Robotics Club at UCF:
Classic Boatname

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The Robotics Club at UCF presents their competitive platform for the 7th annual AUVSI and ONR International RoboBoat competition, Classic Boatname. The vehicle is a polished product of modular design and experience from previous entries. A lightweight foam pontoon design reinforced with maritime polymer paint and a unique motor configuration allows for seamless movement in forward, reverse, rotation, and lateral directions. The electronics are mounted on modular DIN railing for reliability, ease of configuration, and modification. A one-of-a-kind PIDAR system on this year's vehicle precisely rotates a 2-D laser rangefinder to produce an improved 3-D point cloud. Competition-tested computer vision and mapping libraries from previous designs are extended to fuse data from multiple sensors including PIDAR, GPS, and compass for robust course navigation. Several unique 3-D printed mounts and housings were created for the various hardware elements necessary to complete this year's challenges. The team's strategy for 2014 is to equip the surface vehicle with the abilities necessary to accomplish the standard mandatory tasks as well as all four additional tasks new to this year's competition.

Figure 1 Classic Boatname on the water.

Introduction

This year's RoboBoat competition presents the team with several unique challenges that require robust solutions. The past success and modularity of the team's entry into RoboBoat 2013 made recycling the existing base platform a clear choice for this year's competition. Features that have proven successful from year to year include the vehicle's simple power system, software architecture, versatile motor configuration, and platform stability.

An incremental design approach following the spiral development process has produced a sound physical platform. The spiral model steps for hardware development include: requirements gathering and specification, 3D modeling, rapid prototypes, and final implementation. This process allows for the early identification of gaps and design issues before final implementation reducing overall project risk and cost. The teams focus of ensuring the platform is equip with all sensors necessary to complete this year's tasks will ensure a successful entry.

New systems added to Classic Boatname include the PIDAR 3-D laser range finder, underwater camera enclosure/mount, extended camera mount, stabilized front bumper, and optimized hydrophone mount. Accounting for future development the boat design leaves available modular mounting areas on the main frame and sensor mast for additional hardware or sensors.

Mechanical Design

The configuration of the platform's motors, aluminum frame, pontoons and electronics box allow for sufficient control while maintaining interchangeability of components and a stable center of gravity.

Pontoons

A hexagonally flat bottom pontoon is realized with angular geometry. The front and the back of the pontoons are blunt to help dampen any shaking of the boat during rapid orientation changes. The width of each pontoon is carefully measured to stabilize the boat during lateral motion. A physics simulation inside the computer aided design (CAD) software used to construct the pontoons enables the team to refine and test these design choices before construction of the final pontoons and frame.

The pontoon design is a composite structure mostly fabricated in house. The base material of each pontoon is white Styrofoam which is professionally machined using a CNC hot knife. Polycarbonate plates with tapped holes for structural mounting are fitted and glued into insets cut into the front and back of each pontoon. The entire pontoon structure is covered with Styrospray 1000, a two part polyurethane coating approximately 0.03 inches thick. This lightweight coating hardens the exterior of each pontoon creating a solution

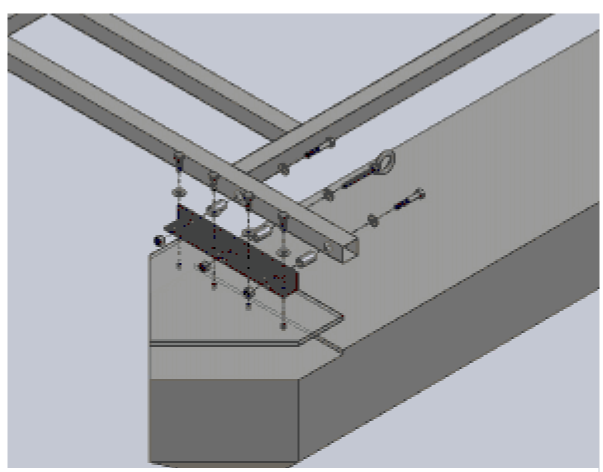

Figure 2 Pontoon with polycarbonate inserts.

that is both aesthetically pleasing and sensible for maritime applications. The total weight of each complete pontoon is less than seven pounds. This design is water tested, and can safely support a vessel weighing up to 140 pounds.

