PropaGator 2013: UF Autonomous Surface Vehicle

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ABSTRACT

PropaGator is a fully autonomous surface vehicle built to participate in the Association for Unmanned Vehicles Systems International's (AUVSI)'s 2013 RoboBoat Competition. This year's event will be held in Virginia Beach, Virginia. PropaGator consists of an aluminum superstructure built upon a catamaran design. This paper describes the hull design, electrical design, software infrastructure, and PropaGator's approach to completing the challenges presented in the RoboBoat 2013 competition.

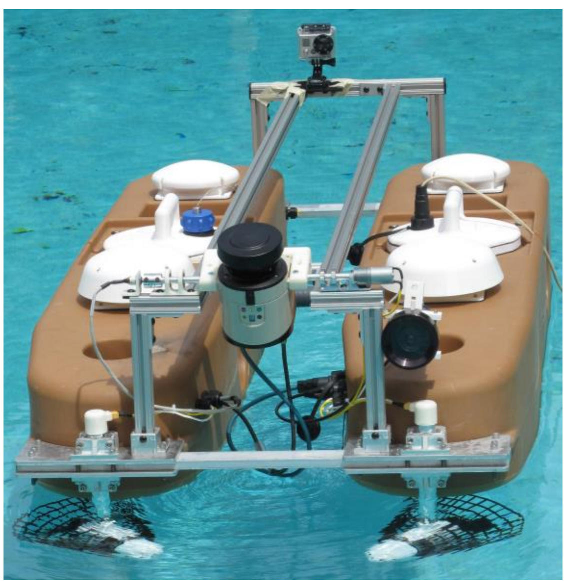

Figure 1: PropaGator the Autonomous Surface Vehicle.

1. INTRODUCTION

PropaGator (see Figure 1) was designed and built by students at the Machine Intelligence Lab (MIL) at the University of Florida. This is the first year that the University of Florida will participate in AUVSI's surface vehicle competition. 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.

The time constraints imposed by the competition motivated the rapid development of a dynamic platform. In order to maximize the amount time for testing, the team utilized open source community-supported software. This ensured that compatibility issues would be minimized and that an abundance of documentation and open source code would be available.

Most of PropaGator's circuit boards were designed and constructed by team members. Students conducted research on the parts, designed the printed circuit boards (PCBs), populated the PCBs with electronic components, and then programmed the microprocessor and programmable logic circuits. In house development fosters a thorough understanding of how the electronics operate. This allowed the team to troubleshoot rapidly and make quick modifications and repairs.

As the open source robotics community continues to expand, the decision to select the Robotic Operating System (ROS) [1] was straightforward. ROS allows for the unification of software by packaging individual programs into nodes. These nodes are then able to communicate with each other through ROS. The overhead required to allow this communication and any necessary debugging is provided by the ROS environment. One of the strengths of ROS is its strong community following, allowing for frequent updates and plentiful examples and tutorials.

Like the designs used on US Navy warships, the PropaGator was created with an emphasis on redundancy and ruggedness. Modeled after the warship HSV-2 Swift shown in Figure 2, PropaGator is a catamaran design allowing for stability and a shallow draft.

Figure 2: HSV 2 Swift, the Navy's mine countermeasure and sea basing test platform.

The boat contains multiple layers of redundancies: four trolling motors for propulsion, four communication paths, two circulation fans per pontoon, additional fans on high current systems, five batteries, and the ability to receive power externally. In order to increase survivability, the team created hardened electronics through the use of reverse power protection, fuse protection, fail-open hardware, and transient power protection. An additional feature of the PropaGator is its small landing pad on the back half of the boat for a quadcopter. Finally, the PropaGator was designed with the safety of the users in mind. To protect personnel from the propellers, trolling motor guards were installed (as shown in Figure 3), preventing finger sized objects from touching the blades from the sides. (It should be noted that the blades have no protection in the back.)

Figure 3: Trolling motor guards.

During the computer drafting and manufacturing processes, all sharp edges were removed. Should the robot become unstable, the team has four methods of stopping movement: a mechanical kill switch on the boat, a wireless e-kill remote, a magnetic kill stick (see Figure 4), and the ability to stop the boat through software.

Figure 4: Magnetic kill stick to start the boat (green side) and to stop it (red side).

