AUVSI Roboboat Journal Paper

Embry-Riddle Aeronautical University Team Seagle 4.0

May 23, 2011

Abstract

The Robotics Association from Embry-Riddle Aeronautical University is proud to present the Autonomous Vessel Seagle 4.0, a vehicle system designed to compete in the 4th Annual International Roboboat Competition. The name Seagle (pronounced '$s\bar{e} - g\text{ə}l$') is an aqueous version of the university's eagle mascot and a play on the word seagull. Seagle 4.0 uses a hydrodynamically efficient wave-piercing pontoon design. Each pontoon incorporates a fin-style keel to which a VideoRay electric thruster is mounted. A lightweight wood laminate deck joins the pontoons and creates a mounting surface for the sensor mast, electrical components and the payload. The Seagle team used innovative new approaches to solve the challenges specific to this competition. Our goal is to make use of the knowledge and experience gained from previous competitions and research while attempting to address all the challenges posed by this year's competition. At the time of this report, the team had logged approximately 30 hours of pool testing and in the Indian River as well as another 50 hours of software simulation. Our goal is to be successful in every element and phase of the competition.

INTRODUCTION

An Autonomous Surface Vehicle is a floating, untethered robot capable of performing complex tasks without human interaction. Seagle 4.0 represents a major advance in technology compared to the previous Seagle platforms.

Components inside the electronics enclosure include the onboard computer, a wireless router for communication during testing and debugging, a Devantech two- axis motor controller, a Parallax servo controller, a Reactive Technologies servo multiplexer, and batteries.

THE MISSION

The mission requires that all vehicles be remote-controllable and be able to be brought back to dock on their own.

The first mission task is a demonstration of the vehicle's thrust. This is accomplished by attaching the vehicle to a thrust measurement system attached to a dock, most likely a strain gauge. The team is required to create a harness system for their vehicle, so only one simple connection is made between the harness and measurement system.

The second task is a demonstration of speed. The vehicle will have to pass through two speed gates designated by red and green buoys, with a yellow obstacle buoy somewhere between gates. The starting gate will be a fixed distance from the dock. The second gate, known as the ”speed gate”, will be located between 50-100 feet away from the starting gate. The system of red and green buoys will be used throughout navigation of the competition area.

There will be four challenge stations in the competition, each one representing the four elements: Earth, Fire, Air, and Water.

Earth (Amphibious Landing) - The vehicle must locate a landing zone and make contact with it. From there the vehicle or a subsystem deployed from the vehicle will go up an incline and retrieve a tennis ball before making its way back down the incline and to the water. If a subsystem is used, all components much be returned to the vehicle before departure.

Fire (Find a fire and extinguish it.) - The vehicle will locate a burning ship, and use a water cannon to extinguish the fire by hitting a designated target box.

Air (Find and report a ”hot” target.) - Four low flying targets will be placed above the competition area. each will have pictures of one of the four elements. One of the targets will be twenty degrees hotter than the rest. The vehicle must report which target is ”hot”, and relay its GPS location to the base station.

Water (Turn off the waterfall.) - A waterfall located a few feet from shore will cover up a red button located on the other side. The vehicle must go through the waterfall, and press the button to shut off the water flow. Once the challenges are completed, the vehicle must return to dock through the navigation channel.

DESIGN OVERVIEW

Seagle 4.0 was developed to meet the requirements specified in the 2011 Autonomous Surface Vehicle Competition rules. Emphasis is placed on safety, performance, simplicity of design, operational effectiveness, and reliability. Figure 1 shows Seagle 4.0 in the pool. Although Seagle 4.0 is intended to perform its mission autonomously, it must also be launched, prepared and recovered by a shore-based team. The system design therefore extends to include all aspects of the operation. Safety is always our highest priority, and every aspect of the design reflects this commitment.

Seagle 4.0 is a small electrically propelled pontoon boat that is differentially driven by two VideoRay motors from the VideoRay PRO 4 ROV. Seagle 4.0 is 36 inches long, 24 inches wide and 14 inches high (excluding the payload and GPS mast). Where appropriate, Seagle 4.0 incorporates commercial, off-the-shelf components to help ensure reliability.

A Seahorse case provides a dry environment for the onboard electronics, including a custom built computer, a Devantech motor controller, a Parallax USB Servo Controller, a Reactive Technologies multiplexer (for switching from remote to autonomous operation), four sealed A123 Nanophosphate lithium ion batteries, a Linksys 2.4 GHz wireless router for faster streaming while testing, and a computer controlled switch for the water cannon. Seagle 4.0 includes a camera for buoy and target perception as well as obstacle avoidance, and a GPS and compass for navigation to specified points on the course.

