The University of Texas at Arlington RoboBoat 2014

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Abstract

This paper describes the design and capabilities of the University of Texas at Arlington's 2014 RoboBoat entered in this year's AUVSI International Roboboat Competition in Viriginia. The paper describes the current capabilities of the boat as well as all the innovative design features. It highlights the features changes from the 2013 competition Roboboat such as: 45% weight reduction, actuated camera stand, redesigned hull, new designed motor mounts, deck redesign and more robust vision, control and sensing architecture. Redesign of the compute hardware, sensing, and power systems lead to a more robust system infrastructure as well as to a uniform software system built entirely on top of the distributed ROS (Robot Operating System) formalism. Within this framework, additional sensor systems, including a panoramic camera that allows a complete view of the surrounding of the boat are integrated with additional navigation modes, including a visual map based path planning component using Voronoi diagrams for buoy field navigation. Additional new challenges will be addressed using an underwater camera as well as a hydrophone.

Introduction

The 2014 International RoboBoat competition is the 6th annual competition sponsored by the Association for Unmanned Vehicle Systems International (AUVSI) Foundation. The competition requires different student teams to design and race unmanned fully automated vehicles that will complete certain objectives in an aquatic obstacle course within a time frame to collect points. Students from different engineering disciplines are opportune to work together for the design and engineering of the vehicles; thus providing them with the opportunity to hone their individual skills as well as develop systems engineering skills.

This is the second time the University of Texas at Arlington (UTA) RoboBoat team will be participating in the competition. The current team consists of undergraduate and graduate students as well as faculty advisors all interested in Robotics and Autonomous vehicles from different disciplines: Mechanical Engineering, Electrical Engineering, Computer Science Engineering and Industrial Engineering. This year, the UTA RoboBoat team has focused its effort on the design and construction of a new lighter boat with enhanced vision, control and sensing capabilities. Building off feedback from last year's competition, all the issues from the 2013 boat will be addressed in the 2014 design.

This report presents all the capabilities of the 2014 RoboBoat, new and old; detailing the various hardware and software components.

UTA RoboBoat Hardware

With regards to the hardware (the main boat), the main considerations were weight, maneuverability and stability. In the new boat, adjustments in hull and deck design and material selection assured that the aforementioned considerations were met. The new boat (without payload) weighs 28.5 pounds, a 45% reduction in weight from 2013's boat. The new boat design is shown in Figure 1.

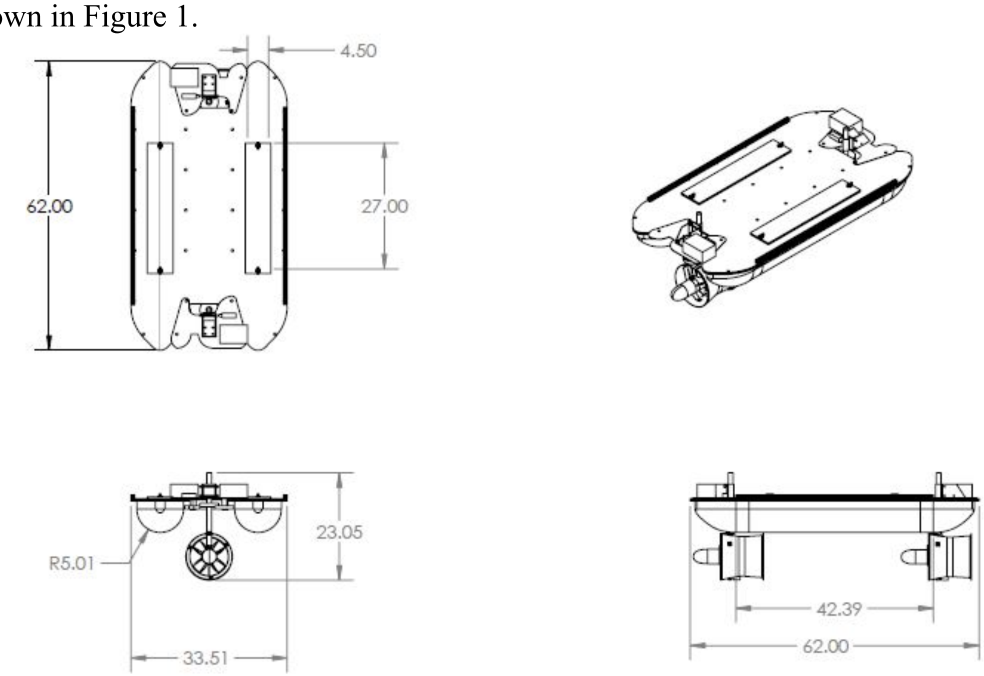

Figure 1: Boat Design

Hull Design

The first step in design of the boat was to determine what the shape of the hull would be.

