Old Dominion University
Autonomous Surface Vehicle Team

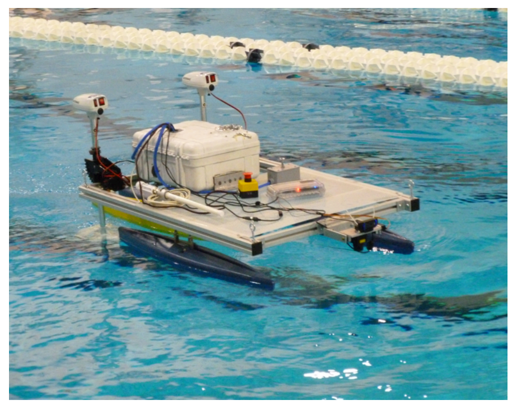
2012 – 2013 AUVSI Competition

Stanton Coffey, Haole Guo, Timothy Hahn, Matthew Hinson, Christopher Johnson, Michael LaPuma, Bradley Lesher, Ryan Snyder, Clayton Stagg, John Too
Department of Mechanical and Aerospace Engineering
Old Dominion University
Norfolk, VA 23509

***Abstract*— The Autonomous Surface Vehicle (ASV) team at Old Dominion University (ODU) has developed an entry for the 2013 Roboboat competition held by AUVSI. In order to remain competitive, the ASV team decided to expand the ASV's capabilities to attempt the autonomous rover challenge station. The team developed an autonomous rover and redesigned the hull to be compatible with the new mission.**

The autonomous rover is propelled by Arduino-controlled stepper motors, and uses a combination of ping sensors, instructions from the ASV, and logic to navigate. The new hull design features additional buoyancy from the addition of a fourth pontoon, and a deck made of T-track members, allowing for simplified reconfiguration and trim adjustment in future competitions. A deployment mechanism was also designed to deploy the autonomous rover.

Existing subsystems were improved: higher resolution web cams, more compact component storage, and a separation of the electrical power supplies for the motors and electronics in order to increase reliability. The ASV team also worked with Gene Hou to develop and test a new design tool based on Analytical Hierarchy Process (AHP).



I. INTRODUCTION

In response to the increased interest in and wide range of application for Autonomous Surface Vehicles (ASVs), the Association for Unmanned Vehicle Systems International (AUVSI) sponsors an annual ASV competition in Virginia Beach, VA. The ASV team at Old Dominion University (ODU) has participated in the competition for the past three years. For this year's competition, the ASV team would like to attempt the object retrieval challenge in addition to the buoy channel navigation, requiring the use of an autonomous rover.

The previous ASV was on its last inch of waterline and was unable to support the weight of both an autonomous rover and its deployment mechanism. Additionally, all the electrical components were scattered across the deck surface, so there was no free deck space for the new subsystems. A deployment mechanism was also required to deploy the autonomous rover from the ASV to a dock. In order to successfully compete, the ASV team developed an autonomous rover, a deployment mechanism, and a new hull to support them. The team also focused on improving the existing subsystems and added cannons to attempt the hoop challenge.

The ASV team also developed and used a new design tool based on Analytical Hierarchy Process (AHP) under the guidance of Gene Hou. The new design tool was used to develop the new hull, and will be used in future semesters to assist design development.

The ASV team leader is Stanton Coffey, and the project faculty advisor is Gene Hou. The members of the electrical team are Matt Hinson (team leader), Clayton Stagg and John Too. The members of the mechanical team are Chris Johnson (team leader), Tim Hahn, Mike LaPuma and Bradley Lesher. The mechanical team was subdivided into two groups: the new ASV hull team consisting of Chris Johnson and Tim Hahn, and the deployment mechanism team consisting of Mike LaPuma and Bradley Lesher. The ASV team also received assistance from two other ASV team members: Haole Guo, a senior electrical engineering student, and Ryan Snyder, a sophomore mechanical engineering student.

II. AUTONOMOUS ROVER

A. *Overview*

The autonomous rover, shown in Figure 1, uses stepper motors for locomotion. The use of stepper motors provides wheel encoding that will allow for greater directional control, driving precision, and distance calculation. The stepper motors are controlled through a motor controller that has the capability to run the two stepper motors with precision micro steps. The motor controller is attached to an Arduino Mega. The Arduino is programmed to control the stepper motors during driving and standstill operations. XBees have been

Fig. 1. Autonomous rover.

utilized to provide wireless communication between the ASV and rover.

