Stevens Institute of Technology
Autonomous Surface Vehicle

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Abstract

The Stevens Institute of Technology Autonomous Surface Vessel (ASV) team designed and fabricated a fully autonomous marine system to complete a set of tasks set forth for the RoboBoat competition sponsored by AUVSI and ONR. The competition takes place from June 9th until June 12th of 2011. The Stevens ASV is capable of navigating a channel, extinguishing a fire on a separate vessel, locating hot targets then communicating the global coordinates to a shore base, retrieving a payload from land, and demonstrating water resistance by traveling under a waterfall to press a button. The ASV system weighs 100 lbs and measures 66 in x 31 in x 30 in. The design came out of a collaborative effort between the Naval Engineering (3), Mechanical Engineering (4), and Computer Science (2) students of Stevens. The work done by the students was sponsored by the Davidson Laboratory, the Office of Naval Research, and the Stevens Mechanical Engineering Department.

1. The Platform

Hull Selection

Four major hull forms were considered for the platform: monohull, catamaran, trimaran, and SWATH. Based on the competition, several criteria were used to evaluate the best hull form. These included

- Significant points are to be awarded for being under 70 pounds, while a very large amount of points are deducted for a vessel over 110 pounds.
- The vessel will operate fully autonomously thus keeping a straight heading is very desirable.
- The maneuverability of the vessel must be very good in order to complete tasks such as the retrieval of items, docking at specific locations, and avoiding obstacles.
- Minimizing the draft would enable the vision system and any recovery system to have a maximum height off of the deck.
- Maximum deck space for placement of various systems
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Each criterion held equal weight on the basis that no one item could be sacrificed at the expense of another. Based on of these criteria, a measure of merits matrix was constructed yielding a catamaran as the best choice. From the results of the table and knowledge of the naval engineers, the platform was designed with a catamaran hull form.

Hull Parameters:

Length	66	in	
Beam total	31	in	
Beam hull	8.5	in	
Max Δ	75.69	Lb	each hull
Design Δ	56.92	Lb	each hull
Depth	30	in	
Draft	6.5	in	

Hull Fabrication

Given design constraints as well as the decision to design a semi displacement hull, a model from the Davidson Laboratory was altered to save time in fabrication. The model chosen was originally a slender monohull vessel therefore two hulls were made. This model chosen only displaced 50 lbs per hull and the vessel was anticipated to be 100 lbs, therefore construction foam was used to add 2 inches of freeboard. The freeboard of the vessel was kept to a minimum to avoid effects of wind on the vessel during the competition. A female mold was created using plaster in order to easily fabricate the hulls themselves out of fiberglass.

Weights Analysis

The weights analysis was performed based upon each system's weight and location. The ASV was broken down into 15 systems with the thrusters and hull counted as the 16th system. For each system the location was recorded from the stern, centerline, and baseline. With this the systems LCG, TCG, VCG, Pitch radius of gyration, and Roll radius of gyration were matched to the hulls characteristics.

Hull Testing

Two tests were done on the catamaran hulls to study the resistance seakeeping. Calm water tests were carried out over two days.

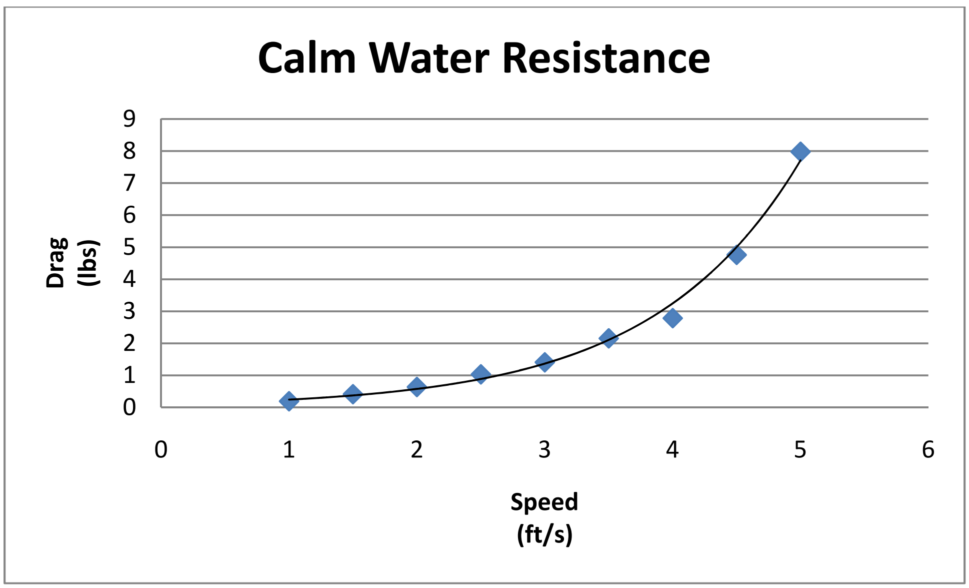

Figure 1 Calm water Resistance data (Davidson Laboratory high speed towing tank)