Frame

A 1-inch square aluminum-tubing frame holds the two pontoons and the electronics box together. The frame is kept the same for RoboBoat 2014 due to a combination of success in past competitions and the optimal mounting capabilities for hardware necessary for the 2014 competition. The frame is designed with four slotted mounting points for the electronics box to ensure adjustability for optimal weight distribution across the length of the vehicle. The tube lengths are cut on a horizontal miter saw, professionally TIG welded together, and then anodized to reduce corrosion and extend longevity. The mounting plates for the electronics box and L-channel are milled in-house using a CNC machine to ensure proper alignment. Aluminum spacers reinforce areas of the frame with through bolts to prevent permanent deformation. One eye-bolt is located on each mounting section (four in total) to the pontoon for easy hoisting during water entry.

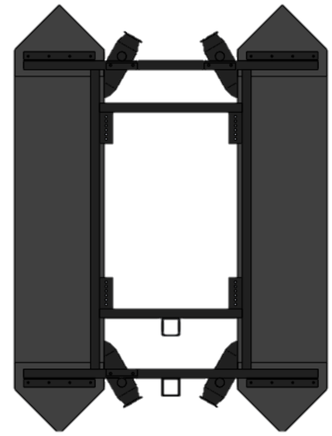

Figure 3 Top down view of frame and motor configuration.

Motor

The motors are configured for a vector thrust design that easily allows the boat to achieve forward, backward, rotational, and lateral movement. The motors are angled 30 degrees inward resulting in an approximate 13% overall reduction in forward and reverse thrust when compared to a fully forward facing motor setup. This sacrifice does however allow for 50% of the thrust to be applied to lateral motion. In the event that power is lost to the front or rear sets of motors the vehicle is configured to maintain reliable movement in the forward, backward, and spin aspects of motion. The symmetry of the motor/pontoon configuration gives the platform exceptional levels of redundancy.

Sensor Mast

The vehicle's Aluminum mast is recycled from last year's platform due to its unobstructed location and superior modularity. It hosts the majority of the vehicle's sensors. The mast is designed with ¼ inch holes spaced one inch along the height of the mast. These holes allow for easy adjustment of the mounting position of the sensors and other hardware affixed to the mast. The mast holder, which connects the mast to the frame, is welded to the frame. The holder also consists of ¼ inch holes spaced one and a half inches apart to allow for the entire mast height to be adjusted. At the top of the sensor mast sits the mount for the GPS antenna and camera payload as both require an unobstructed view of the sky. Directly below this piece is the

Figure 4 Sensor mast.

extended four part camera mount. Below the camera mount is the PIDAR laser assembly, and below this rests the underwater camera mount.

3D Printing

In order to reduce vehicle weight and accommodate various geometries three dimensional printed parts (3-D printed parts) were implemented on this year's platform. Parts manufactured from the in-house printer were designed using SolidWorks and manufactured using layered PLA filament. This manufacturing technique allowed for unique items, such as Logitech business web cameras with no fixed mounting geometry to be affixed to the vehicle's frame using modular part design and surface profile approximation. Items mounted with 3-D parts include the waterproof enclosure used for the underwater light identification challenge, the Logitech web camera used for all other computer vision, the PIDAR assembly, and the wireless networking hardware.

Reinforced Front Bumper

One of the major improvements to the mechanical system this year includes the design and fabrication of a rigid front bumper. The bumper is capable of effectively deflecting buoys away from the chassis while maintaining a stable fixture to the base platform. In addition a unique key- style mount was implemented to fit snug in the sides of the 1" tubular aluminum frame while providing adequate displacement from the Styrofoam pontoons to ensure that the more sensitive floatation components undergo little to no stress during bumper contact.

Electrical Design

Classic Boatname's electrical system is intended by the team to be both consistent in its operation and easy to alter. The use of industry grade DIN railing and a programmable system on chip microcontroller ensures that all electrical design goals are met.

Propulsion

Four Sevylor SBM 18 motors power the propulsion system. 12 volt rated models are chosen given the desired specifications of thrust, form factor, and compatibility. The vertical tiller of the motor houses the wires and allows for mounting to the vehicle's frame. Testing of the motor's thrust output revealed to average around 13 pounds in the forward direction at 13 amps, and nearly 11 pounds at 13 amps in the reverse using the included propellers. The two motors in the front of the vehicle and two in the back are wired to a set of two Roboteq motor controllers. These motor controllers receive serial RS232 signals from a custom microcontroller board in which the commands for motor speeds and direction are packaged.