The Arduino IDE was used in conjunction with open source libraries provided by Arduino. Initially the Arduino was hard-coded to perform specific operations such as forward and reverse drive as well as clockwise and counterclockwise rotation. For the rover to drive either forward or reverse, the motors need to drive in opposite directions because the stepper motors are mounted in opposing directions. Similarly, to rotate about its center the motors are driven in the same direction.

Once calibration tests were completed using hard coding, the wireless control was implemented using XBees. Direct input to the serial comport is transmitted from one XBee to the other which instructs the Arduino how to drive. The input was simplified to a 5 character string: operation, direction, and three digits for distance. Operation can be one of two values, 'S' for straight or 'R' for rotate. The direction is either '+' or '-'. If "straight" is selected then the '+' is forward and the '-' is reverse. Likewise for "rotate" the '+' is clockwise and the '-' is counterclockwise. Finally, the three digit distance is either a forward or reverse distance in centimeters or a rotational distance in degrees.

To navigate, a sensor array of four Ping Ultrasonic sensors are used. Two ping sensors are placed in front of the two wheels in such a location as to prevent the rover from falling off the edge of the platform during operation. These sensors function on an interrupt and stop operation of the rover when the sensors detect the edge of the platform. The other two sensors are placed in a parallel arrangement in front of the rover for object detection.

B. *Navigation*

The purpose of navigation is to give the rover the ability to move under its own power without any external control. The primary goal of the rover navigation is to travel across the dock platform without falling off. Similarly, the goal for an autonomous robot is to be able to construct (or use) a map and to localize itself. While this is not a necessary function, it is preferable. For the purposes of the competition the ASV team has opted not to use GPS localization as this process is too resource intensive and the search area is not significant enough to warrant its use. Once the rover is placed on the dock, it will be necessary for it to be able to traverse the dock without getting stuck or falling into the water. Secondly, the objective is to locate and approach the object on the dock, the hockey puck.

There are multiple means of implementing navigation such as GPS, path planning, and vision. Global Positioning System (GPS) is often a very accurate and very expensive tool. A GPS receiver in line-of-sight with four or more satellites can receive its global position with an accuracy of down to a meter. Some applications can locate a receiver with sub-meter accuracy; these are the sorts of accuracy the rover requires, but they are far too expensive for this application.

Path planning is much more possible with stepper motors than with DC motors and servos. Path planning is the hard-coding of the driven path; each movement the rover makes will be known ahead of time. This is mostly useful when the arena and starting position are fixed and known. Path planning is not likely to work properly because the starting point and direction of the rover on the dock is unknown and the location of the puck are both unknown.

Vision is the use of cameras or other sensors such as IR or SONAR to “see” the environment and avoid or navigate toward an object. Infrared sensors emit an infrared beam of light which reflects off an object and returns to the sensor. The SONAR sensors operate in a similar manner, they emit a supersonic sound frequency and wait for the pulse to reflect off an object and return to the sensor. Both IR and SONAR sensors determine the distance of an object based on the time it takes for the pulse to return to the sensor. In this case, SONAR sensors are used to detect the edge of the dock and the tennis ball. By placing the sensors facing downward, the rover will know when the sensor is hanging over the edge of the dock. Two vertically stacked, forward facing sensors will allow the rover to differentiate between the hockey puck and a pole or column.

The ASV team devised a manner of navigation using triangulation of the rover’s position based on the rover’s location and the location of the surrounding posts that anchor the platform. Figure 2 shows the triangulation.

The star in Figure 2 signifies the rover, and points A and B signify two of the posts supporting the platform. Distance D is the shared hypotenuse of the two right triangles that are created to find the midpoint of a single

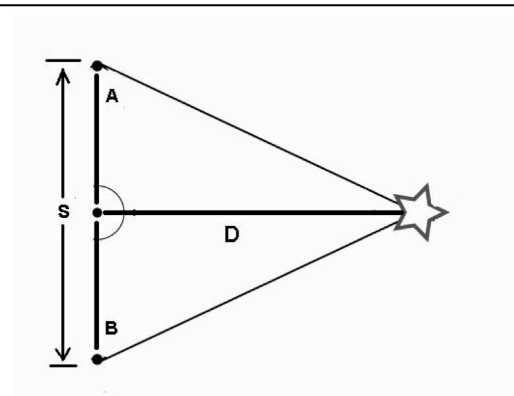


Fig. 2. Triangulation for navigation.

side of the rectangular platform. Using Pythagorean's theorem, a distance S can be found and a midpoint derived from this distance. The same process can be used to find the horizontal distance.

