prototype was able to achieve a speed of 6 $kts$, nearly twice as fast as it would have been able to move if it didn't have hydrofoils. However, it was not able to generate enough lift to completely rise out of the water. Lift can be calculated with the following equation [4],

$$F_l = \frac{1}{2} d v^2 A C_l, \tag{2}$$

where $F_l$ is the lift force in $lbf$, $d$ is the density of water in $\frac{lbm}{ft^3}$, $v$ is the velocity of the ASV in $\frac{ft}{s}$, $A$ is the reference area of the hydrofoil in $ft^2$, and $C_l$ is the dimensionless coefficient of lift.

The reason why the prototype was unable to completely lift out of the water was due to drag. In order to quantify how much drag the prototype was subjected to, it was towed fifteen feet off the port side of a larger boat. A load cell was used to measure the drag force acting on the prototype at a variety of velocities. Additionally, flow simulations were conducted in SolidWorks as another way to estimate the drag force. The results of both the empirical testing as well as the SolidWorks simulations can be seen in Fig. 5. In general, the SolidWorks simulations coincided well with the measured values of drag obtained in the drag test. Part of the reason

Figure 4. Underside of the wooden prototype hull featuring hydrofoils

that the SolidWorks values are higher than the empirical data is that SolidWorks did not factor in the reduced drag on the hull as the prototype was lifted out of the water. Even so, SolidWorks allowed for the team to get conservative estimates on drag and lift while working on the hull's final design.

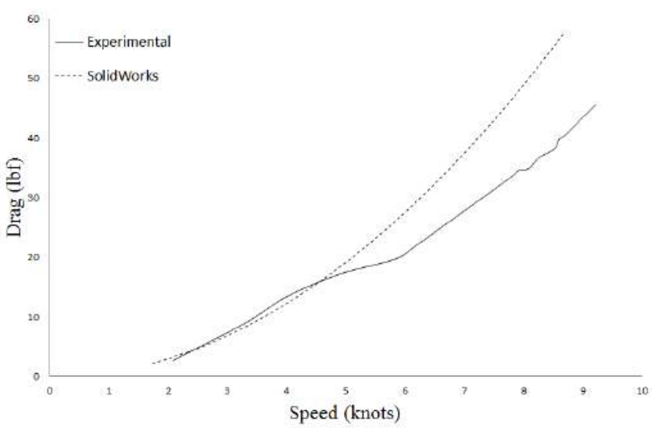


Figure 5. Drag test and simulation results

While the hydrofoils did help lift the prototype out of the water, causing a reduction of drag due to less wetted surface area, the largest contributors of drag came from the motors themselves. Drag may be calculated with the following equation,

$$F_d = \frac{1}{2} d v^2 A C_d, \tag{3}$$

where $F_d$ is the force due the drag in $lbf$, $C_d$ is the dimensionless coefficient of drag, and $d$, $v$, and $A$ have the same meanings and units as Equation 2. Since drag is a function of $v^2$, as the prototype increased its velocity, the drag caused by the motors increased with the velocity by a power of two. The decrease in drag caused by the lifting of the prototype was not able to offset the additional drag caused by the motors, thus the overall drag of the prototype is always increasing with velocity. At a certain point the available thrust produced by the motors became less than the total drag. Therefore the prototype was no longer able to accelerate and gain velocity.

### *B. Hull Design*

After proving that the prototype would never be able to achieve 10 $kts$, a new hull was designed. The upper half of the hull was modeled after the M80 Stiletto shown in Fig. 6. The flat planes that make up the majority of the features on the top half of the ASV are aesthetically pleasing while also being easy to manufacture. The research performed on the prototype with hydrofoils helped motivate many of the design choices used on the submerged portions of the hull. As shown in Equation 1, the length of the waterline constrains the maximum speed a displacement style hull can achieve. However, the maximum velocity of a planing hull does not depend on its length. The maximum speed of a planing vessel can be predicted using Crouch's formula,