The performance requirements of the hull were very specific. The boat must not weigh more than 140lbs, stay afloat for at least 30minutes, fit in a six foot by 3ft by 3ft box, maintain a flat and stable platform, protect electronics from water, and do all of this at low speeds.

The barge and the catamaran/pontoon options were considered as viable options and a direct comparison of an initial model of each hull was made. The catamaran was found to have a very immediate reaction to tipping. At 5 degrees of tip there was a 52ft-lb righting moment and at 10 degrees there was a 102ft-lb righting moment. The maximum righting moment was found to be 104ft-lbs at 15 degrees. This means that the catamaran reaches 98% of its maximum righting moment at 10 degrees of tip. In contrast, the barge was found to have only 19ft-lb moment at 5 degrees and 39 ft-lb at 10 degrees with a maximum moment of 135ft-lbs at 50 degrees. While the barge shows a 30% greater maximum righting moment, it does not reach this until after the entire payload of the boat is likely lost due to the extreme lean angle.

For the purpose of this competition, the pontoon/catamaran is the best choice based on its immediate response to tipping. The profile of the leading portion of the pontoon was chosen to not be pointed. This would essentially make this platform entirely displacement. Consequently the shape will be two half cylinders with semi-spherical ends as shown in Figure 2.

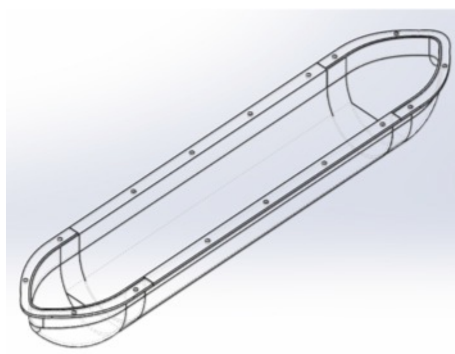

Figure 2: Pontoon Design

13”x 6” access hatches on the deck were created to allow for storage in the pontoons. Using the pontoons for storage is beneficial in two ways. First, pontoon storage lowers the center of gravity increasing the stability of the boat. Second, pontoon storage clears up deck space and reduces the chances of control equipment getting in the way of task oriented equipment during operation. Furthermore, the diameter of the half cylinder pontoons was chosen to be 10 in to allow a large storage space.

To achieve the goal of weight reduction, the previous aluminum design was abandoned and composite materials were used in place. Wet lay-up fiberglass was chosen as the material that matched the desired performance characteristics for the boat. This is due to the facts that it cures at room temperature and is very cost effective, which are both very important details. The fiberglass fabric used for this process is known as E-glass and is the most common due to its low resin content control and low compaction pressures. In order to produce a part in this manner a mold was created. The mold was fabricated from a length of 10" diameter PVC, one 10" diameter 90 degree elbow, 2 4’x8’x.5" medium density fiber (MDF) boards, four angle brackets, automotive bondo, and 2 "2x4"s. To even out the high and low portions of the mold automotive Bondo was coated over the whole mold interior. The top edge of the MDF was filleted with a router and the Bondo was smoothed with sandpaper. As an initial release agent 20 coats of wood floor wax were applied to the Bondo with a heat gun and buffed out. A simple stand was fixed to the bottom to allow the mold to easily store. This was achieved with a frame made of 2x4s. It is important to note that the part needed to be layed up on the inside of the pipe to create a smooth surface on the outside of the pontoon, reducing drag. To ensure that the part would release from the mold a second release agent had to be applied each time a part went into it. This was an aerosol-applied polyvinyl-alcohol (PVA). A gel coat was applied in the same manner onto the PVA. Once the gel coat was allowed to become tacky two layers of fiberglass weave were laid into the profile. This was done carefully ensuring that there were no folds. A catalyst-resin mixture was applied generously to the fiberglass weave and the excess was squeezed out with soft polymer scraping tools. Each pontoon has a sub-deck inside. These were also made out of fiberglass using the same technique (adjusted for size) above.

