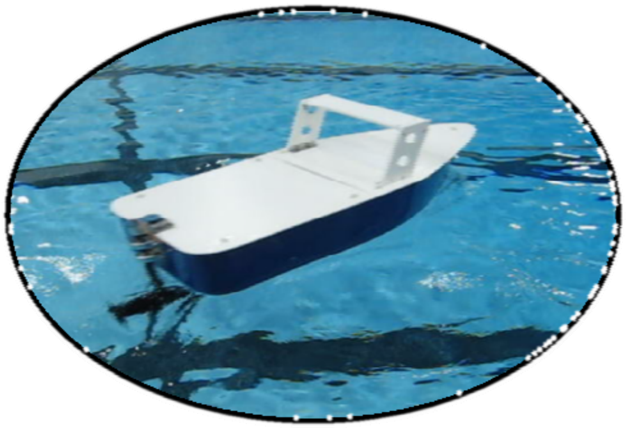
Old Dominion University



ASV Boat Project

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Abstract

The Autonomous Surface Vehicle (ASV) project was originally begun 2 years ago in Virginia Beach, VA. The competition consists of colleges, private companies and organizations to compete annually to achieve overall best in design and performance with an obstacle course completion. The Old Dominion University Engineering Technology department has assembled a team to design a robotic autonomous boat for this challenging competition. The ASV will be fully capable of reacting to its environment and surroundings by doing a series of calculations through programming. This report consists of a description of calculations used and analysis of the overall ASV design, including the hull, propulsion, camera vision, GPS, robotics, and programming.

Introduction

The Autonomous Surface Vehicle (ASV) design project's main goal is to build a robotic watercraft for competition using a boat hull as a platform with various sensors and programs to help maneuver the vehicle. The ASV is programmed to navigate an obstacle course with intentions of autonomous operation only. Additionally, it possesses a radio control backup system in case the vehicle becomes lost, allowing it to be manually controlled back to base port. The ASV boat is initially led by cameras using vision color recognition and computer programming in order to obey commands, maintain position and change headings all autonomously through calculating distances and angles. Our objective is to make an inexpensive, light, competitive ASV to challenge the competition's obstacle course and to take the championship away from the previous year's winner. Old Dominion University's ASV design team composes of six Mechanical Engineer Technology (MET) students who were assembled at the initial design stage in the fall of 2009. Autonomous Unmanned Surface Vehicle International (AUSVI) sponsors the competition among college students, employers, and private organization and judges on best overall design and ingenuity. The rules for the 2010 AUSVI competition determine the overall guidelines for building materials, along with dimensions allowable for the size itself. Funding for the project has been provided through grants.

Autonomous surface vehicles/ autonomous boats (ASV) are part of the latest advancement in technology. Autonomous vehicles consist of robot platforms, which have the base of an automobile, boat or submarine. The scientific and engineering fields have been using these electronic platforms to perform research for years. ASVs are defined to be unmanned robotic vehicles that are operated by a global positioning navigation system (GPS), a camera for vision, controllers that consist of wireless technology and computer devices with the latest software programs. The autonomous boat provides several hours of unmanned operation, fulfilling a pre-defined mission plan. Its size is suitable for, together with the navigation system, executing profiles and other maneuvers with sub-meter accuracy. This floating platform has a GPS receiver together with internal sensors and a controller to compute its position and attitude with high precision and time resolution.

Engineering and science research is very important for further development in research for these ASVs. Students are becoming part of the system to help in the advancement of these technologies. To get emerging engineering students excited about the advancing technology of the robotic field, many competitions amongst universities and private engineering firms have been created, such as the Autonomous Surface Vehicle Competition located in Virginia, Beach, VA , June 10-13, 2010 held by AUSVI. During this competition, many universities compete on a challenging obstacle course that will require precision, accuracy and well programmed robotic ASVs in order to finish the challenge. Judging in the competition is based on several aspects: Propulsion, thrust tests, steering in a straight line, using robotics, navigating buoys through vision and controller systems, encompassing GPS to navigate way points and shooting targets with water cannons.