The results of this testing have lowered the design speed of the vessel from seeing the rapid increase in drag after 3.5 ft/s. To run the vessel at the top speed of 5 ft/s for the entire run would drain the batteries at a much faster rate without any significant gain. Running the vessel at the lower speed allows for the vessel to move at a fast speed when necessary but conserve power to complete other tasks of the mission.

Analyzing the seakeeping data, it was seen that the heave and pitch response of the boat are fairly low for the given conditions of the competition. Since the competition is held in a fairly small pond where the maximum fetch length is 500 ft, the wave periods will be short for normal wind speeds. At very short periods the heave and pitch response of the vessel were both very small.

Thrusters

The thruster system was designed to decrease the need for complex maneuvers and to simplify construction and testing. In looking at the tasks, the three main requirements included sway, yaw, and surge control. The sway control was for minor adjustments such as pressing a button, and docking for the on-land task. The yaw control was for main navigation and the surge control was for the speed gates and bollard pull tasks.

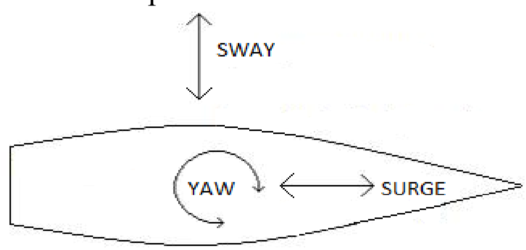

Figure 2

Based off of this, the system of thrusters was designed to facilitate simple coding and reliability. There are two types of thrusters that were installed on the ASV which are the main thrusters and the transverse thrusters. The purpose of the main thrusters is main navigation and large movements (yaw and surge) while the transverse thrusters are used to facilitate small transverse corrections in location (sway).

2. Mechanical Systems

(Earth) Amphibious Landing

Arm

Based on competition, a capture mechanism had to be designed to recover the autonomous robot. Originally a two-member mechanical arm was designed to deploy the autonomous robot. The design has since been modified to a four-bar mechanism that is similar to the original two-member mechanical arm. The problem that occurred with the two-member arm was that each servomotor powering the members required a great amount of torque to maneuver the arm. Because of this, the design was changed to the four-bar mechanism with a linear actuator attached to the platform of the boat that powers the arm. With this, there is less of a risk for failure from the arm, specifically at the joints. This also allows for a much simpler winch-pulley system to control the autonomous robot. The below figure shows the final design of the mechanical arm used to launch the land rover.

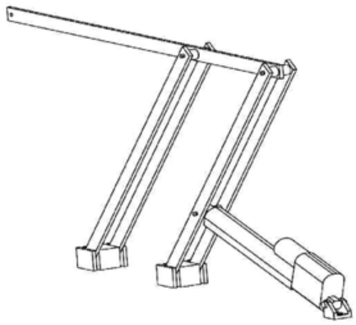

Figure 3 Arm

The mechanical arm was manufactured and assembled with aluminum 6062. The final design, created in SolidWorks and analyzed in FourBar, was custom machined at the Davidson Laboratory. The linear actuator was ordered and integrated with the mechanical arm. The torque on the arm was analyzed at all positions to ensure the design met structural requirements as well as the actuator requirements.

Winch

Another component required to go along with the four-bar mechanism was a winch and pulley system. This winch and pulley is used to recover the robot after it has retrieved the tennis ball. This system was used for a simple way of returning the robot to the ASV after its amphibious landing. Also, the winch and pulley helps connect the robot to the ASV with a wired connection instead of wireless. The motor for the winch was a 782:1planetary Gear Motor. This motor was chosen for its high torque and ability to wind up the Ethernet cable attached to the robot.