2. Mechanical

2.1 Hull

In an effort to expedite the construction of the boat, two commercial pontoons were utilized to provide buoyancy and an even keeled platform. Aluminum frames hold the two pontoons together at the front and back of the boat. The trolling motors and superstructure were mounted to the aluminum frame. All aluminum parts were manufactured using either a water jet or a milling machine. Hull penetrations for cabling and ventilation were sealed with either gaskets or O-rings. The hull width was designed to be as wide as possible (within competition parameters) while still being able to pass through doorways. On top of the pontoons, a superstructure made of t-slotted aluminum was attached to allow for the mounting of additional parts. PropaGator has the following design parameters:

- Water Displacement: *115lb*
- Overall Dimensions: *72” × 30” × 28” (L × W × H)*

Similar to the reactor cores found in nuclear powered aircraft carriers, PropaGator contains two vertically oriented, watertight, removable electronics enclosures (as shown in Figure 5). A rubber gasket on the throated slot oof the reactor cores ensure a water tight seal.

Figure 5: Port reactor core showing the Intel i3 processor PCB and ergonomic handle.

The reactor cores consist of aluminum reinforced ABS plastic frame with an ergonomic handle. Increasing the boat’s water tight integrity, a Hall Effect sensor was installed into the lid of the port reactor core. The sensor is the on/off switch (activated with the kill stick shown in Figure 4) for the boat. Using a Hall Effect sensor made for one less penetration in the hull.

To connect the cores to the boat, slotted throats with gaskets were mounted to the pontoons. The slotted throats create a seal for the cores in the stow position and hold the cores up in the maintenance position shown in Figure 5. The ABS vertical backplane provides easy mounting points through the use of receded sockets and cable passages. To assist with troubleshooting in a low light environment white LED strips were installed to assist team members in identifying electrical problems.

2.2 Propulsion and Auxiliaries

For propulsion, PropaGator utilizes four fixed trolling motors. A common commercial trolling motor sold by many distributers was selected both because it met our specifications and could be purchased locally. The front two trolling motors point 30 degrees inwards while the two rear trolling motors face 30 degrees outward. The orientation of the motors was selected to create a vehicle that could move in any direction on the water. All motors point forward to allow for maximum forward speed.

Each motor is able to provide approximately five pounds of thrust at nine amps, creating 20 pounds of combined forward thrust. The motors were controlled using thrust curve based data obtained during motor testing.

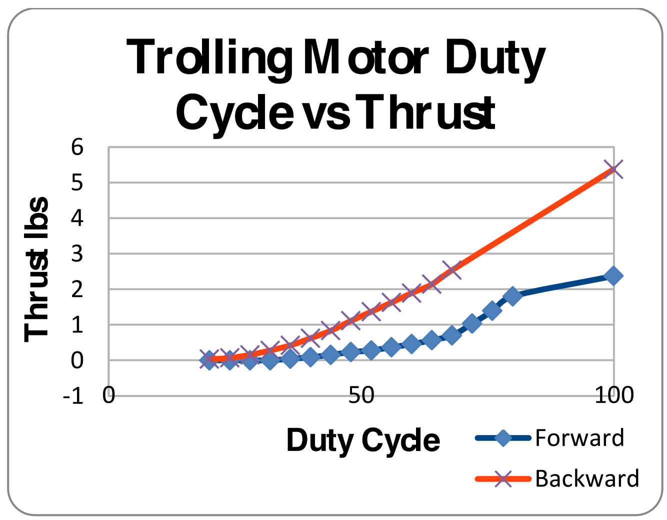

Figure 6: Curve graphs showing minimum and maximum thrust based on duty cycle.

Because of the high current draw from the trolling motors, significant effort was placed on designing a substantial cooling system. Each pontoon contains a covered intake in the rear and a covered exhaust in the front, as shown in Figure 7.

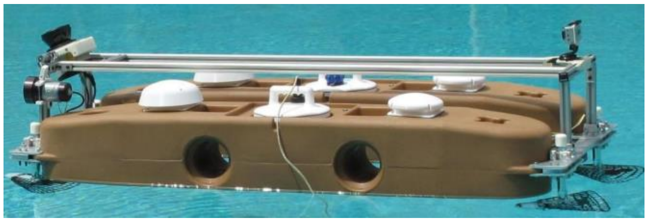

Figure 7: Intake and exhaust covers.