$$v_p = \frac{C}{\sqrt{\frac{D}{SHP}}}, \tag{4}$$

where $v_p$ is the maximum planing velocity of the boat measured in $kts$, $C$ is a constant based on the hull form of the vessel, $D$ is the amount of water the vessel displaces in $lbs$, and $SHP$ is the shaft horsepower at the propeller. The displacement term is another justification on keeping the weight of the ASV to a minimum. To achieve this, plugs for the ASV's hull were cut out of EPS foam using a CNC mill. The plugs were then conditioned so that a fiberglass female mold could be created. Once the molds were finished, the ASV was constructed out of fiberglass. By using fiberglass the ASV can have structural strength while still being light.

A catamaran design was chosen over a monohull for several reasons. First, catamarans offer more stability in the roll direction than a traditional monohull. Second, catamarans are also able to displace the same amount of water with a shallower draft compared to a comparable monohull allowing the

Figure 6. U.S. Navy's M80 Stiletto

ASV to navigate shallow waters safely. Finally, catamarans also typically have the advantage of providing less resistance in the water than a comparably sized monohull [5]. The shallow deadrise helps provide a smooth ride to reduce noise for the onboard sensors while still providing a large planing surface to generate lift [6]. Hard chines were added to the side of the hull to give the ASV better forward tracking. The upper style chines also help redirect the water from riding up the side of the ASV which results in a reduction of drag. The V-shape front of the pontoons are designed to help break waves in choppy waters. Once the water is separated, the pontoons have a constant cross section until the stern of the ASV ends with a hard transom. The hard transom allows the water to separate from the ASV at a known point and helps to prevent issues with flow separation.

### *C. Azimuth Steering System*

PropaGator 1 featured four trolling motors that were rotated at set angles of 30° from forward, allowing the ASV three degrees of freedom; translation in two directions and heading. While this configuration can achieve instantaneous motion in any direction, the ASV loses efficiency since all motions are a result of four thrust vectors with components in opposition. Since the ASV primarily moves forward, it makes sense to design the forward direction to be the most efficient direction for the ASV. By utilizing two azimuth thrusters, PropaGator 2 is still able to achieve the same mobility as PropaGator 1's four trolling motors. An azimuth thruster is simply a marine propeller than can be rotated about the vertical axis to assist in steering. By going from four motors to just two steerable motors, the drag caused by the motors was reduced. Additionally, by using steerable motors, PropaGator 2 is more efficient than its predecessor, especially when moving forward and backwards.

### *D. Propulsion System*

The drag test experiments verified that the large trolling motors were the largest contributors towards drag at high speeds. As a result, the team decided to design and manufacture their own propulsion system with no submerged motors as shown in Fig. 7. The goal was to minimize drag by shrinking the water footprint of the propulsion system. Rather than having the motors in the water like the motor pods developed by Hsieh et al. [7] or standard trolling motors, the motors are located inside of the hull. The power is transmitted from the motor to the propeller through a timing belt that is attached to the output shaft of the motor and the rim of the propeller. This rim-driven transmission eliminated any drag caused by the hub of a propeller and is discussed in more detail in section II-D2.