Platform

The hydrodynamic pontoons on Seagle 4.0 are fabricated from Styrofoam Extruded Polystyrene Insulation. This common closed-cell foam material has a trademark light blue color, machines well, is resistant to salt water and most common chemicals, has a low coefficient of water absorption and is exceedingly buoyant, having a density about 1/30 that of water. The pontoons on Seagle 4.0 are fabricated by inserting a plywood fin keel between CNC milled pieces of Extruded Polystyrene. Plywood mounting plates are laminated to the top of each pontoon to provide an attachment surface for the plywood deck.

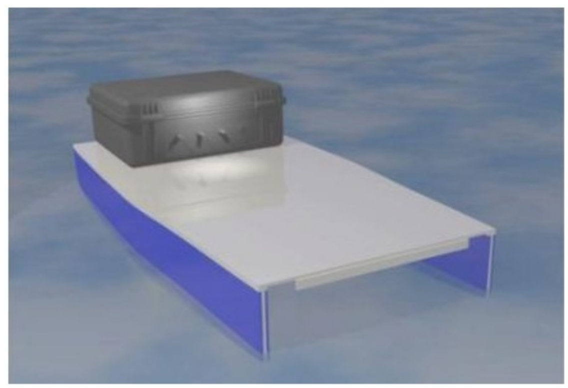


Figure 2 shows the initial design created in CATIA. The plywood keels also provide a secure structure for the thrusters. The Styrofoam and plywood are joined using Gorilla Glue brand polyurethane adhesive. The deck is joined to the pontoon assemblies with wood screws, creating a lightweight structure that can be easily assembled and disassembled. The pontoon assemblies and main deck are coated with glass microballoon filled epoxy to make them tougher and more resistant to water.

A pontoon-style platform was chosen for Seagle 4.0 to provide a stable mount for the electronics and instruments. The stability of the design will allow the Seagle 4.0 to perform more consistently, especially in the navigational aspect of the competition.

Electronics Enclosure

The Electronics Enclosure is a Seahorse brand watertight case mounted directly to the top deck above the pontoons. The stock Seahorse case is watertight, and the use of water resistant connectors along with careful attention to sealing around cut-outs provides a reliable water resistant enclosure for the electronics.

Camera

Seagle 4.0 is equipped with one AXIS 2007W Wireless Network Camera. The camera provides video at 30 frames per second with a resolution of 640x480 pixels. For use on Seagle, the camera is connected via a Cat-5 cable to the on-board router. This was chosen over the available wireless connection for faster, more reliable video. The use of a network camera like the AXIS makes it very easy to check that the camera is functioning correctly at any time, by simply connecting to the on-board router through any outside computer. The camera is placed in a water tight box to protect it from any large splashes that it may encounter, as well as the cascading water from the ”Water” challenge waterfall.

Water Cannon

The water cannon used by Seagle 4.0 is powered by a 09576 model utility pump manufactured by Central Machinery. This pump is self-priming and has a total lift of 23 ft. Two half-inch diameter hoses are attached to the pump. The inlet hose draws water from beneath one of the pontoons. The outlet hose is fitted with a 2mm diameter nozzle to shoot the targets. The nozzle is fixed in a forward-facing direction and is aimed by steering the vessel.

Thrusters

Seagle 4.0 is propelled by two VideoRay thrusters from the VideoRay PRO 4 ROV. The thrusters are powered by brushless motors and together generate 17 pounds of thrust. The thrusters are located on keels halfway along the length of the platform, which gives Seagle 4.0 a zero degree turn radius when combined with the ability to control the thrusters in both the forward and backward directions.

Wireless Router

A Linksys 2.4 GHz wireless router is connected to the on-board computer to connect the camera to the computer, as well as to provide access to the software from a remote location. Testing and debugging can be conducted without wires or physical contact with the vehicle. This allows the team to monitor Seagle 4.0 from shore.

GPS & Compass

The Novatel Smart Antenna with OmniSTAR corrections is a compact, lightweight and weatherproof package that gives a 0.6-meter circular error probable accuracy. The compass is Sparton Digital Compass SP3004D. The 3-axis, tilt-compensated digital compass provides 3-dimensional absolute magnetic field measurement and full 360 tilt compensated bearing, pitch, and roll, as well as an accuracy of 0.3 degrees. The GPS and compass are used together for waypoint navigation. Since GPS cannot generate heading information when the vehicle is stationary, the compass is used to determine heading at low speeds.