Each of the intake and exhaust covers has a 120mm fan attached in order to move air through the pontoon. Fans are also mounted to the high current circuitry.

Flow simulations (see Figure 8) where conducted in order to calculate the necessary air flow to keep the electronics functioning well within their specified temperature limitations. The simulations also helped determine the shape of the intakes and exhaust covers.

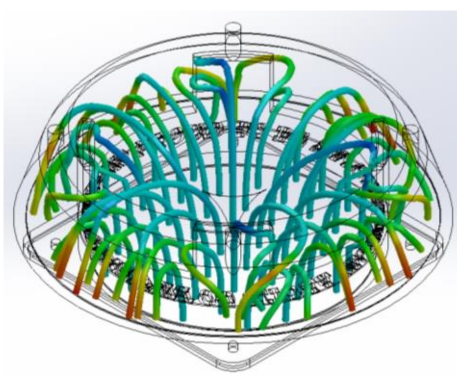

Figure 8: Flow simulations.

2.3 Cabling

During the process of installing the electrical components, cable management and water tight integrity quickly became an issue. To allow cables to pass through the pontoons, cable grips were used to create a water tight seal. For cable management, retracting harnesses were installed. The harnesses allow slack in the cables during the raising of the reactor cores and remove the slack during stowage of the cores.

2.4 Challenge Station Equipment

In order to provide a 3-dimensional laser image using the LIDAR, the sensor is rotated about a fixed axis. Two aluminum shafts, supported by double ring bearings, are attached to the LIDAR (shown in Figure 9).

Figure 9: Front view of the LIDAR motion system.

On the right shaft (in Figure 9) a six amp DC motor is utilized to provide the panning movement. The absolute encoder is attached to the left shaft to provide position feedback. Using the motor, the LIDAR pans approximately 30 degrees.

To compete in the "Shoot through the hoops" challenge a toy dart gun is mounted to the superstructure of the boat. The dart gun fires missiles using electrically spinning disks and holds up to six darts. Adjusting the toy's angle of attack is performed manually by tightening a bolt attached to the gun and a discrete pivot.

Most US Navy warships have landing pads for helicopters. PropaGator has one too. At 2.5ft × by 2.5ft, the landing pad provides a relatively large surface area for the quadcopter launch and land. Adhesive Velcro holds the quadcopter to the boat during transit and acts as a recovery system during landing, preventing the copter from significant motion during transportation while on the boat.

3. Electrical

3.1 Power Plant

PropaGator is powered by five 6000 mAh 16.8V lithium polymer (LiPo) batteries which provide approximately four hours of continuous operation. While in the lab, the boat can be switched from battery power to shore power automatically through a waterproof plug and a power switching circuit. Before going to the computer, power is split into a high current rail and a lower current rail. Splitting the rail helps prevent fluctuations in power caused by the motors which could negatively affect the computer and sensitive sensors.

3.2 Computer

For upper level decision making, the boat has been outfitted with an Intel i3 processor, four GB of RAM, and is powered by a 125W power supply. The team decided to use Ubuntu 12.04 (Linux) because the operating system is stable and natively supports ROS. Communication between circuit boards is conducted through USB. In order to support the large quantity of PCBs and sensors, a 10-port USB hub was attached to the computer.

3.3 Communications

Using a wireless router gives PropaGator the ability to communicate with its users through different mediums. Multiple users, including the quad copter, can wirelessly connect to the boat through secure shell network protocol allowing different portions of the boat to be programmed at the same time. Should wireless communications not prove adequate due to bandwidth restrictions or wireless interference, an Ethernet tether can be plugged into the boat allowing multiple users wired access through a network switch. Additionally, the LIDAR communicates through an Ethernet cable plugged in to the wireless router. Finally, to connect to the internet in the lab or the RoboBoat wireless router during the competition, a USB wireless adapter was installed.

3.4 Electronics

Instead of purchasing motor controllers to drive the trolling motors, the team opted to design their own. A four layer printed circuit board provides a dynamic platform that not only moves drives current motors, but also had enough remaining capacity from its Atmel XMEGA microcontroller to also obtain feedback from sensors.

Current draw from the motors is measured using a shunt resistor. Utilizing this measurement, the system can determine if a motor has been stalled. The motor controller can operate from a source of 7V to 32V and was rated for 20A at 16.8V. Communication with the i3 processor is conducted through USB 2.0.

