Autonomous Surface Vehicle

Senior Design Group #8

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“We pledge our Honor that we have abided by the Stevens Honor System”
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Abstract

There are myriad problems in the world that are too great in magnitude for humans to solve. One recent example of this is the Deepwater Horizon oil spill in 2010, where an explosion caused millions of barrels of oil to leak into the ocean through a hole in a pipe underwater. This caused a massive oil spill that required more manpower and time to clean as time passed. This need for a solution caused several research groups to develop robotic platforms to help clean the oil spill. Most well known of these is a robot developed by MIT known as the SeaSwarm, which autonomously navigates through the oil slick and absorbs the oil with a nanofiber net.

In order to foster the design process and develop skills in systems engineering by completing missions with autonomous robotic boats, the Association for Unmanned Vehicle Systems International (AUVSI) developed the RoboBoat Competition. This competition is comprised of ten tasks that simulate problems that an autonomous boat may encounter, from channel navigation to receiving a payload from a dock.

For the 3rd year in a row, Stevens Institute of Technology is submitting an entry to this competition in hopes to win the competition and allow its students to develop skills to design a solution to a series of problems. Unique to this year’s entry is the inclusion of a team of electrical engineers, who will be tasked with the programming and sensor integration of the boat. They will use sensors such as a Kinect sensing device, high definition cameras, sonar sensors, and infrared sensors. After completion of the project, the team will have an autonomous surface vehicle (ASV) that utilizes all these sensors to complete the tasks set out by the AUVSI.
Introduction

The purpose of this project is to design and create an autonomous boat to compete in the AUSVI Roboboat competition. This competition is an obstacle course designed to be completed by using multiple sensors on the boat. Since the rules to the competition are not released until November, we will use last year’s rules, which will be explained in the Design Requirements, to begin testing our equipment and start writing our base programming.

The competition is comprised of two mandatory sets of tasks and one optional set of tasks. The first set must be completed sequentially before the robot can proceed to the second set of tasks. The second set can be completed in any order, while the third set of tasks can be completed at the same time as the second set.

This is the third time that Stevens is submitting an entry for this competition. As of now the boat that will be used in the competition is already constructed and a majority of the sensors that will be used in to complete the tasks have been purchased by previous teams. However, many things can be improved over past entries. Last year’s entry had navigation problems, where the boat ended up following a duck around the course rather than navigating properly through the course. This prevented the team from completing the first set of tasks, which ultimate resulted in poor competition performance.

Testing and configuration for the sensors is currently being performed by the team, and the base program is being rewritten from LabView to C++. Other main tasks include converting a mini-rover from wired communication to wireless communication, implementing a Kinect sensor for better obstacle detection, and simplifying the circuitry and wiring contained in the control box. Once all the sensors are configured and attached, testing will be done in the Davidson Lab on the Stevens Institute of Technology’s campus.
Design Requirements

The AUVSI has several design requirements that need to be met with regards to the boat’s construction. Because the rules have not been officially released for the 2013 Competition, the group will meet the requirements set in the document “5th RoboBoat Competition – Final Rules” from the 2012 Competition. When the updated rule set is released, the team will make any necessary modifications to meet the requirements outlined in the newer set of rules.

The general requirements for the boat are outlined in the following chart:

<table>
<thead>
<tr>
<th>Rule</th>
<th>Requirement</th>
<th>Detailed Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>Autonomy</td>
<td>The vehicle must be fully autonomous and all decisions must be taken onboard the ASV</td>
</tr>
<tr>
<td>R2</td>
<td>Buoyancy</td>
<td>The vehicle must be positively buoyant and be buoyant for at least 30 minutes in the water</td>
</tr>
<tr>
<td>R3</td>
<td>Communication</td>
<td>The vehicle cannot send or receive any information while in autonomous mode, with the exception of communications for reporting the ‘Hot Suit’ target</td>
</tr>
<tr>
<td>R4</td>
<td>Deployable</td>
<td>The vehicle must have its own 3 or 4 points harness for crane deployment</td>
</tr>
<tr>
<td>R5</td>
<td>Energy Source</td>
<td>The vehicle must use self-contained electrical energy source. Sailboats are permitted</td>
</tr>
<tr>
<td>R6</td>
<td>Kill Switch</td>
<td>The vehicle must have at least one 1.5in diameter red button located on the vehicle that, when actuated, must disconnect power from all motors and actuators.</td>
</tr>
<tr>
<td>R7</td>
<td>e-Kill Switch</td>
<td>In addition to the physical kill-switch, the vehicle must have at least one remote kill switch that provides the same functionality</td>
</tr>
<tr>
<td>R8</td>
<td>Payload</td>
<td>The vehicle must have a place to mount a payload up to a 60-inch cube weighing up to 5 lbs</td>
</tr>
<tr>
<td>R9</td>
<td>Payload Location</td>
<td>The payload must have an unobstructed view of the sky and front of the vehicle</td>
</tr>
<tr>
<td>R10</td>
<td>Propulsion</td>
<td>Any propulsion system is fine (thruster, paddle, etc) but moving parts must have a shroud</td>
</tr>
<tr>
<td>R11</td>
<td>Remote Controllable</td>
<td>The vehicle must be remote-controllable to be brought back to the dock</td>
</tr>
<tr>
<td>R12</td>
<td>Safety</td>
<td>All sharp, pointy, moving, sensitive, etc. parts must be covered and clearly identified</td>
</tr>
<tr>
<td>R13</td>
<td>Size</td>
<td>The vehicle must fit within a six-foot long by three foot wide by three foot high “box”</td>
</tr>
<tr>
<td>R14</td>
<td>Surface</td>
<td>The vehicle must float or use ground effect of the water. Mostly submerged/flying is forbidden</td>
</tr>
<tr>
<td>R15</td>
<td>Towable</td>
<td>The vehicle must have designated tow points and a tow harness installed at all times.</td>
</tr>
<tr>
<td>R16</td>
<td>Waterproof</td>
<td>The vehicle must be rain/splash resistant. The competition is held “rain or shine”</td>
</tr>
<tr>
<td>R17</td>
<td>Weight</td>
<td>The vehicle must be 140 lbs or less.</td>
</tr>
</tbody>
</table>
Relevant to the group’s design interests are R1 (Autonomy), R3 (Communication), R5 (Energy Source), R6 and R7 (Kill switch and E-kill switch), R10 (Propulsion), and R11 (Remote-controllable). Since this is the third year that Stevens is competing in the AUVSI Robo-Boat Competition, there is already an existing boat chassis that meets the rest of the physical design requirements.

Meeting these general specifications will not require a significant amount of effort and engineering design due to their necessity in the construction of the boat. The main requirements to be met come in the form of three sets of tasks that comprise the final competition. The group will allocate the majority of its time and resources to completing these tasks successfully.

Contest Tasks

The competition is composed of three sets of tasks that must be completed to obtain points for final scoring and allow for officials to measure the performance of each boat. The first set is made up of four mandatory tasks related to navigation and localization that are required to be completed sequentially. Failure in these tasks means that the other sets of tasks cannot even be attempted. Because of this high risk, the team will devote most of its time testing boat functionality in these tasks so that the boat is able to complete them in any condition.

The second set of tasks consists of four challenge stations that can be attempted in any order. Each challenge is casino-themed and requires the use of image processing and other different sensors to complete them successfully. The third set consists of two optional challenges; one challenge is performed at the same time as the second set, while the other can only be attempted after completion of every other task.

First Set:
Task 1 - Propulsion Test

In this task, the group will demonstrate the amount of thrust the ASV can generate in ten seconds by attaching it to a strain gauge. This task does not have to be performed autonomously, so the group will be able to control the boat with a remote control.
Task 2 - Navigation Test:
In this task, the boat will demonstrate the ability to steer a steady course by navigating to the starting gate from the dock. A diagram of this task is shown in Figure 2.

Task 3 - Speed Test:
After the completion of task two, the vehicle will then be timed on how long it takes to transit between the starting gate and the speed gate. The starting gate and speed gate will be located such that it is possible to travel between the two in a straight line.

![Diagram of Navigation Test and Speed Test](image)

**Figure 2: Navigation Test and Speed Test**

Task 4 - Channel Navigation Test:
After passing through the speed gate, the boat then will navigate a channel outlined by red and green buoys. The boat will be expected to use the 3R (red-right-return) navigational mantra, which means the boat will keep the red buoys on the port side when entering a large body of water and on the starboard side when exiting a large body of water. The boat will avoid the yellow buoys, which represent obstacles, and navigate through the channel until it reaches a blue buoy, which represents the end of the channel. From this buoy, the boat will be able to navigate to the challenge stations for the second set.
Task 5 - “Poker Chip”

For this task, the boat locates a landing zone and makes contact with it by docking. Once it is there, it will deploy a rover that will navigate the landing zone and pick up a “poker chip,” which is a hockey puck covered in black Velcro. The rover then will navigate back to the boat and deposit the poker chip in the boat. Upon completion of the task, the boat will then un-dock and proceed to the next task.
Task 6 - Jackpot

In this task, the boat is required to actuate a button. The robot will travel through a field of poles which each have a button attached to them. Next to one of these poles is a white buoy full submerged underwater, which signifies that the pole corresponds to the “jackpot.” If this button is pressed, the team will complete the task and earn the maximum amount of points for the task. If the robot presses any of the other buttons, the boat fails the task but will still earn half of the points for the task.