Motor Controllers

The VideoRay thrusters on Seagle 4.0 are controller by two Castle Creations Mamba Max motor controllers. The controllers allow for forward and reverse motion of the thrusters, which is combined with the mounting location of the thrusters to give Seagle 4.0 zero radius turning capabilities. The motor controllers have software that allows them to be tuned, which allows the team to make adjustments for more precise control over the performance of the thrusters.

Multiplexer

Seagle 4.0 uses a Reactive Technologies multiplexer, which is a two-channel servo input selector. The servo controller connects to the multiplexer output, allowing the drive motors and other actuators to be controlled either by the onboard computer or by radio control. The active input is selected by a radio control channel, allowing the vessel to be overridden or disabled at any time by the safety pilot.

Component Diagram

Please refer to Appendix A.

SOFTWARE DESIGN

The software developed to accomplish the mission uses an AXIS network camera to locate the buoys, obstacles, and objectives. All of the objects to be located have distinct and well-known visual characteristics, so no other sensors are required for perception. Before the course can be attempted each vessel must complete a thrust test. The maximum amount of thrust produced during this portion of the competition is measured, and Seagle 4.0 can be autonomous or remote controlled.

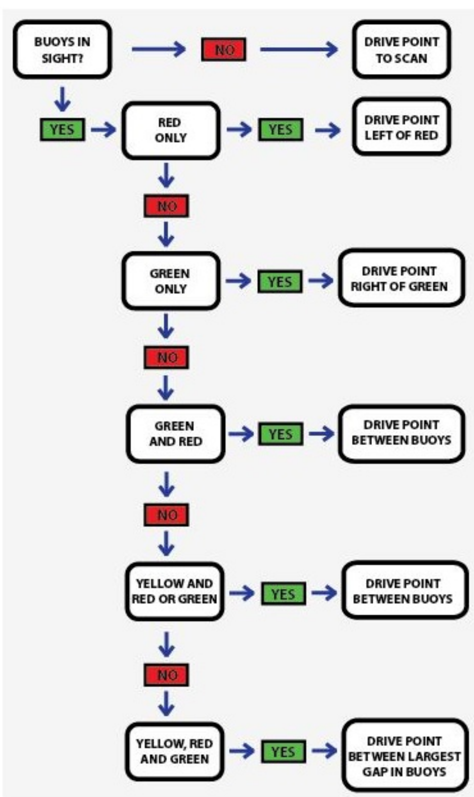
The first task in the competition is the speed gate challenge. In this portion of the mission, the buoy recognition software finds the first gate. The heading from the compass is used to steer the proper course and by using the vision Seagle 4.0 finds the second gate, signifying the end of the speed gate challenge. Having traveled the length of the speed gate, the algorithm switches into the buoy channel navigation and obstacle avoidance portion of the mission software. As Seagle 4.0 moves through the buoys for the first time, it keeps red buoys to the left and green buoys to the right. When encountering yellow buoys, Seagle 4.0 will find the greater distance between the yellow buoy and either red or green buoy. When Seagle 4.0 reaches the blue buoy signifying the end of the channel, the state machine will switch over to the next state.

The software will then follow the magnetic bearing giving at competition for the first challenge station. After finishing a station, or attempting for a predetermined amount of time, Seagle 4.0 will return to the blue buoy and depart on the next bearing to attempt the next challenge station. When all challenge attempts have been completed, Seagle 4.0 will return to the blue buoy for a final time, before heading to the end of the buoy channel. Here, Seagle 4.0 will switch back to the buoy channel navigation and obstacle avoidance portion of the mission software.

In this case, the orientation about buoys will be switched, with red buoys to the right and green buoys to the left. Yellow buoys will be avoided in the same manner. After passing through the channel, Seagle 4.0 will return to dock to complete the mission.

Navigation Algorithm

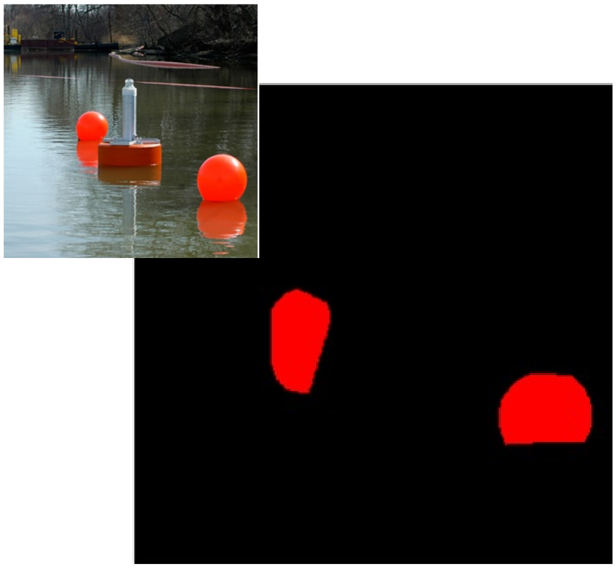
When the vessel senses a single red and a single green buoy, it will calculate a point equidistant between them and drive towards it. If the vessel only sees a red buoy, a drive point offset a user-specified distance to the left of the buoy will be selected and the vehicle will drive towards that point. If the vessel only sees a green buoy, a drive point offset a user-specified distance to the right of the buoy will be selected and the vehicle will drive towards that drive point. If the vessel does not see any buoys the drive point will be set to turn in place to reacquire the buoys. Figure 4 shows the buoy navigation algorithm.