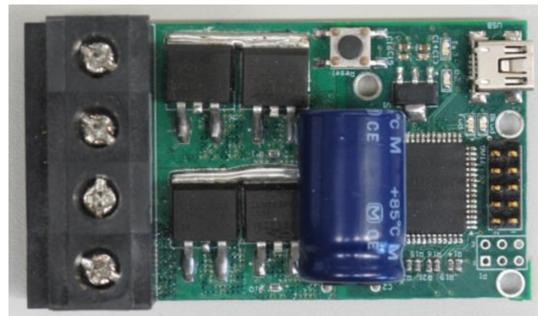

Figure 10: One of the four motor controllers.

To monitor our external sensors and components, we designed an input-output (I/O) board. The I/O board (see Figure 11) uses an Atmel XMEGA 256 to drive our servos, small motors (for the challenge stations), and to read our thermal sensor.

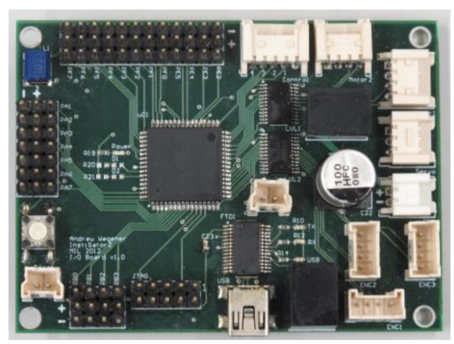

Figure 11: The I/O board.

In addition, the I/O board is interfaced with a 2.4GHz transceiver for the e-kill sensor.

Since LiPo batteries can be damaged from overuse, students designed a high current circuit board that to monitor the health of the batteries. The Power Router (shown in Figure 12) allows for hot swapping of power sources, giving us the ability to swap out batteries without the boat turning off the system. All system power passes through this board.

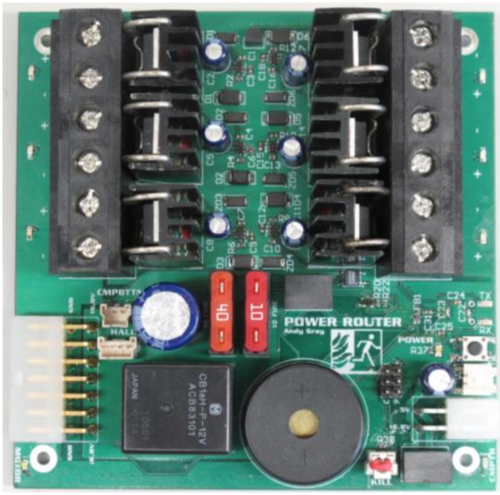

Figure 12: The Power Router PCB.

Should the batteries be drawn too low, the board begins a load shed process where high current components are secured first before the computer power iss secured. Rated at a total of 50A, the board has a 40A fuse for high current sources and a 10A fuse for the computer and sensors. The board is shaped to conform to the 120mm fans mounted behind the board. Slots were cut into the board to allow airflow across the heat sinks. An ATtiny 1634 microprocessor monitors battery voltage and current usage. The Power Router also monitors the Hall Effect sensor for the magnetic kill stick and the pontoon temperature. For safety, the kill button was attached to the processor's high priority interrupt pin. Activating the kill button immediately opens the relay supplying power to the motors and alerts the team audibly using a 120dB buzzer. The hot swappable circuitry also prevented reverse polarity damage. Should the board fail, the large relay supplying current to the motors fails in the open position.

4. Sensors and Actuators

PropaGator used the following sensors for position determination:

- *Microstrain 3DM-GX1 Attitude Heading Reference System*
- *Yuan10 Skytraq S1315F-RAW GPS*

To detect obstacles and challenge objectives, PropaGator utilizes the following sensors:

- *SICK LMS100 Laser Measurement System*
- *Matrix Vision mvBlueFOX camera*
- *Melexis MLX90614 Infrared Thermometer*

PropaGator's LIDAR had a view of 270 degrees of planar ranges. The sensor operates at 50Hz, providing a distance for every half degree of the 270 degree field of view. The speed of the attached motor allows for a complete sweep at 3Hz. Using the absolute encoder data and the data from the inertial measurement unit (IMU), ROS provides a nice graphical user interface to visualize the 3D LIDAR data for testing. The ROS visualizer helped greatly in improving the algorithm for correctly detecting objects. A sample image generated in our laboratory is shown in Figure 13.