Batteries

The boat contains two main power rails which represent a logical and physical separation between the 'logic' and 'motor' power. The logic power rail is responsible for providing power to computing systems and associated electronics. This contrasts with the motor power rail that is liable for keeping power to hardware components that move the platform or components therein. Power isolation has two major benefits: preventing interference between different systems and allowing for reliable emergency cut-off of power to actuating devices per competition requirements. A 4-cell LiFePO4 battery with a 6.6 Ah rating provides a nominal 12.8 volts from which the motor rail receives its power. 3 additional batteries may be placed in parallel to extend the runtime of the motor system for a total capacity of 26.4 Ah (approximate runtime of 3 hours under normal circumstances). The logic components of the vehicle (e.g. onboard computer) are powered from 6-cell Li-Po batteries providing nominal 22.2 volts. A high-efficiency switching voltage regulator provides a regulated 12 volt power source required to operate various sensors and devices on this logic rail. Charging of all the batteries is achieved via an external Hyperion EOS0615IDUO3 battery charger. Two sets of batteries for each rail are available to maximize vehicle runtime during practice.

Figure 5 Set of vehicle batteries.

Printed Circuit Board

A custom printed circuit board (PCB) is intended to integrate all analog and digital signals for this year's vehicle. The PCB contains an ARMv7 based PSoC5 microcontroller/system on chip that handles several responsibilities including:

- Interpret RC receiver signals.
- Command motor controllers
- Monitor vehicle status (Battery voltages, temperature, etc.)
- General Purpose Input Output (GPIO).
- High current output.
- Serial communication to main computer.

The high current output on the PCB consists of a high power N-channel MOSFET in an open drain configuration. This allows for switching of devices up to one amp. This is utilized on the vehicle to switch high current components including the autonomous indicator strobe, side lights, and low battery alert indicators. Commercial Molex connectors and many open GPIO buses on the board enable reuse of the PCB in future platforms.

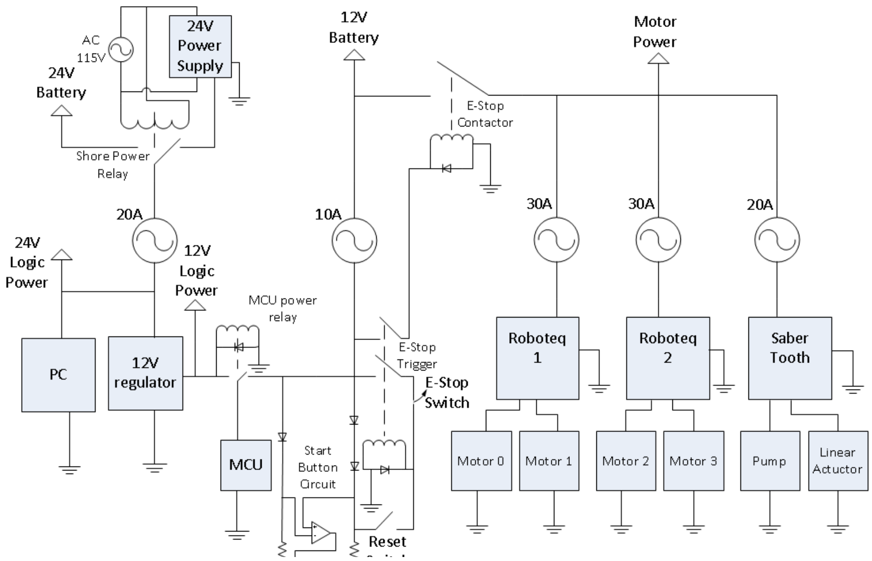

Figure 6 Power distribution diagram.

Power Distribution

Managing the power on the motor and logic rails of the vehicle is achieved via the use of an industry standard DIN rail. Chosen for its modularity and standardization of parts the DIN rail provides a solid mounting point for high current devices. Shore power is delivered through the use of an external power supply fixed to the vehicle's trailer and encased in a NEMA 6P enclosure. The power supply uses a 120 volt AC power supply providing 24 volts at 15 amps. A shore power relay triggered by the AC current itself switches from battery power to the power supply. This effectively replaces the batteries with the power supply when an AC current is supplied for additional testing and development when not in the water.