An Old Dominion University Mechanical Engineer Technology team has been assembled for competition as well as a senior design project. The main objective is to build an ASV boat that meets the requirements and guidelines of the competition. The team is working within guidance of five main advisors: Dr. Lin, Dr. Hsuing, Dr. Dean, Prof. Moustaffa and Prof. Leutke. The project is a work in progress, but will meet the objectives and deadlines prior to competition.

Hull Overview

Hull designs of ships have been a timeless craft that dates back to when man was discovering his environment. The designing of a hull is an important integral part of an ASV design because much has to be taken into consideration, such as how much weight will the boat carry, what application this hull will serve. The dimensions of the boat (length, beam width, shear and draft) all have to be considered in designing process when calculating the ships center of gravity, meta-center and most important the buoyancy. A hull has to be able to float its loaded by the amount of water that it displaces. Many hull types exist like catamaran, hydrofoils, tri hull and the oldest and most used is the mono-hull. As you may discover, many considerations are applied in hull design for a ship. This report will include a description of the overall boat design together with hull selection, and methods to create a hull.

Upon much consideration and discussion by the MET ASV design team, a mono-hull shape was chosen. The initial reason for choosing a mono-hull was due to its' capabilities of being stable with a low center of gravity. Other considerations were the overall space allowed inside to place electronics, laptop computer and large equipment of such. Mono-hulls can provide a fast platform for a boat at lower speeds because of a low wetted surface area. Since most of the equipment on a mono-hull is inside of the boat, rather than on top like a catamaran, the center of gravity for the very heavy items rests at water surface level to maintain the stability of the boat. If a mono-hull is designed wide enough, the capability of being very buoyant is easily achievable. Catamarans and pontoons, such as the ones used by teams in previous AUSVI competitions, can typically have the same amount of wetted surface areas as a mono-hull, but dependent on pontoon size. The question that emerges from this is: Why are most cargo and military vessels mono-hull? The reasoning behind this is that unless the vessel is moving at a very high rate of speed, it is unnecessary to create such a wide platform that makes steering, docking and navigation more difficult.

The overall length, width and depth of the boat's hull are other factors to be considered in buoyancy, steering and drag through the water. Four feet, nine inches for the hull length was chosen due to the bow of the boat needing a sharp entry point to move the rest of the hull through the water. The whole concept of bow entry angle can be compared to that of a person diving into the water. There needs to be an area that will pierce through water so the rest of the body can enter. The shorter boat length, with the same width, would create a larger angle for the bow to enter the water. The large bow angle would expose more surface area in the water while moving in the forward direction resulting in increased resistance and therefore creating more drag. A key consideration in the team's hull design was to avoid a barge shape of hull (large bow angle) which would consume more power to move forward in the water because of the increased drag. The decision for the overall design dimensions of the ODU MET hull was four foot nine inches (length) by two feet (width), with a depth of ten inches. The side wall depth of ten inches with three inch thickness gave the hull a good safety factor, due to the inside of the hull being loaded with heavier equipment, thus giving a decent draft of four inches for stability. The depth of the hull also allowed for a laptop to remain opened inside the hull to allow for control programs to operate during navigation without the laptop shutting down.

Steering

One of the most important designing considerations of an autonomous boat is steering. When considering steering a boat there is many things to consider and many variables in the equation. Some of the variables that effect steering are thrust, drag, boat center of gravity, accuracy of the steering motor, and design of the boat.

First, we will start with what we have the most control over, the steering motor. It was decided through research that there were two main choices for the steering motor and both were tried. The one that is currently on the boat and that will be used for competition is the servo motor. There are numerous reasons for this choice. First, because the boat must be RC this is the most practical and most widely used approach. Second, servos come with something called a potentiometer. This of course gives constant feedback in autonomous mode. This is a great thing because it must always be known what angle the boat is steering at. Next, as a back-up there will be three position sensors set-up at 0°, 90°, and -90°. This will make sure that even if position is lost once steering hits one of these three positions it will be known again.

Now, what servo will be chosen knowing that our propulsion system weights about 10 pounds and has 30 pounds of thrust? Well, it is a HS-7950TH Ultra Torque HV Coreless Titanium gear servo.(2.1) This was chosen because it has 486 ounces per inch of torque, it is digital and programmable, and like what was said before it has a potentiometer for feedback.