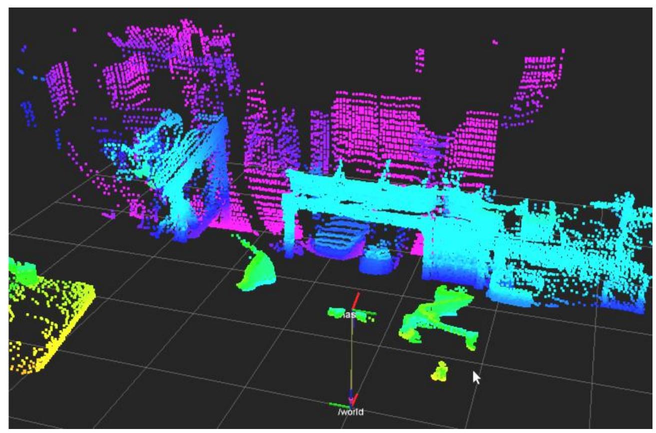

Figure 13: ROS-visualized LIDAR data.

With a range of 40ft, the boat uses the LIDAR to look for obstacles in the water and objects on land. The wide field of view, active panning, and slow movement of the boat facilitate a high detection rate of obstacles in front of the boat. After calibration using a fast extrinsic calibration method **[**2**]**, PropaGator uses an adaptive Euclidean cluster extractor for obstacle detection. Figure 14 shows an image from PropaGator (with the xyz coordinate axis in center) identifying a buoy and labeling the object with a red sphere (on right).

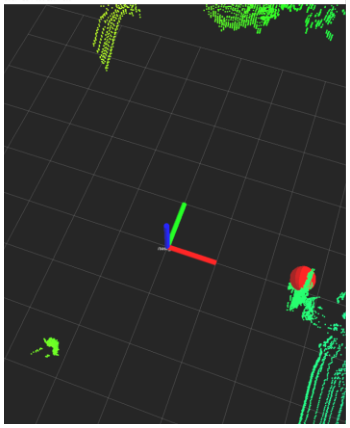

Figure 14: Computer augmented LADAR image of buoy (red sphere right).

The extractor reports objects that are within a half meter above the water and have 20 to 80 laser hits. Reports from the extractor are passed to the navigation planner for object classification. Depending on the challenge the boat is attempting, the behavior of the LIDAR can be changed by varying sweep angles and sweep speeds.

Determining PropaGator's position, course, and speed is performed by tightly coupling an IMU and GPS into an inertial navigation system. The boat's IMU updates at 100Hz and the GPS at 20Hz. The high frequency of both sensors allows for a very accurate picture of the boat's position. Because the plastic pontoons are nearly transparent to radio waves, the GPS antenna was installed inside the boat creating one less way for water to enter.

The machine vision camera was mounted on the front of the boat to provide an un-obstructed view. With camera chosen, we can adjust image size, aperture, and frame rate through USB. In an effort to simplify measuring the temperature of an object in front of the boat, a thermal sensor mounted on top of the camera. The mount holding the sensor allowed for tool-free adjustments. The thermal sensor communicates with and I/O board using I2C.

For the "Catch the ball" challenge, PropaGator will use a quadcopter to recover the disk. A relatively large landing pad was installed on the stern of the boat, maximizing landing surface area while still allowing access to the boat systems. Velcro was attached to the landing pad and quadcopter to assist with the recovery and to secure the aircraft to the boat. With open source computer vision (OPENCV), the quadcopter used a downward looking camera for disk and boat identification. A Velcro net was added to the bottom of the quadcopter in order to enable disk recovery. Communication between the boat and aircraft utilizes wireless internet.

5. Software

5.1 Kalman

PropaGator uses an Unscented Kalman Filter [3] to fuse the IMU and GPS modules to determine the pose (position and orientation) of the boat. The team considered using paddle wheels to determine water speed, but we had concerns about cross wash producing inaccurate results.