A proportional-derivative control law is used to determine how the vessel drives to a specified drive point. Using a local, vehicle-based coordinate frame, the distance and angle to the point of interest is calculated. As the vehicle approaches the drive point, it will begin to slow down. The turning component commanded from each thruster is based on the heading angle to the drive point. The greater the heading angle to the drive point, the greater the difference in thrust. A derivative control term has been added to the thrust command algorithm to reduce overshoot. This variable is a damping system applied to the forward thrust to prevent over-corrections. A user-specified dead band on the turning component of proportional control prevents the vessel from hunting back and forth when the turn angle is near zero. A throttle control function has also been added, which allows the user the set the total percent of throttle that the vehicle applies to the thrusters.

Vision Algorithm

Seagle 4.0 uses four primary vision processing tools, namely Color Threshold, Remove Particle, Fill Hole, and Convex Hull. Color Threshold defines a range of hue, saturation, and lightness (HSL). Anything within the range is passed on, while everything else is removed. The remaining tools clean up the image to remove any anomalies of small pixel groups and smoothes the shapes left over. In the case of navigation, the process is run for each buoy type. A range of HSL values for each color has been determined through trials in different lighting conditions for each color. These values can be fine tuned prior to competition for the lighting conditions. After all of the image processing, the resulting image is a black background with red blobs representing objects that fit the HSL range. Figures 5 and 6 show the before and after results of a filter for red buoys, with the final image displaying red blobs where the buoys are. Notice how fine tuning of the HSL values can eliminate the slightly darker white and red buoy in the center



The IMAQ Vision toolkit provides forty- nine separate particle analysis tools, including calculation of area, perimeter, and moment of inertia, among others. IMAQ Vision also includes many different functions for manipulating particles. For example, we can call morphology functions that erode, dilate, fill holes, convex (fill holes on the edges), reject objects on the border, and separate blobs. Following color plane extraction, the IMAQ Find Circles command is used to find buoys in the image. This separates any overlapping circles and classifies them based on their radius, area and perimeter. Starting from a binary image, this process can determine the radius and center of a circle even when multiple circles are overlapping. To help filter the data, a minimum and maximum acceptable radius in pixels is specified. In addition, after the computer vision algorithms have been run, additional filtering is done on the data set to help filter out additional objects that are not buoys. To accomplish this, the only largest objects in the image are used, which filters out buoys that are further away and objects in the distance with no relevance to the navigation.

The other objects of interest are detected using the same process along with the appropriate particle filters that will focus further on the target shapes.

TESTING AND DESIGN INTEGRATION

Seagle 4.0 underwent many stages before the final presented product. The mechanical design progressed from a single-hull platform that provided stability and ample room for equipment during testing, to the two-pontoon design final vessel. The team used basic software templates developed for other robotics systems at Embry-Riddle in order to create specific and refined code for Seagle 4.0. Software, especially the vision algorithm, was continuously tested in the lab. The team took the vessel out during different weather conditions to create videos of buoys and targets in the water. These videos were converted to Audio Video Interleave (AVI) format. The team was able to test the code with the videos in the lab without having to set up and run the vessel for every code modification. LabVIEW was essential in the programming process. The front panels display various inputs and outputs that can be tested and checked while the code is running. This allowed the team to test navigation code in the lab by displaying the values sent to the left and right thruster when presented with a sample video. As stated previously, the code did not necessarily have to be tested on a fully functional platform.

CONCLUSION

Seagle 4.0 is a fully autonomous surface vehicle designed and manufactured by engineering students at Embry-Riddle Aeronautical University. In developing Seagle 4.0, the team maintained a mission focus, seeking to meet all the base requirements while providing better than expected overall performance. We believe that Seagle 4.0 demonstrates exceptional systems integration, combining proven software and hardware solutions with unique ideas and novel solutions to accomplish the mission tasks. We expect Seagle

4.0 to be a leader in performance and to attract the attention of perspective visitors and employers.

TEAM ORGANIZATION

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APPENDIX A: COMPONENT DIAGRAM