So, we have to take a look at what are going to be variables and what will be constants. Since, the trolley motor will work on relays we know that the wattage will be constant. So, the power is constant and that means that once the boat accelerates to the thrust being equal to drag the velocity is equal. Since the motor is electrical this is instantaneous.

Okay, now that we have everything chosen and all of the variables there is how do we make the boat steer autonomously? Well, what is normally used is very similar to the controls of an airplane, the Equations of Motion for a boat. This can be quite complicated for the simple fact that every boat is different and because there is many environmental effects can cause perturbations.

Energy Storage

A very important part of designing an electric boat is storage of the energy. Two of the most predominant ways of storage use are batteries and ultra capacitors. When it comes to rechargeable batteries there are five major types that are used. They are NiCd, Lead acid, NiMH, and lithium ion batteries.

The lead acid battery is arguably the cheapest battery when it comes to power versus price. It works by “The negative electrode supplies electrons to the external circuit (or load) during discharge. In a fully charged lead-acid storage battery the negative electrode is composed of sponge lead (Pb). The positive electrode accepts electrons from the load during discharge. In a fully charged lead-acid battery the positive electrode is composed of lead dioxide (PbO_2).”

The NiMH battery has a specific power in watts/kilogram of 1000. The NiMH battery is still is pretty heavy in comparison to the lithium ion and only has a battery life of two years. An instance of usage for this in everyday life is the original Prius.

For lithium ion there is actually two types, alkaline and polymer. The alkaline to date is the most used and comes in many shapes and sizes. It weighs less and has more power for the same size battery as the NiMH. The Lithium ion alkaline also offers a quicker recharge than the NiMH. There are some problems with the lithium battery it is more costly initially and is not as durable. The alkaline battery has a maximum specific power in watts/kilogram of 1500 one and a half times that of the NiMH. The Lithium ion polymer has most of the same benefits and disadvantages of the alkaline but has a specific power in watts/kilogram of nearly 2800. It is also safer because it is a solid.

Vision System

In robotic systems, a vision subsystem provides a crucial function by taking visual information and discriminating the data received from the camera. Recently, vision systems have been increasing in robotic and autonomous applications. They are primarily used for part identification, part location, part orientation, inspection, and range finding tasks (Rehg 252).

For our needs, the vision system we have developed can identify a specific object based on color as well as find the location of the identified objects. The vision system, depending on the specific task in the competition, returns the angle of the heading change in order for the boat to complete each task.

For our system we are using an Arecont AV5155 five Megapixel IP camera. This camera was chosen for its auto exposure capabilities in various lightning scenarios. The camera will interface with a laptop running C++ code to analyze the images captured by the camera. The C++ program uses the VXL computer vision libraries for research applications (Introduction). These powerful libraries allow for image thresholding and edge detection.

Deciding where to place the camera is an important part of the boat’s design. The camera must be able to see a specific region of interest. As noted by the comprehensive rules, various objects will be placed at different heights throughout the course. Ideally, the camera will be able to see each of these object heights with only minimal movement.

Camera placement was decided by determining the minimum distance we need to see a desired object and calculating the height and angle required. As per the comprehensive rules, the minimum distance that the each buoy set will be placed away from each other is five feet. From this data, a length of 4 feet from the camera to the water surface was used to determine the camera height. With a known draft, the height of the top of the boat to the water’s surface could be calculated. From these two lengths, the desired angle could be calculated by fixing and height and using trigonometric functions to determine the length. Where x is 1 foot:

$$\tan^{-1}\frac{4\,ft}{\left(x+{}^{10}\!/_{12}\,ft\right)}=\tan^{-1}\frac{4\,ft}{\left(1\,ft+{}^{10}\!/_{12}\,ft\right)}=65.4^{\circ}$$

The camera support was also made so that the angle could vary. This allows for automated control of the camera’s tilt if required or manual adjustment to accommodate field tests. The camera is mounted on a prebuilt pan and tilt system using two servos to interface with Dr. Hsiung’s microcontroller.