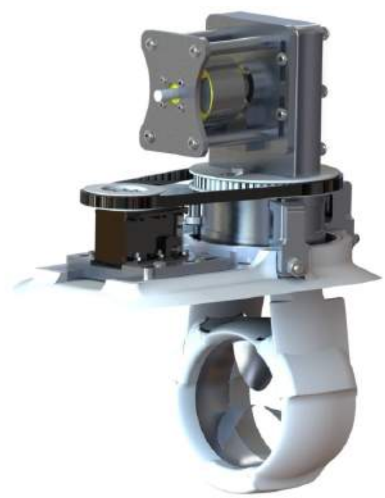

Figure 7. Assembly of PropaGator 2's propulsion system

*1) Kort Nozzle:* The RoboBoat competition requires all propellers to be shrouded for safety reasons. Last year the team used a plastic net to cover the propellers. This met the requirements of the competition, but it also created additional drag. By designing a propeller that is enclosed by a duct, also known as a Kort nozzle, the team was able to create a duct that helps generate high thrust at low speeds [8] while still producing minimal drag when moving through the water. Ducted-propellers can also help increase fuel efficiency by allowing the ASV to run the propellers at a lower RPM while still maintaining the same velocity as an equivalent ASV with free-propellers. Finally, the ducts prevent prop walk, a phenomena where the stern of the boat tends to strafe in the direction of the propeller's rotation. Typically twin-screw vessels, boats with a propeller on the starboard and port side, will have two different shaped propellers; one that rotates clockwise to achieve forward motion and one that does so by spinning counter-clockwise. This balances out the forces that cause prop walk. However, by using the ducted-propellers, only one type of propeller needs to be manufactured which allows for easier replacement if one breaks.

*2) Propeller Design:* The motivation behind the development of the propulsion system was to reduce drag as much as possible. During simulations and testing, it was determined that the hub in a ducted propeller serves two purposes; provides strength to the blade roots and provides an attachment point for the motor. Consequentially, the hub does not produce any thrust, but it does produce drag. By going to a rim-driven design, the hub's only remaining purpose was to provide strength to the blades. Unfortunately, the hub only offers strength to the root of the propeller, which in general, experiences loads that are much lower than those experienced by the tips [9]. By inverting the propeller into a hubless configuration as shown in Fig. 8, the moment arm acting on the propeller tips is reduced, causing an overall reduction of bending moment on the rim-driven propeller compared to an equivalent standard hub-driven one. By eliminating the hub, the drag that it produces is eliminated. The hubless propeller also has the advantage of being resistant to propeller fouling due to debris [10].

The propeller blades themselves were designed using Crouch's Method [11]. First, the maximum planing speed of the ASV was calculated using Equation 4. Then the required pitch to obtain that speed can be found using,

$$p = \frac{1215.22 \cdot v_p}{.9 \cdot RPM}, \tag{5}$$

where $p$ is the pitch of the propeller measured in $in$, $RPM$ is the maximum rotations per minute the motor is capable of spinning, and $v_p$ is calculated in Equation 4. The pitch is the theoretical distance that the propeller should move forward with one rotation, like a screw turning through wood. In practice, the propeller never moves as far forward as the pitch would suggest since the water slips around the propeller as it is spinning. The difference between how far the propeller should move in the water and how far that it actually moves is known as apparent slip. In order to accommodate for the presence of slip, the pitch must be made larger by multiplying it by an empirically determined correction factor.

Figure 8. Hubless propeller designed and manufactured for this project

After the pitch had been determined, the diameter of the propeller was calculated. Ideally, since the goal is to reduce the drag caused by the propeller assembly, it would be best to make the propeller as small as possible. While a very small propeller could provide adequate thrust at high speeds, it may not be able to provide enough thrust at lower speeds to reach the planing state or to effectively maneuver. To determine the minimum diameter the following equation was used,

$$D_{min} = 4.07 \cdot \sqrt{BWL \cdot H_d}, \tag{6}$$

where $D_{min}$ is the minimum required diameter to provide useful thrust at all speeds measured in $in$, $BWL$ is the beam on the waterline measured in $ft$, and $H_d$ is the draft of the hull measured in $ft$. Since PropaGator 2 is designed to be a twin-screw vessel, $D_{min}$ must also be made smaller by being multiplied by an empirically determined correction factor.

Typically propellers with two blades are more efficient than ones with more blades. However, in order to get the blade area required for effective thrust, they require a large diameter. Since the goal was to minimize the diameter of the propeller as much as possible, a three-bladed propeller was designed. The extra blade allows for additional blade area without increasing the propeller's overall diameter. Other common propeller parameters are rake and skew, but after researching the effects of rake and skew and what they are used for, the team decided that their inclusion in the propeller design did not offer any advantage to the application of PropaGator 2.