Propulsion

During the design process, the possible use of jet motors were considered, however after research we decided to continue with the use of the trolling motors from the 2013 model. This is because in order for jet motors to be used, holes must be cut in the hull of the boat, with the main body of the jet covering the hole on the inside. Since the current hull design includes the storage of electronics, this is not a feasible idea. Also, in order to maneuver the boat, multiple jet motors would be needed, therefore increasing the amount of holes needed to be to cut in the hull. Two larger jet motors could be used, but these motors were made for boats much larger and heavier than RoboBoat competition will allow. Multiple smaller jet motors could be used, but these motors were designed for boats much smaller. The alternative would be to design and build a custom jet motor. The disadvantage to this is the time and money that would be needed for this venture, whereas the current trolling motors have already been researched, developed, and proven effective. Two steerable trolling motors capable of producing were placed equidistantly between the pontoons. The propellers are covered by a 3D-printed shroud.

Deck and Sensor Platform Design

The deck was also redesigned to specifically accommodate the sensing and control architecture. Also, plexiglass deck was abandoned for the lighter KAY-CEL polyurethane foam deck board. Since the design of the hull accommodates the storage of the electronic equipment, the deck will be considerably less cluttered this year. 80x20 aluminum rails placed in an H-shape on the deck are used to connect several important electronics. Off the rails, rapid printed prototypes and 5" carbon fiber rods are used to attach the underwater microphone and camera to the side of the boat. At the center of the boat, the vision and mapping architecture is assembled; a metal plate attached to two carbon fiber rods provide support for the GPS, fronting facing camera and radio equipment. Between the two rods, a 41" carbon fiber rod carrying the 360 degree camera assembly is attached to a servomotor to serve as the actuated camera stand. This central camera mast will be raised to provide a better view of the buoy filed and can be lowered to allow the boat to stay within the size limitations.

UTA RoboBoat Control, Sensor, and Computation Design

To take advantage of the new boat platform, to address the new requirements imposed by the new competition tasks, and to overcome some of the hardware instability issues arising during the 2013 competition, the control, sensor, and computation components on the boat were re-designed from scratch.

Computation, Control, and Power Hardware

Utilizing the new, accessible pontoon design the computing, control, and power systems were re-designed to fit into the pontoons, leaving the deck of the boat empty for the sensor components and any payload that might be added as additional tasks for the boat emerge. This not only leads to a better organized and easier to expand boat layout but also significantly increases weather resistance of the overall boat.

To allow for the embedding in the pontoons and to optimize available computation resources, the laptops used in the 2013 boat were replaced with a small form factor PC motherboard with a quad-core i5 processor. Similarly, the embedded microcontroller for motor control used last year was replaced with a more powerful and expandable Beaglebone Black embedded microcomputer with added real-time computing capabilities and a custom-designed electronics shield that provides isolation between the computing and electronics components and provides for real-time monitoring capabilities of the battery status and the power system. Use of this new control hardware allows streamlining the communication architecture for the control software but also addressed many of the control stability issues that hampered the 2013 boat at last year's competition. The Beaglebone Black is used to control all motors and monitor the power system.

Similar to the computing and control hardware, the power system has also been re-designed from the one used last year and embedded in the pontoons. The power system on the 2014 UTA RoboBoat is driven by Shorai Lithium Iron batteries and designed to have completely isolated power systems for the electronics and the motor drives. The separation of the power circuits is aimed at ensuring that power ripples from the motor system do not influence the computing hardware and is achieved through optical isolation on the specially designed shield for the Beaglebone Black controller hardware.

Propulsion Control

As described previously, the propulsion system for the UTA RoboBoat uses 4 degree of freedom thrust vectoring design introduced in last year's boat. This provides the boat with a redundant drive system that, in principle, allows for fully holonomic movement of the platform, including turning in place, moving sideways, and other maneuvers, as required. To be able to utilize this design, a simplified dynamic model of the platform was developed which models the pontoons using asymmetric drag characteristics and derives thrust values for desired platform velocities (translational and rotational) for different modes of operation. The latter is important as the redundant propulsion design with 4 degrees of freedom (two thrust motors and two steer motors) allows for multiple solutions to achieve the same steady-state platform velocities.

To be able to use this thrust model in the context of precision navigation, it is essential that the thrust characteristics of the motors are known. To do this, thrust testing was performed and control input to thrust curves were developed for the used motors and propellers.