A series of functions in C++ are made for each task the vision must accomplish for the competition. Each of these tasks consists of three subtasks that the functions will cover. These subtasks are image thresholding, object identification, and object location.

In order to accomplish these tasks, the VXL computer vision libraries have been implemented. Specifically, the vil core library for image manipulation is used to threshold an image and for the edge detection routines used in the object location subtasks. VXL provides a lightweight and powerful research tool for multiple computer vision fields. The vil core library is stand-alone, meaning its functions can be used without any other VXL core libraries (X.2).

When the thresholding functions gate_thresh() and ring_thresh() are called upon, an image is first captured from the camera and then the appropriate RGB values are applied to the image. The program scans each line pixel by pixel and compares the RGB values to the threshold values. If they are above or below, depending on the threshold routine, it will change the pixel to the desired color. In Appendix A, figure 5.3a shows a test image before the thresholding and figure 5.3b shows the image after the threshold values are applied. As you can see, all non red or green values were turned to a pure black pixel with RGB values of 0, 0, and 0 respectively. The image is then saved to be called upon by the next function.

The gate_check() and ring_check() load the image from their respective thresholding functions. The gate check function is used for both gate and buoy obstacles during the competition. The gate check function scans the bottom third of the image every ten lines for a red edge or green edge. Once it reaches the top third of the screen, it returns an array. This array has 3 items as follows: [Red Value, Green Value, scanline]. The red and green values are Boolean. If the red value is true and the green value is true, this is the ideal case. If the function only returns a red value, it tells the camera that it must turn right and if it only sees green it must turn left. The vision system will be used to calculate the angle for the color based obstacles. The vision system is incorporated into the main program via specific C++ functions. The scanline value corresponds to the horizontal scan line which will be used in the final function to calculate the angle. The ring check function follows the same principle, except it will scan the top two thirds of the screen. It will check for the two sides of the ring. If this function only detects one edge in the left side of the screen, it will return a command to pan the camera to the left. If a single end is detected on the right side of the screen, it will return a command to pan the camera to the right. The gate check returns an array with four values. The first three values it returns are the horizontal pixel for the first outer edge, first inner edge, and second inner edge respectively. The fourth value is the horizontal scan line which will be used for the calculation functions.

The gate_calc() and ring_calc() functions require the array values from the ring check and gate check functions. The ring and gate calculation function operate on the same principle of perspective. Figure 5.4 in Appendix 5 shows how the angle is calculated using edge detection for the gate and buoy obstacles. The calculations are as follows according to figure 5.4:

$$\frac{G2(pixels) - R2(pixels)}{2} + R2 = BuoyCenter(C.B.)$$

$$C.B. - \frac{ScreenWidth}{2} = b(pixels)$$

$$b(pixels) \cdot \frac{ObjectSize(inches)}{(R2 - R1)} = B(inches)$$

From these calculations, the opposite side of a right triangle is calculated. In order to define the adjacent side, experimental perspective data was collected. The experiment used a on box with a known width of 11 inches. The object was placed in front of the camera at two feet to 22 feet in two foot increments. Three images were saved for each distance and the width of the box in pixels using an image editing software. The data collected was used to calculate the Box Ratio in inches/pixels and in feet/pixels. Table 5.1 in Appendix 5 shows the experimental and calculated data for the experiment. The data was graphed with the abscissa as the pixel per inch and the ordinate as the camera distance. Graph 5.1 shows the perspective data. This data fits a power function which was found to be $y = 1701.6x^{-1.015}$, where x is pixels per inch. Using this equation, the A side of the triangle in figure 5.5 can be calculated by using the distance of R2 to R1 divided by the known object size.

$$A = 1701.6\left(\frac{(R2 - R1)}{ObjectSize}\right)^{-1.015}$$

Finally, know that sides A and B are known, the angle of the triangle can be calculated as:

$$\theta = \tan^{-1}\frac{B}{A}$$

Theta is equivalent to the change in degrees that the boat must change its heading to be centered. This is because the placement of the camera is directly. The gate and ring calculation function use the same principles as shown. These functions both return a floating point value for the angle the boat must turn. The main program calls on this function only when the specific task must be completed. These functions will be called on repeatedly so the boat remains on course.