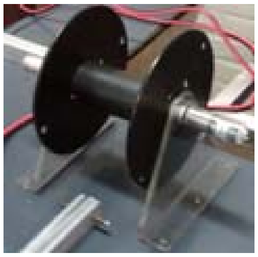

Figure 4 Winch

Rover

The autonomous robot chosen for this task was picked based on maneuverability in various terrains, and the low weight. The Lynxmotion Tri-Track was chosen, which weighs a mere 3.6 pounds and can maneuver easily through rocky terrains.

Multiple alterations were made to the Lynxmotion robot, because the robot is subject to contact with water. The robot was covered in multiple areas with PVC, epoxy, and silicon to ensure it was completely water-proof. Based on the necessity of the competition, two components were also added to the robot. The first component is a Velcro "bumper" attached on the front of the robot. This was required for the capture on the tennis ball during the competition. The second component added to the robot is a vision system for navigation of the robot. This vision system consists of a digital camera attached to the front of the robot encased in PVC for protection from water damage. Finally, a hoist of three wires was created to relieve some of the force on the Ethernet cable that connects the robot to the winch and the computer.

Figure 5 Lynxmotion robot

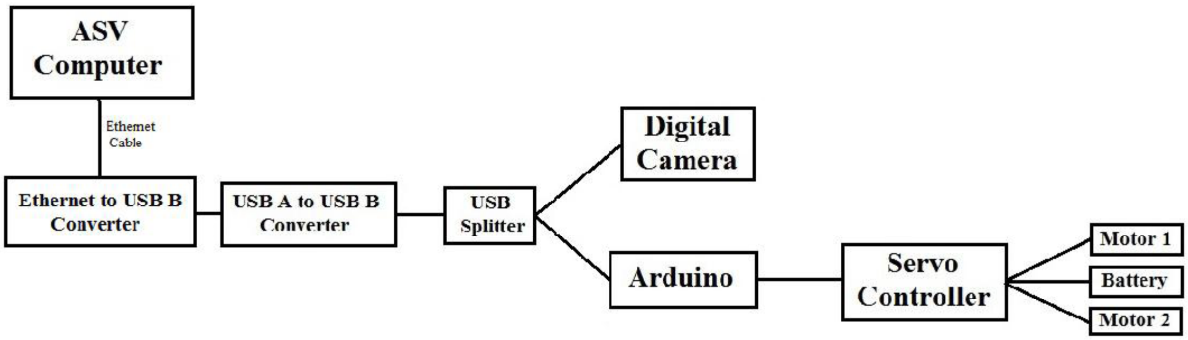

Figure 6 Electrical diagram connecting the rover to the main computer

(Air) Find and Report the 'Hot' Target

Infrared Sensor

. The ASV is required to locate four targets and report back to the base station the global coordinates of the target that is 20 degrees hotter than the rest. To detect the target that is 20 degrees hotter an infrared sensor is used.

The IR sensor chosen has a temperature range between -20°C to 500°C. The accuracy is 1.5% of the reading. Most importantly the optical resolution is sufficient to give an accurate reading of the location of the "hot" target. This sensor has a 13:1 D:S ratio, which is defined as the optical resolution expressed as a ratio of the distance to the target spot divided by the diameter of the spot. If the robot were 13 feet away, the sensor would be reading an area with a 1 foot diameter.

(Fire) Find the Fire and Extinguish it:

Water Cannon

The original pump chosen was a miniature diaphragm pump. These pumps produce outstanding pressures in comparison to their miniscule footprints and light weights, however they are fairly expensive. With the ship's overall weight falling short of original estimates and the budget always being a factor, it was decided that a wash-down pump (commonly used for showers onboard ships) would be used. This pump has more than enough power to shoot the cannon at long range targets. The pump was placed in the hull instead of on the deck as previously planned to keep the center of gravity of the vessel low. Plastic tubing was used to attach the on-deck nozzle to the pump and a servo motor mount with a digital camera. This servo motor mount controls the aim of the nozzle using the input of the nozzle mounted digital camera.

(Water) Turn off the Waterfall

Waterfall Stopper

For this challenge station, the ASV must find a waterfall located a few feet from the shore. Once the waterfall has been located using the vision system, the ASV must go under the waterfall and find and hit a red button that resembles an emergency stop button, in order to stop the waterfall.

For this obstacle, a stopper mechanism was designed to hit the red button. The final design is a bumper mechanism that includes a PVC plate attached to a rod on the ASV. This plate will act as a stopper and will hit the red button. This mechanism is not very precise itself, but will depend heavily on the steering of the hull to hit the button accurately. The final design is an arm made from an aluminum rod that will be attached to the hull at the base and is attached to a plastic plate on the other end. This ensures the stopper is durable yet lightweight.