With these two distances calculated, the rover will navigate to the midpoint of the horizontal and vertical distances and commence a 360 degree scan of the platform. Upon finding the puck, the rover will signal to the ASV that it has the puck. The rover then returns to the starter location. In the event the puck is not discovered in its first scan, the rover initiates a binary search algorithm in which it divides the platform into equal sections and searches each of these sections. If the rover proceeds through this whole process without the puck, it returns to the starting position and signals for retrieval.

All distances used for the measurements mentioned above are taken by two parallel mounted Ping Ultrasonic sensors on the top of the rover. These two sensors were tested extensively to find the distance between the sensors that prevents interferance of the two signals. The sensors are mounted vertically from each other to determine if objects detected are poles or the puck.

C. *Object Retrieval*

The task of identifying the puck is solved by using two vertically stacked Ping sensors. The lowest sensor is mounted just about the ground. This sensor is used to identify the distance from the puck. The second sensor is mounted just about the first and determines whether the object is the puck or something else. Both sensors face the same direction, but see different distances if the puck is found. The lower sensor sees the distance to the puck, while the upper sensor sees a further distance. In this case, the rover knows that it has found the puck and not a vertical pole.

The puck retrieval design is simple. The space under the platform and between the stepper motors is sufficient to house the puck. A gate was attached to a servo motor that closes to seal the same area. When the puck is found, the rover rotates 180°, opens the gate, backs up over the puck, and closes the gate. This design is a simple and effective method of trapping the puck and moving it back onto the ASV.

III. Deployment Mechanism

A. *Overview*

The deployment mechanism, shown in Figure 3, was designed as a collapsible ramp because of its simple design, small space requirement, and because it allows the autonomous rover to deploy itself without being tethered to the ASV. The geometry of the mechanism was designed to be compatible with the capabilities and limitations of the autonomous rover. In addition, adjustment was built into the mechanism, since the competition rules state that the final dock height and landing area geometry will not be known for certain until the day of the competition.

Additionally, the design of the linkage allows the ramp to be deployed using only a single lightweight servo, reducing weight and system complexity. The materials were selected based on their strength-to-weight ratio and corrosion resistance. Technic LEGOs (The LEGO Group, Billund, Denmark) were used to prototype the geometry of the mechanism. After the concept was proven, a more realistic model was built and analyzed using Creo Elements/Pro (Parametric Technology Corporation, Needham, MA). Additional calculations were performed on the critical areas of the design to determine the stresses and design factors.

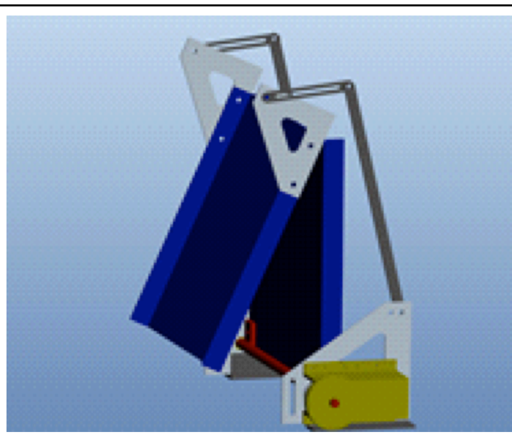


Fig. 3. Deployment mechanism.

B. Servomotor/Gearing

The deployment mechanism is not designed to support any weight besides self-weight when deploying or retracting, allowing for a lightweight drivetrain. The greatest demand on the servomotor was found to occur at several points in the motion of the mechanism: when deploying from full retraction, retracting from full deployment, and at the mid-deployment position where the linkage acts as a third class lever and increases the rate of deployment of one of the trays. In order to select an appropriate servomotor, static, kinematic and dynamic analyses were performed to determine the maximum required torque.