Once all of the propeller parameters were determined, shown in Table I, the team generated a CAD model of the propeller and then cut it out on a 4-axis CNC mill. The propellers were cut out of blocks of Delrin for its resistance to moisture, long-term fatigue endurance, and high strength and rigidity.

Table I
PROPELLER PARAMETERS

| Parameter | Value |
|---|---|
| Number of blades | 3 |
| Diameter | 3.5 $in$ |
| Pitch | 7 $in$ |
| Rake | 0° |
| Skew | 0° |
| Cross section shape | NACA 66-006 |
| Developed blade area | $1.20in^2$ |

### E. Waterproof Quadcopter

For the obstacle buoy navigation challenge, the team intends to launch a quadcopter off the back of the ASV. The quadcopter will be able to get a bird's-eye-view of obstacle locations so that it can plan the most efficient trajectory for the ASV. Last fall the team had success autonomously launching and recovering a quadcopter off of PropaGator 1 [12], and a similar system was designed for the new platform. The quadcopter uses a custom-designed HUGO waterproof frame made by Aerotestra shown in Fig. 9. Its downward facing camera has its video processed by an ARM ODROID board installed with Linux Ubuntu and the Robot Operating System (ROS). Stabilization of the vehicle is handled by an ArduPilot-Mega 2.5 and communication between the quadcopter and the ASV is handled with XBee RF devices.

Figure 9. HUGO, a waterproof quadcopter used by PropaGator 2

## III. ELECTRICAL

During workups toward the 2013 competition, PropaGator 1 suffered from numerous electrical and hardware issues. PropaGator 1's student made motor controllers suffered from H-bridge shoot-through faults destroying several boards. A non-isolated electrical system caused power brown outs when sensors were connected or removed. Also, wireless communications between the shore and the PropaGator 1 were limited to 40 feet due to the positioning of the wireless router antennas. After last year's competition, emphasis was placed on creating a more reliable electrical system and communication network.

### A. Power Plant

PropaGator 2 utilizes four lithium polymer eight-cell batteries for an operating voltage of 33.6 $V$. Each battery has a rating of 6000 $mAh$ for a combined rating of 24000 $mAh$. The batteries are able to power the ASV for approximately 3 hours. Power from the batteries is passed through a merge board which prevents fresh batteries from charging dead batteries. All electrical components are fed from the 33.6 $V$ supplied by the merge board. To power the brushless motors, 8000 $W$ electronic speed controllers are utilized. PropaGator 2's main computer is powered by a 220 $W$ supply. Any sensors not powered by USB from the computer are fed with 12 $V$ supplied by high efficiency switching regulators.

## B. Computer and Communications

To ensure that the ASV had enough processing power, an Intel I7 processor was selected for PropaGator 2. The operating system was installed onto a solid state drive ensuring a rapid computer startup. Last year, PropaGator 1 was able to fill an entire 256 $GB$ hard drive with logging data in approximately one hour of run time. PropaGator 2 will be outfitted with a 2 $TB$ hard drive which will allow up to eight hours of data logging.

During the 2013 competition, wireless communications with the PropaGator 1 were very unreliable. Communication bandwidth was low and the range was poor. Learning from the headaches caused by poor communications, PropaGator 2 has been outfitted with a new wireless system. Utilizing two wireless routers in bridge mode, the ASV is able to have a wireless data rate in excess of 1000 $Mbit/s$. Newer, more powerful routers, utilizing a less congested frequency spectrum (5 $GHz$) provide the ASV with a more reliable communication medium. When the ASV is not in autonomous mode, it will be remotely controlled using a student designed wireless controller. The controller communicates with the ASV via 900 $MHz$ transceivers.