Thrust Testing

Initially, the thrust testing was performed a lake near UTA. However, disturbances produced by wake boarding on the lake caused turbulent waves to form spontaneously causing issues in testing. Accordingly, the subsequent thrust test was performed in a residential area pool, which furnished a more ideal environment for thrust evaluations. The fish scale, multimeter, batteries, battery chargers, rope, and laptop were utilized during the thrust test. The control group started thrust testing through electrical safety checks. A member then attached rope to the back two padeyes of the RoboBoat. This rope was then tied in the middle to another rope leading to the fish scale. The other side of the fish scale was attached to a rope tied onto a chair for a fix support. Concurrently, another member was testing each battery with the multimeter. For consistent results, a battery swap was conducted between each thrust test. Otherwise, if the voltage were below 12 V, then batteries deterioration could occur due to the overextended usage below a tolerance level. Figures 3 showcases the thrust testing setup.

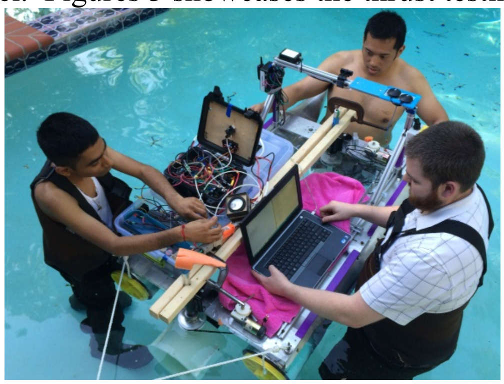

Figure 3: Thrust Testing Setup

While attempting to find the maximum and minimum frequencies to power on the RoboBoat, it was noticed that the suggested pulse-width modulation (PWM) range was smaller. For the reduced range, 10 equally spaced input settings were established. In general, thrust was measured from the back propeller using an analog fish scale with the output voltage taken at the devised splice connecting the propeller to the power supply.

The analog fish scale used was calibrated to ensure correct readings. To do the calibration, three standard weights with known values were weighted and the values for the analog scale recorded with a digital scale used for comparison. After doing the testing procedure and performing the thrust test, data was collected and analyzed. As shown in figure 9, the results from the thrust testing show that there is a linear relationship between the thrust of the motor and the voltage.

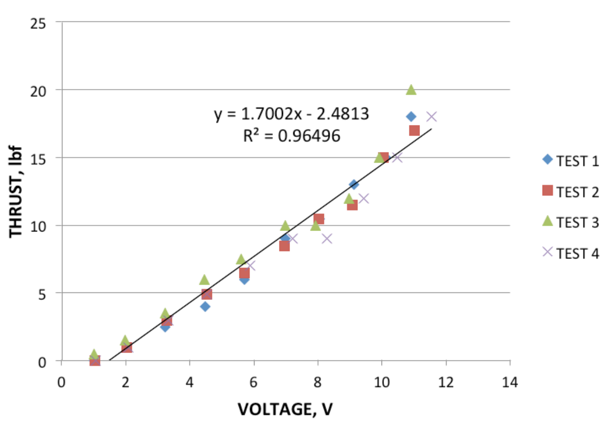

Figure 4: Voltage Versus Thrust Data From Thrust Testing

As seen on the thrust graph, the maximum thrust that is generated by the motor is 20 lbf at a voltage of 12 volts, which was not the thrust expecting from the initial MATLAB simulation.

The specifications of the motor states that the maximum thrust that the motor can produce is about 30 lbf. The minimum thrust is zero at each test run, and there is some voltage since the propeller is moving slowly in the water. Even though projections for the RoboBoat indicated about 40 lbf from the initial MATLAB simulation, actual performance of the thrust revealed that the value was lower than expected. A possible explanation for the lack of thrust is due to the batteries being incapable to power the RoboBoat at high input settings. To address this, the new boat will use an increased capacity battery configuration which will use two batteries to power the drive system.

Sensor Systems

To address the new task challenges, the sensor system was extended by a panoramic camera system, an underwater camera, and a hydrophone.

Vision System

The vision system is the main sensor system used for the speed gates, the buoy field, the docking challenge. In addition, it will be used for boat navigation in the underwater pinger and return to dock parts of the overall challenge. The vision system consists of a forward-facing stationary camera mounted on the lower sensor platform in the middle of the boat, and of a panoramic camera system using a Fujinon super-fisheye lens that will be mounted at the top of the raiseable sensor platform. The forward-facing camera's main task will be in detailed navigation as well as in reactive obstacle tasks while the main tasks of the panoramic camera will be to establish and maintain an overall view of the vicinity of the boat, to build maps for the navigation planning, and to allow precision tracking of the boat in the context for the obstacle field and the docking challenges. Figure 5. Shows the view of the panoramic camera in a test setup in the software development laboratory of the UTA RoboBoat team.