Emergency Stop

Safe platform operation is maintained with the implementation of an emergency stop circuit. Using a 200 amp 12 volt coil contactor triggered by a single pole double throw relay full stop of the vehicle is readily available. One of the throws of the trigger relay triggers the contactor and the other is used to control the relay itself. A normally closed emergency stop switch is used to cut off the power to the trigger relay, and a normally open reset switch is used to re-energize the trigger coil. A circuit was added to reuse the reset switch as the initial start button for the transition into autonomous mode of the vehicle. This circuit uses a diode drop as a reference and a double diode as a trigger. The double diode is initially acknowledged when the switch is open, and set to an equipotential when the reset switch is pressed. The data read from the double diode and the reference diode is passed to a comparator in the microcontroller and is seen as a high (1) when the switch is pressed a low (0) when the switch is idle.

Wireless Networking

A high power wireless networking solution provides software developers the ability to debug the vehicle's code remotely. This ability is a key factor in efficient use of testing time on the course supporting remote configuration and adjustment of parameters on the fly for optimization. Previous designs utilized standard IEEE 802.11b/g/n network wireless routers to maintain a remote connection but have proven to be unreliable at distances achieved across the entirety of the competition lake. Ubiquiti Networks airMAX Rocket M wireless base station is a powerful 2x2 MIMO modem that has incredible range, speed, and RF performance in outdoor environments. The network is configured as a point-to-point link bridging the vehicle and operator command center networks.

Software Design

Focus on software development is paramount for this year as new sensors have enabled greater capability. Proficient solutions to completing the start gate, speed gate, and buoy avoidance challenges are to be written from the ground up. The new software development goals include important changes in obstacle detection, mapping, and control abstraction. Code for the boat is run real-time on platform using the onboard workstation grade desktop running a Linux operating system.

Architecture

The robot's underlying software architecture is similar to last year's entry and is a standard across all Robotics Club at UCF vehicles. Platform control and communication is routed through the SAE Joint Architecture for Unmanned Systems (JAUS) standard. The vehicle leverages an open source C++ implementation called JAUS++. Sensor data is packed in JAUS messages and subscribed to by the AI program which evaluates and acts on the data. JAUS not only makes the platform hardware agnostic but it also permits the reuse of control code across completely different platforms such as underwater or ground. The boat runs a program which maintains connections and communication to all hardware devices while a separate AI program can be started, stopped, and reconfigured without the need to reconnect to sensors. Using the framework provided by JAUS software located on other network computers can subscribe to sensor data and take hardware control for fast testing and development. The software architecture implementation also includes logging of all data generated by the sensors. This information can be played back within a simulation sandbox for evaluating AI behavior on recorded data. This powerful feature enables fast debugging of robot decision making, and obstacle detection. This feature also enables developers to test new AI features without the need to physically operate the robot.

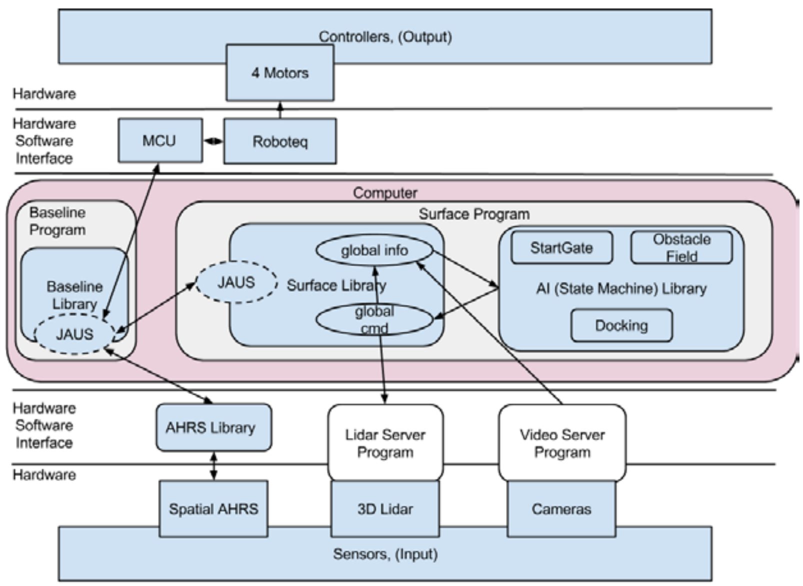

Figure 7 Software architecture.