# IV. Sensors and Actuators

## A. LIDAR

A SICK LMS111 LIDAR is mounted to the front of the ASV. The LIDAR has a planar sweep of 270°. The laser operates at 50 $Hz$ providing a range for every 0.5° of the sweep. The attached servo tilts the LIDAR up and down at approximately 0.5 $Hz$. Combining the tilting motion with the laser scan, the ASV is able to visualize its environment in three dimensions. Using the feedback from the servo and the data from the inertial measurement unit (IMU), ROS provides a nice graphical user interface to visualize the 3D LIDAR data for testing as shown in in Fig. 10. The ROS visualizer helped greatly in improving our algorithms for correctly detecting objects.

## B. LEDDAR

The LEDDAR sensor module uses infrared light (IR) to measure distances along a plane. IR light is emitted from the device and monitored by the receiver using a special lens. The device returns ranges from 16 beams spread across a 45° wide plane 50 times a second. While not a replacement to the LIDAR, the LEDDAR could be used as an accessory to the LIDAR by monitoring the shoreline and detecting the floating dock. Mounting the LEDDAR on its side ensures that the sensor can always see in front of the ASV regardless of the ASV's pitch.

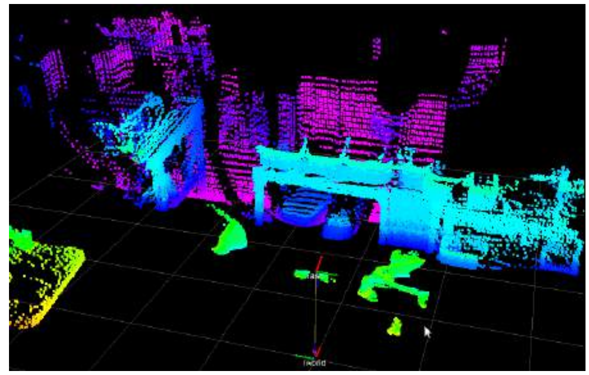

Figure 10. Visualization of LIDAR data taken in the lab using the ROS visualizer

## C. Dual GPS System

With two GPS modules, PropaGator 2 is able to determine its heading even when stationary. Using moving base real time GPS kinematics, a vector is created from the two antennas. The vector provides the ASV a true heading which is immune to magnetic influence or gyro drift.

## D. Passive Sonar

The ability to track a point source of sound in the water is encapsulated into the passive sonar pressure vessel. It contains a student designed passive sonar amplification and filtering board, Fig. 11, necessary power regulation, and USB communication. The hardware is capable of tracking multiple acoustic sources simultaneously provided they are at different frequencies. A Texas Instruments digital signal processor is used to collect the acoustic data, which is then transmitted to the main computer for further processing.

## E. Additional Sensors and Actuators

For position determination, PropaGator 2 uses a Sparton AHRS-8 (altitude heading and reference system) and two Yuan 10 Skytraq S1315F-RAW

Figure 11. Passive sonar amplification and processing hardware

GPS. To visually detect obstacles and challenge objectives, PropaGator utilizes an IDS Imaging UI-1240RE camera (forward facing), and a Point Grey Firefly MV camera (down facing). Propeller rotation and LIDAR tilting are performed by Dynamixel MX-64T servos. The electronic speed controllers used to control the 1200 $W$ Rimfire .60 motors are Hydra ICE 240s.

## V. Software

### A. Robot Operating System

The PropaGator team continues to use ROS for its open source nature and strong community following which allows for frequent updates and plentiful examples and tutorials. The Machine Intelligence Lab, including teams like PropaGator, has migrated all of its robots to ROS. This makes it easy to write software for one robot and be able to use it on another. The lab also actively contributes to the ROS open source community. ROS facilitates the unification of software by packaging individual programs into nodes. These nodes are then able to communicate with each other through ROS [13]. The overhead required to allow this communication and any necessary debugging is provided by the ROS environment. ROS also provides 3D visualization tools such as RVIZ, which allow the current states of the ASV's actuators to be shown on a screen as shown in Fig. 12.