The dynamic force required to move the third class lever in the partially deployed position and the torque required for the fully retracted position are small compared to the torque required in the fully deployed position. However, the adjustment of the linkage is critical: if incorrectly adjusted, the partially deployed position requires a much higher torque and becomes the limiting factor. For correct adjustment, the minimum total torque from the servomotor required to maintain static balance must be at least 29 lbf-in. To drive the deployment mechanism, a Hitec HS-785 HB winch servo was chosen. It has a 5:1 gear ratio and produces a total maximum torque of 56.7 lbf-in for a design factor of almost twice the maximum required torque. The geared servo is also lightweight and compact.

C. *Stress Analysis*

The critical high-stress areas of the deployment mechanism were located using the results from a static analysis. The fully deployed static analysis was modified to reflect the full weight-carrying capability of the mechanism. Instead of considering self-weight only, the mechanism was assumed to be almost fully deployed with a 10 lbf weight resting on the end of the ramp. The autonomous rover is projected to only weigh 3lbf and will not traverse the ramp until it contacts the dock, leading to greatly reduced loads on the mechanism. This strategy for analysis results in an adequate factor of safety. In addition, the linkage was analyzed as though there was only one linkage instead of a dual linkage. Fasteners were then specified at the connections by examining the shear and crush stresses at the connection points. The components themselves were also analyzed at several points where the stress level was likely to be high.

The stress analysis showed that the design is adequate. A range-of-motion analysis in Creo showed that the mechanism is capable of deploying to any dock ramp angle between 15° and 25°. The width of the mechanism gives adequate clearance for the autonomous rover and was verified experimentally. The range of motion and the angles of the ramp as analyzed in Creo fall within the limits of the autonomous rover and enable the deployment of the rover for all ranges of possible dock heights at the competition. Additionally, experimental testing verified that the deployment mechanism can be used successfully on the ASV. Aluminum was specified for the components and stainless steel for the fasteners, resulting in good environmental compatibility.

IV. ASV HULL

A. *Overview*

A new hull design was proposed by the mechanical engineering team in Fall 2012, and featured a clean deck area with all the electronics stored in two new larger pontoons, providing additional deck space and buoyancy for the addition of the autonomous rover and deployment mechanism with space remaining for the future addition of new subsystems. However, supply problems prevented the acquisition of the new pontoons. In addition, the results of the AHP analysis completed in March 2013 indicated that a better design would be achieved by modifying the existing design. Figure 4 shows the new hull design with the deployment mechanism and autonomous rover.

The new hull design reused the pontoons from the previous year with the addition of a fourth aft pontoon to provide the required additional buoyancy. A new deck was designed from T-track members to facilitate easy reconfiguration and trim adjustment. It is also larger than the old deck, and effort was made to optimize the design and reduce the weight to offset the increase in size.

Many sub-systems from the previous ASV were reused. The entire electrical system encompassing data acquisition, computing, and output remained unchanged except for the power supply system and the vision. In order to resolve reliability issues, two batteries were used instead of one, so that the motor power supply is separate from the computer and microcontroller power supply. For the vision system, two new cameras were purchased to increase the field of view and the resolution of the images. The propulsion system including the motors and the basic navigational strategy remained the same with the exception of minor changes to calibrate the navigation programming for the new hull, and to make the algorithms more robust.

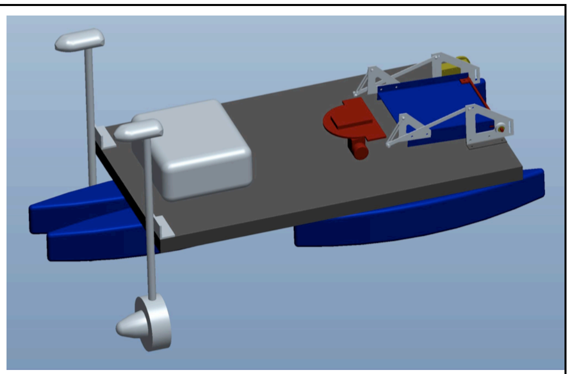


Fig. 4. Redesigned ASV hull.