![Figure 5: Jackpot](image)

Task 7 - Cheater’s Hand

In this task, there is a large printout of the “cheater’s hand” located on the shore, which consists of five images of playing cards. One card will have a blue square on it rather than a suit. The robot is required to locate this card and shoot it with a water jet to complete the task.

![Figure 6: Cheater’s Hand](image)
Task 8 - Hot Suit

For the “Hot Suit” contest, there is a set of metal signs on the shore, each marked with one of the four suits of playing cards. One of the signs will be approximately 20°C warmer than the other signs. The boat is required to locate this sign and report which suit is hot (Clubs, Diamonds, Hearts, Spades) as well as its GPS coordinates.

![Figure 7: Hot Suit](image_url)

Third Set:
Task 9 - Five Card Draw

In this optional task, each team is given a random set of 5 playing cards at the start of each run. The “dealer” will have a random hand of 5 playing cards as well, which will remain fixed during the competition.

At each challenge station, there is a card exchange station. You can swap any number of cards in your hand to get the best possible hand that will beat the dealer (following poker rules). The card will be attached magnetically to a card exchange board and will require the boat to remove it.
Task 10 - Return to Dock

This task is simple. In order to successfully complete this task, the boat has to autonomously return to the dock. It will complete this by returning to the channel that it navigated in the fourth task. It will then navigate through the channel the opposite way by following 3R (red-right-return). It will then return to the dock.
Design Approaches

Several design requirements listed by the AUVSI Foundation do not merit significant design attention by the group due to their necessity for the project, such as autonomy and propulsion. Because this is the third time Stevens is participating in the competition, several requirements have also been addressed in the pre-existing boat’s design, such as kill switches, remote control, and waterproofing. The main design focus that the group will be concerned with is the competition and completion of the three sets of tasks. However, this section of the report will briefly address some of the design requirements for the boat’s construction that will require modification to the existing chassis:

Communication – The vehicles cannot send or receive any information while in autonomous mode (with the exception of communications for reporting the Hot Suit target)

This particular requirement is expected to change slightly for this year’s competition. In past competition, the rover used to complete the Poker Chip task had been tethered to the boat by USB cable. One expected change for this upcoming competition is from a USB tether to wireless communication. This won’t affect the boat design significantly as the wording of the rule will change due to technicality.

Energy source – Vehicle must use self contained electrical energy source

The past teams have used two 12V batteries in series to provide X W of power to the computer and propulsion system. The configuration previously chosen had the power to cause power dips and spikes in the computer, which could damage the system. Based on a preliminary system analysis, the batteries appeared to be connected to both the computer and the motors at the same time. In order to fix this, the group will switch the power system over from two 12V batteries powering the whole system to one 12V battery powering the computer and one 24V battery or equivalent battery configuration powering the thrusters.

Propulsion - Any propulsion system is fine (thruster, paddle, etc) but moving parts must have a shroud

The team will not change the thrusters, but may change the configuration. Currently, the boat is expected to steer with differential steering. This method of propulsion may be preferred for the thruster task and the speed task, but will be slower to turn during the channel navigation. There is also concern that the thruster is unable to operate and produce thrust in reverse, which means that the boat would not be able to leave when it docks. Because of these reasons, the team will be working with the mechanical engineering team also involved with the project on creating a steering rudder actuated by a gearmotor that was previously used for the tether winch. This will allow for more precise steering during the navigation as well as the ability to reverse and direct the boat. It is also possible to keep the current configuration and just add a rudder.
First Set

Task 1 - Propulsion Test

The propulsion task is straightforward. The only requirement is that the boat demonstrates the maximum amount of thrust that it can produce over ten seconds. This can be accomplished simply by running the motors at full power for the ten seconds.

Task 2 – Navigation Test

This task will be completed by using the cameras and the Kinect on the boat to navigate to the first set of buoys. A discussion with previous group members about the competition may be necessary; if GPS coordinates of the buoys are known or if we are allowed to do test runs through the course, the boat could just use known or learned GPS coordinates to navigate to the start gate. If a test run is allowed, the group will attempt to implement simultaneous localization and mapping (SLAM) so that the boat will know the environment and be able to navigate through it.