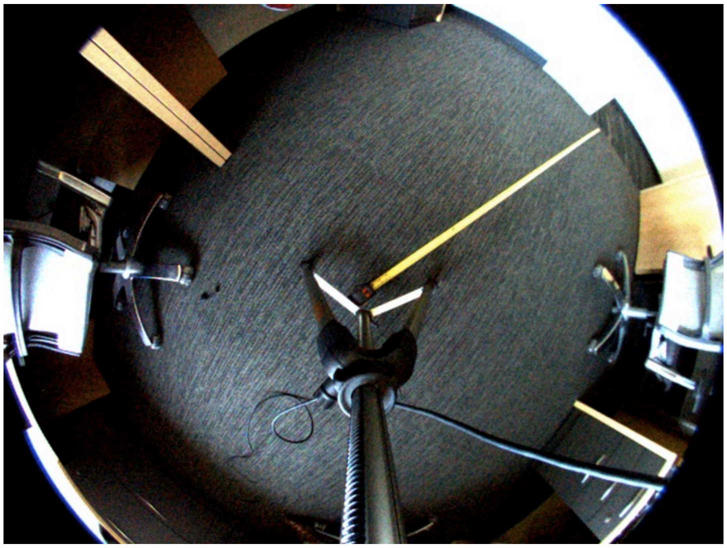

Figure 5: Field of View of the Panoramic Camera

This image illustrates how the panoramic camera can obtain a complete view of the entire surface of the environment with higher resolution in areas closer to the boat, decreasing the further objects are from the boat.

GPS and Compass

To address navigation tasks without visual targets and to be able to reliably identify the locations for the challenge tasks, a GPS and compass system are mounted on the stationary sensor platform in the center of the boat. This system will be used to integrate with the visual identification components to allow navigation to specified locations and in particular to targets that are outside the visual range of the cameras (such as returning to the dock).

Underwater Vision System

An underwater camera is mounted inside a carbon tube reaching down from the deck into the water under the deck. This camera will be used to address the color sequence identification challenge. This camera system is stationary and boat location will be controlled throughout this challenge to keep the while continuous light close to the center of the visual field to optimize identification ability for the colored lights.

Underwater Hydrophone System

A hydrophone will be mounted inside a second carbon tube under the deck of the boat reaching from the deck into the water. This hydrophone will be used to listen for the pinger sound in the underwater pinger search challenge. Initially, the use of a hydrophone array was considered which could limit the need for moving the boat from buoy to buoy in order to identify the one that housed the pinger based on sound amplitude. However, due to resource limitations, the current boat uses only a single hydrophone which will require an active search strategy to identify the pinger location.

UTA RoboBoat Software Architecture

Moving the compute hardware to the integrated i5 computer board running Ubuntu and the Beaglebone Black running Angstrom leads to a significantly more uniform software architecture on the boat due to the move to a completely Linux-based infrastructure that supports the distributed ROS (Robot Operating System) [1] more natively. All need for additional RS232 interfaces to the embedded microcontroller are eliminated and all software now communicates using ROS. The operating system on the Beaglebone Black which is used for device control has been modified to include Xenomai real-time task support to allow for predictable and accurate control loops needed to ensure good performance of the steering system of the boat and to increase the reactiveness of the overall control system. Real-time control and the ROS distributed communication and task integration system are tied together through shared memory in order to ensure the best performance.

Propulsion and Navigation Control

For navigation control, three modules are implemented in ROS, one handling the boat dynamics [2][3], effectively translating desired movement directions into commands to the four boat motors, one to handle the vision-based navigation for the speed and obstacle navigation tasks, and one for GPS-based open water navigation to reach the destination for the challenge tasks.

To be able to develop these capabilities while the boat was still under development and to allow for efficient testing, a simplified simulation model with the new sensor systems has been developed using the ROS/Gazebo system. While this simulation does not completely accurately reflect the complex dynamics of the actual boat platform, it useful to initial algorithm development and testing. The basic view of the simulator is shown in Figure 6.