Navigation

Vision System

For the competition, the ASV must perform various tasks that can be done in a variety of ways. The first criterion to consider is the vision system. Specific sets of tasks require the ASV to visually detect different colors and shapes. This can be done using LIDAR technology, a set of digital cameras that use stereo vision, or a single camera using color recognition. A classification tree was made, and it was determined that the best option was to use stereo vision. Because Labview does not recognize a three dimensional image or point cloud, it was decided to use the single HD USB camera due to time and complexity constraints.

GPS/Digital Compass

The group originally was going to use an accelerometer to account for any discrepancies in the GPS readings but through further testing and research, it was discovered that the accelerometer would contribute little to the accuracy of the location of the boat. The functions that would be contributed by the accelerometer are basically covered between the GPS and the digital compass.

The two components of the tangible navigation, the GPS and the digital compass, were all placed with the computer system in the waterproof case. These two components use USB 2.0 and were attached to the motherboard of the computer. These devices were then integrated into the programming and the readings were calibrated.

Figure 7 Digital Compass

Figure 8 USB GPS

Computer System

The onboard computer system was chosen based off specific metrics such as performance, electrical requirements, space, and weight. Computer vision requires a lot of computation to search images quickly and therefore a muti-core processor that could make use of parallelism was more attractive than a single processor; since the decisions need to be made in real time, even a small delay in processing instructions could lead to the system going off course. At the same time, electrical requirements were an issue because the computer runs off of battery power, and as the performance of the computer increases so does its electrical demand as well as heat production. By choosing components such as a 32GB solid-state hard drive, it was possible to reduce the electrical demands by a somewhat significant amount.

In order to be able to update and control the vessel from a laptop that is not physically connected to the machine, it was necessary to set up an ad hoc wireless network connection between the vessel's on board computer and an outside laptop. This enabled remote desktop capabilities without having to connect a display, mouse and keyboard to the onboard computer in the event that quick changes need to be made, especially during the competition when time is limited.

3. Programming

Due to the difficult nature in designing and programming an autonomous robot, it was crucial that a majority of time was spent on problem solving rather than on interfacing with each hardware component. To expedite this, LabView was chosen as the primary development environment; its easy-to-use graphical programming language allows for rapid development and is simple to understand by anyone without a computer science background. Additionally, LabView has been designed with projects like this in mind, and therefore comes with many libraries and add-ons that are specifically developed for use with hardware equipment for robotics, including machine vision. In some ways, however, LabView was restrictive because of its simplistic nature, and in a few instances C++ libraries were custom written and imported into LabView for more advanced operations (e.g., real-time decision making). With LabView and C++ together, all that was required to fulfill the programming needs was met.

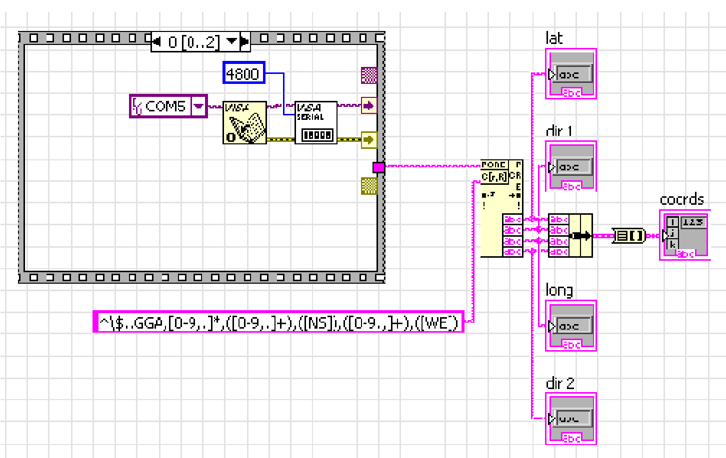

Figure 9: An example of LabView graphical programming language to retrieve coordinates from the GPS device.

Perhaps one of the most important parts of designing a complex system such as this is to design into it a verbose mechanism that allows for auditing if errors or problems occur during execution. Therefore, whenever an event occurs it is logged into an event log that gets reviewed after each execution to make sure that everything is going as planned. Similarly, errors are also logged when they occur and are logged separately. In this way, a very powerful debugging tool is established, to reduce some of the time configuring and testing each process.