Motor Control

The unique motor configuration of Classic Boatname allows for seamless movement along 3 degrees of freedom on the water: translational motion along two perpendicular axes parallel to the surface, as well as rotational motion about the axis perpendicular to the surface. This setup equips the boat with the power necessary to provide effective propulsion for time-sensitive tasks without sacrificing the versatile movement needed for completing the tasks.

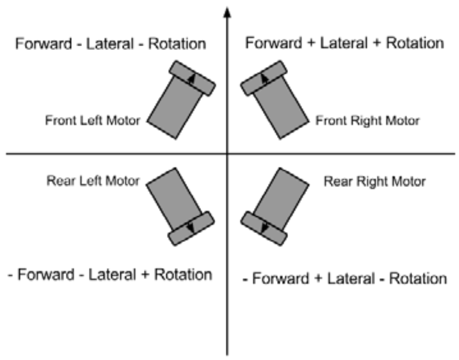

Figure 8 Illustration of motor configuration and control values.

Reliable and smooth lateral control will give the vehicle a time sensitive edge during the automated docking challenge (due to forward facing sensors) and will also be used for advanced maneuvers around targets and challenge course buoys. Rotational speed has also been improved thanks to the symmetrical diamond configuration of the motors.

The AI now has access to maneuvers such as face a target while moving around it; align to target angle, and lateral search as opposed to traditional left/right sweeping searches. These new capabilities support lining up to targets without losing them from sensor view. Commands such as move to GPS waypoint, maintain velocity, and heading commands are carried over from last year's robot. High level waypoint commands are translated to velocity commands and then to thrust commands in three channels (linear x, linear y and rotational z). Velocity is estimated by GPS data combined with mapped objects in the AI. Thrust output is determined by individually tuned PID controllers for rotation and linear velocities.

Low level motor control requires mixing three channel movement commands to four motors. Symmetrical positioning of motors simplifies the mathematics needed for this process. Each motor can be placed in a quadrant where each quadrant is a unique linear combination of the three channels.

Object and Buoy Detection

A Logitech C930 webcam at the center of the sensor mast is used in all missions of the course. Computer vision algorithms are used to filter live frames from the webcam by color using the HSV color space. This space separates channels differently than RGB and helps account for changing brightness due to weather conditions. The camera is also greatly aided in its detection of course objects through the use of the new custom 3D PIDAR system. This sensor is a 3D LIDAR capable of detecting distances to objects in the environment with extremely high accuracies (centimeters). Range data

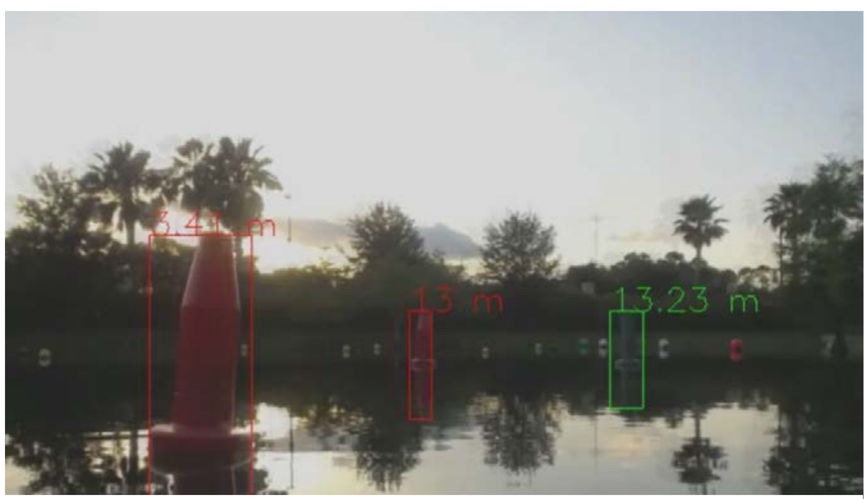

Figure 9 Object detection output with range estimation in meters.

from the PIDAR is compiled into 3D point clouds from which range images are spawned. These range images are calibrated to the main Logitech camera using camera calibration techniques so as to overlay the images perfectly. After color filtering of images is completed the range images from the 3D LIDAR are examined to further filter colored blobs that are detected. Blobs which have no range associated with them are discarded and only those blobs which have correct distances are counted as buoys. This technique is used in all missions and in all stages of object detection and mapping in the AI program.