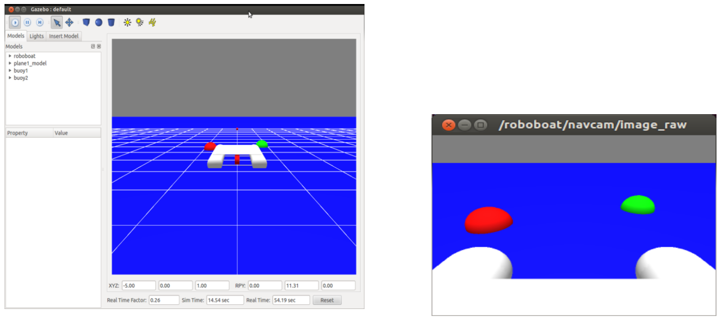

Figure 6: ROS/Gazebo Simulation of the Boat System

Navigation

To address the changed task requirements, the purely reactive control approach based on visual servoing used for last year's boat was augmented with a mapping and path planning component to allow for more deliberative navigation needed for buoy field navigation and precision docking. To achieve this, vision processing had to be augmented, mapping code had to be added, and a path planning system had to be developed.

Vision Processing

To be able to address both the colored buoys and the dock components which are identified by symbols, the vision processing system extracts objects of interest in the picture based both on color and shape. For the former, a blob coloring approach on the two camera images is used which can efficiently identify regions of a specific color, the size of the area, and its location within the image. This identification component is used largely for the buoys where shape is not important. To identify dock areas as well as the symbols identifying the dock, additional feature-based vision processing is added to the basic vision processing component of the software system. This allows the system not only to distinguish the symbols identifying the docking regions, but also to track the orientation of the dock elements in order to allow precise docking.

Mapping and Map Tracking

Using the objects of interest identified using the vision processing components, the mapping component first maps the image location of the objects into Cartesian coordinates relative to the boat and then integrates this information with previous information into a Cartesian object map of the surrounding of the boat. To achieve this mapping, mapping equations for both the panoramic and the forward-facing camera systems were determined experimentally.

Integration of new image information into the existing map is performed here using a probabilistic framework similar to Kalman filtering and allows not only to maintain a more precise map where temporary observations (or non-observations) of a buoy or object does not invalidate the map in the long run, but also allows to visually track the boat during the navigation task and update its location within the obstacle field or dock are with significantly higher accuracy than permitted using GPS or inertial sensors.

Path Planning and Control

To address the different challenges, three different path planning and path control modes will be sued on the UTA RoboBoat. For maintaining position in the light identification challenge as well as to avoid local obstacles and final docking steps, a reactive navigation control mode based on visual servoing will be implemented. To perform navigation to remote and GPS-based targets, a via-point based path planning method that searches for the best route through a number of pre-programmed via points will be used. This allows safe navigation through the lake without risk of hitting the water's edge without relying on visual markers. The third mode will be used largely for navigating the buoy filed and will use the visually-derived map discussed in the previous session to plan a path. To find the path, a path planner based on Voronoi diagrams will be used. Use of Voronoi diagrams together with a heuristic path search that emphasizes available clearance and low curvatures over path length ensures that paths are maximally safe and efficient for traversal by the boat. Expansion of the visual objects to account for the size of the boat as well as a safety margin (together with the holonomic properties of the boat) here ensure that all paths derived will actually be navigable by the boat platform.

Light Sequence Identification

To identify the sequence of underwater lights, the underwater camera will be used. To find the light and ensure clear observation of the light sequence, an initial search procedure followed by visual servoing based on the while center light will be used to move the boat within the vicinity of the provided GPS coordinate.

Underwater Acoustic Signal Search

To identify the location of the underwater pinger, the hydrophone under the boat will be used. As only a single hydrophone (as opposed to a hydrophone array) is used, an active search procedure will be sued that moves the boat between the possible location buoys. Based on changes in the signal amplitude during the movement, the buoy above the pinger will be identified and reported.

Conclusion

Based on experiences in last year’s competition and the change in competition tasks, the UTA RoboBoat team has re-designed the boat to be used in 2014 from scratch, integrating both lighter materials but also additional sensors and control hardware to obtain more reliable and robust performance. The team involved is a multidisciplinary student team. The new boat using accessible fiberglass pontoons not only reduces the weight of the boat significantly but also allows moving of compute hardware into the pontoons, thus de-cluttering and waterproofing the platform. Additional changes to the control hardware have led to a tighter integration of the software components, moving the entire system into the distributed ROS framework.

Acknowledgments

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