If neither of these is possible due to how the competition is run, the robot will then navigate to the starting gate by rotating in place at the dock until it registers the closest red and green buoys with the camera and the Kinect.

Task 3 – Speed Test

For this task, the robot will use the camera and Kinect to locate the next closest red and green buoys. Once it locates the speed gate, the robot will then actuate the thrusters at full thrust to achieve the highest speed between the two gates.

Task 4 – Channel Navigation Test

Go through the navigation channel by using the Kinect depth sensor to find the closest set of buoys, use the camera to verify buoy color (Red, green, yellow obstacles, and blue for the end), and navigate through the barriers by keeping the center of the processed image between the center of the closest obstacles. One practical solution which may prove to be effective is to square the robot off once it passes another set of obstacles.

Second set

Task 5 – Poker Chip

To complete this task, the rover will use a camera and perform image processing to follow along the marked perimeter. When it recognizes the puck, it will pick it up and then return to the robot by the same route. Odometry will be incorporated if possible; it is not yet known if there is any feedback devices located on the rover. If may be beneficial to mark the boat with a colored marker so that once the robot locates the puck, it can just bring the puck back to the boat directly, taking care to avoid the edges of the platform so that it does not lose the puck or fall off the platform.
Task 6 - Jackpot

For this task, it is necessary to use a particular kind of ultrasonic sensor, known as a “fish finder sensor.” This sensor operates on the principle of SONAR and allows a user to locate schools of fish or, relevant to the competition, a large underwater object. This will allow the boat to locate the underwater buoy that corresponds to the correct button that will complete the task.

Task 7 - Cheater’s Hand

The cheater’s hand appears to be one of the simpler tasks to accomplish for the group. In this task, the robot will use a camera to detect which card has the blue tape outline on it. Once the card is located, the robot will simply shoot the target with the water jet.

Task 8 – Hot Suit

The hot suit will be slightly complicated to complete. Detecting the hot suit with an infrared sensor will be simple, but transmitting the coordinates back will be challenging. The AUVSI rules require a particular format for this transmission. This format is documented in Appendix A.

Third set

Task 9 – Card Exchange

This challenge will be more difficult than the others, which may be why it is a bonus competition. Not only will the robot have to detect the suit of a card, but it will also have to determine the value of a card (from 2 – Ace). In addition to this, the robot will need to know the dealer’s hand, its current hand, and what poker hands can be made from its hand that will beat the dealer hand. There are methods of shape recognition that can be done with an open source computer vision library known as OpenCV. The group will utilize this to complete the task of recognizing suit and card value.

Task 10 - Return to Dock

There are several ways for this task to be accomplished. One way is to have the robot rotate in place upon completion of the final task until it sees the blue buoy. The boat then navigates to the blue buoy, locate the channel used in task 4, and negotiate the channel by keeping the red buoys on the starboard side.

Another alternative would be for the boat to log the GPS coordinates of the blue buoy once it completes task 4. It can then use these GPS coordinates to navigate back to the blue buoy when the robot attempts to return to the dock. It will then perform the same navigation as state above by keeping the red buoys of the channel on the starboard side until it returns to the dock.
Conclusion

The AUVSI Roboboat will be designed to complete the tasks described in the above sections. In addition to programming the boat to complete each task successfully, the group will also program it to be robust enough to operate in different weather conditions. The scope of the project includes converting a rover from a tethered connection to a wireless connection with the boat, improving the performance by converting the program from LabView to C++, and integrating the Kinect sensor with HD cameras for improved obstacle detection and recognition. The majority of the work will be directed at completing the first set of tasks, which is a concern following last year’s competition. After this is accomplished, the group only needs to program the boat to navigate to a challenge station and complete the task. Once the updated rule set is released, the group will be able to finalize the requirements for this year’s competition and begin work on design approaches to meet them.
References

2012 AUVSI RoboBoat Competition Rules
http://www.auvsifoundation.org/foundation/competitions/roboboat/

2012 Stevens ASV Journal Paper
http://stevens.edu/asv

Open CV
http://opencv.willowgarage.com/wiki/

SLAM
Appendices

Appendix A: Network Communication Protocol

5.2.5 Network Communication Protocol

All messages are TCP messages (UDP will not be supported). The protocol is ASCII based and each command is terminated with a Linefeed (LF) character (ASCII value: 0xA). The protocol description below will use the value “\n” to represent the Linefeed characters. The following commands are available:

Ping command:

- Used for: Testing connectivity with reporting service
- Sender sends: “PING\n”
- Service response: “PONG\n”

Report command:

- Used for: Reporting the ‘hot’ target and its position
- Sender sends: “REPORT;<university>:<target name>@<gps>\n”
- Service response: “SUCCESS\n” or “FAIL\n” or “ERROR\n”

Meaning of response:
- SUCCESS = reported accurately the hot target.
- FAIL = reported the wrong target or GPS
- ERROR = the request is malformed

Possible values for <targetname>: “HEART”, “DIAMOND”, “CLUB”, “SPADE”
Format of values for <university>: regex: [A-Z]{2…5} A two to five upper letter code to identify your university/team. Ex: URI, UCF, GTASL, VT, etc. Teams will need to come “register” their acronym the first time they schedule a time in the water.
Format for GPS positions (in WGS84 datum): “<LATITUDE>,<LONGITUDE>”

Examples:

- ASV: “PING\n”
  Service: “PONG\n”
- ASV: “REPORT;AUVSI:CLUB@40.688888,-74.045111\n”
  Service: “FAIL\n”
- ASV: “REPORT;AUVSI:DIAMOND@36.802327,-76.191379\n”
  Service: “SUCCESS\n”
- ASV: “TIMELEFT\n”
  Service: “ERROR\n”

Any other command issued will be answered with “ERROR\n”
Appendix B) Task Layout
### Table 1: Static judging scoring sheet

<table>
<thead>
<tr>
<th>Subjective Measures</th>
<th>Max. Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility of team website</td>
<td>50</td>
</tr>
<tr>
<td>Technical merit (from journal paper)</td>
<td>50</td>
</tr>
<tr>
<td>Written style (from journal paper)</td>
<td>50</td>
</tr>
<tr>
<td>Technical accomplishment (from static judging)</td>
<td>75</td>
</tr>
<tr>
<td>Craftsmanship (from static judging)</td>
<td>75</td>
</tr>
<tr>
<td>Team uniform (from static judging)</td>
<td>10</td>
</tr>
<tr>
<td>Video quality (from introduction video)</td>
<td>25</td>
</tr>
<tr>
<td>Discretionary static points (awarded after static judging)</td>
<td>40</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>375</strong></td>
</tr>
</tbody>
</table>

### Table 2: Performance judging scoring sheet

<table>
<thead>
<tr>
<th>Performance Measures</th>
<th>Max. Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>See Table 3</td>
</tr>
<tr>
<td>Generate F pounds of thrust (thrust measurement lbs)</td>
<td>(F / weight) * 100</td>
</tr>
<tr>
<td>Pass through the starting gate</td>
<td>100</td>
</tr>
<tr>
<td>Navigate from Starting to the Speed gate in T seconds</td>
<td>250 - T</td>
</tr>
<tr>
<td>Enter navigation channel</td>
<td>50</td>
</tr>
<tr>
<td>Navigate through X buoy set in the channel</td>
<td>X x 50</td>
</tr>
<tr>
<td>Avoid N obstacles in the navigation channel</td>
<td>N x 100</td>
</tr>
<tr>
<td>Successful dock+deployment or go up the ramp at Poker chip station</td>
<td>1000</td>
</tr>
<tr>
<td>Return back to water with poker chip</td>
<td>2000</td>
</tr>
<tr>
<td>Jackpot station</td>
<td>1000</td>
</tr>
<tr>
<td>Cheater's Hand station</td>
<td>1000</td>
</tr>
<tr>
<td>Hot Suit station</td>
<td>1000</td>
</tr>
<tr>
<td>Make at least one beneficial card swap</td>
<td>500</td>
</tr>
<tr>
<td>For each additional beneficial card swap</td>
<td>100</td>
</tr>
<tr>
<td>Beat the dealer at 5-card draw</td>
<td>250</td>
</tr>
<tr>
<td>Be the only team/vehicle to attempt a challenge station (bonus) *</td>
<td>500</td>
</tr>
<tr>
<td>Return to dock</td>
<td>500</td>
</tr>
<tr>
<td>Finish All Tasks with T minutes Left on Clock (whole + fractional)</td>
<td>T x 100</td>
</tr>
</tbody>
</table>

* = If a team is the only team to have attempted a specific challenge station during a stage of the competition (qualification or final), they will be awarded 500 bonus points for that station irrespective of whether or not they succeeded.