B. Weight/Trim Analysis

An analysis of the component weight contributions, weight distribution and trim was performed in Excel (Microsoft, Redmond, Washington). A static analysis was performed to determine the location of the buoyancy force required for stability. For each component of the ASV, the weights and the lengths of their moment arms were measured experimentally. These results were then analyzed to determine how the total weight could be decreased. After optimizing the total weight of the ASV, the location of the required buoyancy force was then calculated from the weight distribution and the summation of moments.

The trim analysis was performed using the location of the buoyancy force and the location of the pontoons. A mathematical model of the hull was built in Excel to study the effect of pontoon placement and to ensure that a trimmed, stable configuration was possible within the design constraints. Given the desired locations of the fore and aft pontoons, the mathematical model produces the resulting pontoon draft and trim, along with the overall ASV length.

Additional testing was performed in the water after the hull was built to fine-tune the boat configuration for stability and trim, and to calibrate navigational and vision algorithms.

The total weight of the ASV is estimated to be 92 lbf, which is well within the 110 lbf weight limit imposed by the competition. Additionally, the boat is now able to support the added weight of the autonomous rover and the deployment mechanism. The deck surface is open with the exception of the waterproof box, which houses the computer, batteries, and various other electronics. The only components remaining outside of the box are the motors, deployment mechanism, autonomous vehicle, and the GPS. There is also space remaining for the addition of future subsystems. The trim analysis and the experimental testing show that the pontoons may be positioned to achieve an even trim while maintaining adequate stability and remaining within the length requirement. Also, the navigational algorithm was verified to be compatible with the new ASV hull, and the addition of a fourth pontoon did not increase drag or decrease maneuverability significantly.

V. Budget

This year's ASV team was initially granted a budget of $5,000. In order to comply with university guidelines, plans and lists of necessary parts were compiled and consolidated to ensure all parts the team would need for the upcoming month were ordered and accounted for the month prior to ordering.

Although many changes were made to this year's ASV, money was saved by utilizing items the team had on hand as much as possible. Also, price comparisons between different suppliers helped to keep the overall cost of the project to a minimum. Because of these measures, the 2013 ASV team was able to complete the project within budget.

VI. Project Management

The 2013 ASV team was divided into two teams: the electrical team and the mechanical team. The electrical team was in charge of programming the navigation code for both the ASV and the deployable vehicle, and for developing the autonomous rover. The mechanical team was subdivided into two groups: the new ASV hull team and the deployment mechanism team.

A Gantt chart was used to keep track of progress. This allowed the team to determine if the project was on-time and on budget. The ASV team had weekly meetings at the group level to allow all the sub-teams to give an update on their progress.

In the middle of March the mechanical team learned that it was not possible to get the new pontoons that were a critical part of the new hull design. However, the recently-completed AHP analysis indicated that a different design, one that did not require the new pontoons, would fulfill the team's objectives more efficiently. The mechanical team was then able to use the design from the AHP analysis instead of the original design. Another challenge faced by the mechanical team was the long wait time for parts ordering and delivery, and for parts machined by the college machine shop. In spite of the challenges, the mechanical team built the new ASV hull and deployment mechanism, and had its first test in the water on April 14th. In the time of a crisis, the ASV team was able to avoid a disaster through careful project management.

VII. Conclusion

The ASV team at ODU has expended considerable effort in developing an ASV for the 6th Roboboat competition. The new ASV has been developed using some new design techniques, and features many improvements besides the entirely new autonomous car system. The ASV team is looking forward to the final test in July.

Acknowledgment

The ASV team would like to acknowledge the assistance and advice from Gene Hou, a professor in the Mechanical and Aerospace Engineering Department at ODU.

References

[1] Arduino-References. [Online]. Available: http://arduino.cc/en/Reference/HomePage, Date Accessed: October 1, 2012.

[2] AUSVI. (2013, Jan. 1). *6th Roboboat Competition Preliminary Rules* [online]. Available: http://www.auvsifoundation.org/foundation/competitions/roboboat/

[3] Fall 2012 ASV Team, "Autonomous Surface Vehicle Competition 2013: Hull Redesign Proposal," Old Dominion University MAE 434W, Final Term Paper.

[4] Pololu Robotics and Electronics [Online]. Available: http://www.pololu.com/catalog/category/12 Date Accessed: October 1, 2012.

[5] R. G. Budynas and J. K. Nisbett, *Shigley's Mechanical Engineering Design*, New York: McGraw Hill, 2011.