State Machine

The course is broken down into missions with one for each challenge. Each mission can be broken down further into states and sub-states in which discrete actions are taken based on fused sensor data. When certain conditions are met states will transition to new states until an end state is reached and/or the mission is complete. Each mission has a time-out value which ensures the vehicle can “give up” and move on to the next mission maximizing challenges attempted.

PIDAR

A 3-D printed enclosure mounted directly under the front camera houses the PIDAR, a unique compound device that allows for an off the shelf 2-D Hokuyo UTM-30LX LIDAR (Laser Rangefinder) to generate 3-D range data. An encoded Dynamixel MX-28R servo motor mounted inside the enclosure turns a pair of 3-D printed geared shafts to transmit power to turn the Hokuyo. The Hokuyo is continuously rotated about the system’s designated x-axis where +x can be described as the “forward” facing vector of the vehicle parallel to the water’s surface. The LIDAR and encoder feedback is processed by a Raspberry Pi miniature embedded computing platform which processes the results into a spherically oriented 3-D point cloud with an update frequency of 40Hz. A Mercotac Model 830 mercury filled slip ring is used in the assembly to ensure connection between the two ends is maintained. The data generated by this system is transmitted to the boat’s main computer via a hardwire Ethernet connection. A UDP server running on the PIDAR transmits point data and listens for command messages from the boat.

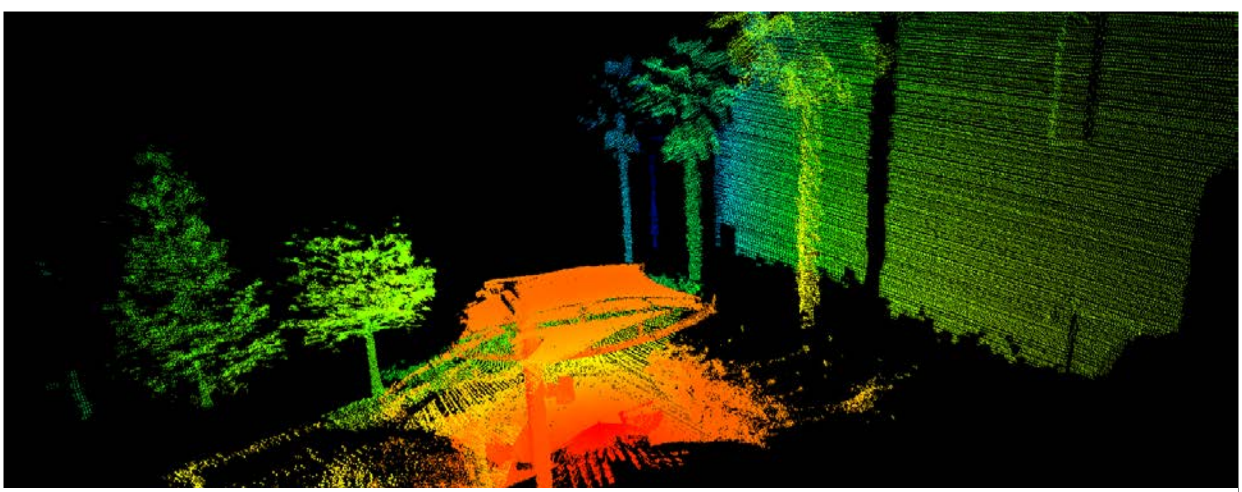

Figure 10 3D point cloud taken outside and color coded for distance.

Conclusion

The Robotics Club at UCF has devoted a year of hard work to ensure the success of the Autonomous Surface Vehicle (ASV) known as Classic Boatname. Unique features that have allowed the platform to maintain robust levels of versatility and modularity such as its 3-DOF motor configuration, pontoon-frame assembly, and DIN rail- outfitted electronics box have enabled the team to focus on mission critical improvements. Features such as the PIDAR, extended camera mount, hydrophone mount, underwater camera enclosure, front bumper, and all of the corresponding software enables the vehicle to be an effective competitor in the RoboBoat 2014 challenges.

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