5.2 Controller

Control software was developed specifically to allow the boat to move instantaneously in any direction and with controlled turning. A thruster mapper receives the wrench (force and torque) output from the controller and maps individual thrust values for each of the trolling motors using a least squares approximation to allow for minimal effort [4,5]. Because the trolling motors are fixed, the controller must be very accurate. Thrust testing on the trolling motors produced data that was used to linearize thruster curves and to remove the dead-band in the motors. Using the linearized data, a tuned proportional derivative controller, and carefully mounting the trolling motors led to very accurate boat movements. Boat movement directions are sent to the controller from the user via from the navigation planner (or during testing, with an Xbox controller).

5.3 Navigation

The navigation planner creates a world model of the environment using vision from the camera and information from the LIDAR. The planner then navigates the boat to the goal position while avoiding obstacles. Figure 15 shows the

Navigation Planner guiding Propagator through the two pairs of red and green buoys.

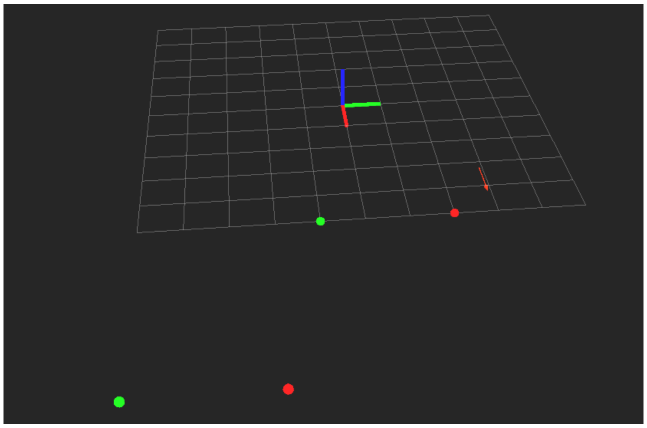

Figure 15: Navigation Planner guiding PropaGator through buoys.

Objects decay over time to allow for drift in the robots position in the world frame. The ROS visualizer provides a nice graphic of the robot's state and its environment.

5.4 Mission Controller

To give PropaGator 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 unblock 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. Using the ROS state machine allows for easy debugging and monitor of the machine.

5.5 Simulator

Because it is not practical to take the boat to a water body every time testing needs to be conducted, the team created a simulator. Figure 16 is an image from the simulator showing PropaGator (red and green blob) aligning itself for an approach through the buoy channel.

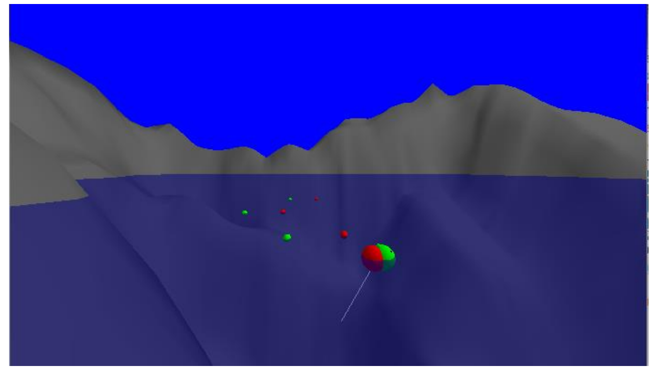

Figure 16: Simulator image.

The simulator creates a graphical environment using a semi-accurate physics model. Challenge behaviors and mission planning is simulated in this environment.

5.6 Machine Vision

Computer vision was conducted using OPENCV [5], 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 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 objects center of mass using its corresponding (x,y,z) LIDAR position.

6. Conclusion

The team knew that creating a competitive autonomous surface vehicle from scratch in a short period of time would be a difficult task. As a result, the team's strategy was to produce a platform quickly in order to maximize the amount of available design and testing time. The boat went through various iterations of hardware, electronics, and revisions of software to arrive at the current design in 10 months. Despite the short design cycle, the team is pleased with how the PropaGator is presently functioning, especially the reactor cores. For next year's competition, the team would like to utilize smaller pontoons in order to make the PropaGator more light-weight and maneuverable.

7. Acknowledgements

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- Gold Sponsors: Lockheed Martin, Harris, Rockwell Collins
- Silver Sponsors: UF Dept. of Electrical and Computer Engineering, UF Dept. of Mechanical and Aerospace Engineering, Advanced Circuits, DigiKey, PNI

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

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