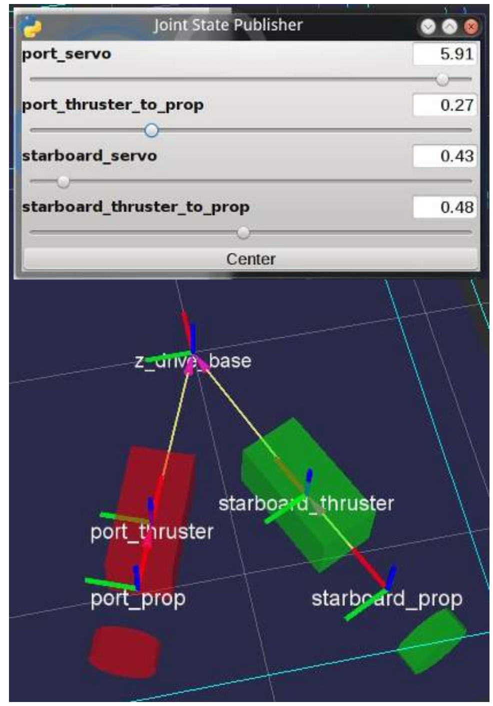


Figure 12. Sample screenshot of RVIZ

### B. Kalman Filter

PropaGator2 uses an Unscented Kalman Filter [14] to fuse the IMU and GPS modules to determine the pose (position and orientation) of the ASV. The GPS modules provide velocity data for the filter.

### C. Navigation

The navigation planner creates a world model of the environment using vision from the cameras and information from the LIDAR and LEDDAR. The planner then navigates the ASV to the goal position and orientation while avoiding obstacles. Objects decay over time to allow for drift in the robot's position in the world frame.

### D. Mission Planner

To give PropaGator 2 a set of ordered and specific tasks, a mission control program was created. The program is a state machine that monitors the status of each task that is running and has timeouts to abort a task if it fails to complete. Preventing one task from consuming the entire run time, the program allocates a measured amount of time to each task. Debugging and monitoring is greatly simplified by utilizing the ROS state machine.

## E. Simulator

Because it is not practical to take the ASV to a body of water every time testing needs to be conducted, the team designed a simulator. The simulator creates a graphical environment, shown in Fig. 13, using a semi-accurate physics model. Challenge behaviors and mission planning is simulated in this environment.

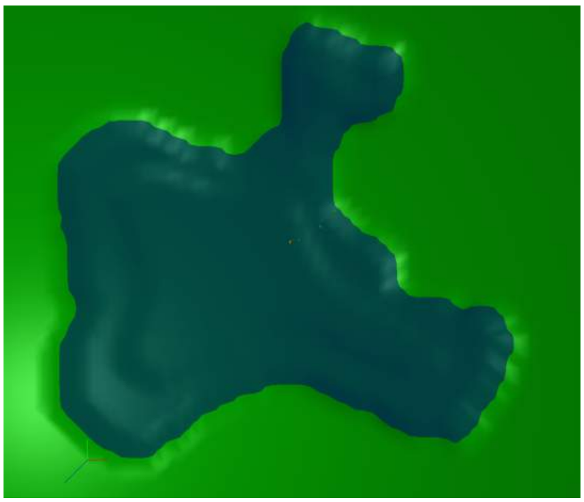

Figure 13. Simulated RoboBoat lake based upon the actual competition

## F. Computer Vision

Computer vision was conducted using OpenCV [15], Open Source Point Cloud Library (OPENPCL), and the Python programming language. Software was written utilizing OpenCV to visually detect obstacles and identify challenge objectives. OPENPCL allowed data from the LIDAR to be translated to the camera for better identification. PropaGator 2 uses loose thresholds on the vision and filters out noise using the LIDAR's 3D points being projected on the 2D camera image. The filtered image is published highlighting the object's center of mass using its corresponding (x,y,z) LIDAR position.

For the parking challenge, the team programmed an OpenCV application that detects the various shapes by finding contours and then counting the number of sides that composes each contour. For example, PropaGator is able to identify a triangle when it detects a contour with three sides. Prior to identifying the contours, each camera frame is conditioned with a Gaussian blur (to reduce noise) and passed through a color threshold. A screenshot of the OpenCV vision application can be seen in Fig. 14.

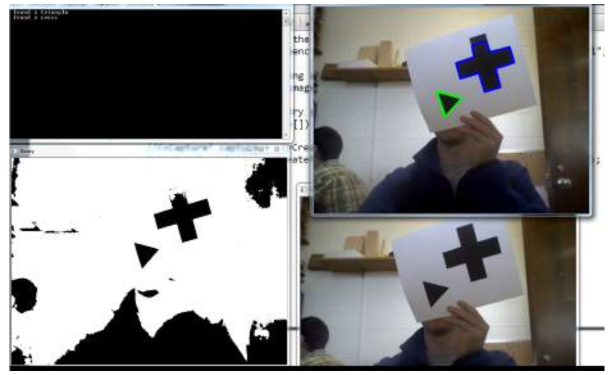

Figure 14. Sample screenshot of vision software

## G. Controller

PropaGator 2 is an overactuated system, i.e. it has more inputs into the system than it has outputs. The ASV's outputs consist of its three degrees of freedom; two to describe its planar position on the water and one for its orientation. The four inputs of the system are the two thrust vectors from both propulsion motors as well as the two orientations of each steering servo. Because of the over-actuation, given a desired trajectory, there may be an infinite number of actuator configuration solutions. To solve this issue, the ASV uses a cost function to determine which configuration to take. A block diagram of the ASV's controller can be seen in Fig. 15.

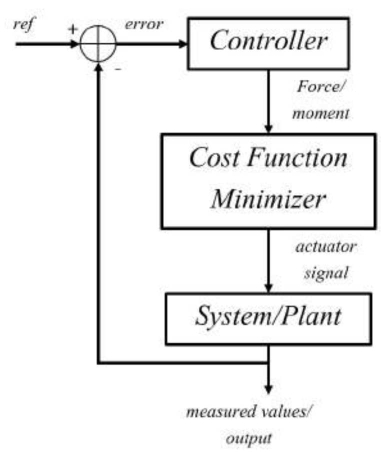


Figure 15. Controller block diagram

First the error in the ASV's position and orientation is calculated by taking the difference between the reference signals and the measured signals. The error enters a standard PD controller where it determines the required force and moment that should be applied to the ASV. The cost function minimizer takes the force and moment values and determines which of the infinite configurations should be applied to the ASV in order to minimize the user defined parameters. The cost function finds the solution for the actuator configuration that minimizes the error in position and orientation, energy required, and the change in steering angle [16].

## VI. Conclusion

After twelve months and thousands of man hours, the PropaGator team is proud to present a new competition ASV that is faster, lighter, and more efficient in the water compared to last year's design. Conducting research on hydrofoils confirmed the team's simulations and calculations and laid the foundation for designing a new hull and propulsion system. PropaGator 2 is expected to be used during the next several years for both research and competitions.

## VII. Acknowledgments

The University of Florida PropaGator team would like to thank everyone who has supported us throughout the year, including the University of Florida's Electrical and Computer Engineering department and Mechanical and Aerospace Engineering department. We would like to extend an appreciative thank you to our adviser, Dr. Eric Schwartz (with whom this project was made possible), Dr. Antonio Arroyo, and the Machine Intelligence Laboratory at the University of Florida. We would also like to thank Shannon Ridgeway who made the production of a new hull a reality. Finally, we would like to thank each of our corporate sponsors for graciously assisting with both monetary and product donations or discounts:

- Platinum Sponsors: Vectorworks Marine and Aerotestra
- Gold Sponsors: Lockheed Martin and Harris Corporation

The latest PropaGator developments can be found at our web page http://mil.ufl.edu/propagator

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