The vision system was tested three times with three different angles. Red and Green PVC pipes were placed in front of the camera and the angles were measured to be 9°, -15.23°, 9.83°. The angles calculated by the gate calculation functions turned out to be 9°, -15.02°, and 10°. The maximum error seen during testing was ± 0.2 degrees.

Global Positioning System (GPS)

The type of GPS used is the Garmin 18x PC unit. There were other units that were similar to this unit that had different connections, but this unit was chosen for numerous reasons. There was no need to worry if the unit was Federal Communications Commission FCC compliant, as all units sold to the public market are. This unit was chosen because of its high sensitivity (highly accurate receiver), yet it is quite small (a diameter of 2.4 inches). The GPS unit needed to be accurate because the autonomous boat would be operating in a space that would be surrounded by numerous objects that it could possibly hit and the boat would need to accurately no where its final destination is in order to complete the rest of the obstacle course. The GPS unit uses a 12-V cigarette lighter adapter as the power source. This unit also has DB-9 serial port connector. There was some slight trouble that was run into with the serial port, as most laptops on the market today do not come with a serial port. This was solved by purchasing a DB-9 serial port to USB adapter. There was no need to worry about compatibility issues as the USB be adapter came with drivers to so that the laptop could properly recognize the information coming from the GPS. A USB capable unit was available, but it could not output data in NMEA 0183, which is the industry standard. The Garmin 18x PC unit can output data in NMEA 0183 or proprietary Garmin format. For the autonomous boat, the NMEA 0183 standard would be used.

The concept that the autonomous boat will use in order to be guided by a GPS is to, first, determine the destination or target position of the autonomous boat. Then once the boat has received its coordinates, it will receive signals from satellites in order to pin point its location. A computer program will capture the received information and make the necessary calculations using target position and GPS signals in order to determine the direction the boat must turn.

There were multiple programs used in order to properly perform what is required to guide the autonomous boat. The first program used is called "Advanced NMEA Logger." This is a third party program that is capable of reading any NMEA sentence formats outputted by the GPS. The program is constantly retrieving sentences from the GPS about every second. The program is also capable of logging the sentences that it receives into a text file. This capability is something that will be used for the second program. The second program is Microsoft Visual Studio (C++). A C++ program was written to read the last line of the text file made by "Advanced NMEA Logger" program every two seconds.

The main purpose of this program is to guide the autonomous boat to a certain destination when given the destination. The program starts off by opening and retrieving the last line of the text file that the Advanced NMEA Logger program creates. The last line ($GPGGA sentence format) is then stored in memory, at which point the longitude and latitude are then pulled from this line. The longitude and latitude from the pulled line are in Degrees decimal-minutes. In order to make calculations simpler, these values were changed to decimal degrees, which is the format most commonly seen in mathematics.

Once the program converts the first point's longitude and latitude, it then has a two second delay before retrieving the last line from the text file (the text file from the Advanced NMEA Logger is constantly being updated). This two second delay is required in order to create a vector. This vector will be used to create a triangle between an initial point, a second point, and a destination point, which will help determine the number of degrees that the boat must turn. After the second point is retrieved, the same process for the first point is repeated. The longitude and latitude for this line are converted from Degrees decimal-minutes to decimal degrees. Trigonometry is then used to calculate the number of degrees that the boat must turn in order to reach its destination.

Once the calculations have been performed, the program will make an evaluation on which way the boat should turn. This will give the autonomous boat the number of degrees to turn and in which direction. Currently the program is only set up for the first quadrant (positive x and positive y). This means that the boat would only give an accurate reading in the East-North region of the cardinal directions. The cardinal directions is similar to the x and y coordinate system, which means that +x and +y is the same as E and N, -x and +y is the same as W and N, -x and –y is the same as W and S, and +x and –y is the same as E and S.

The program is currently set up for testing purposes; however, it can be easily changed to a fully operational program. The program is setup to receive inputs from a user for the longitude and latitude position of each point on the triangle. The only restriction is that the points must be in the first quadrant, as stated above. Depending on where the initial point and second point of the triangle are located, the boat could either be approaching the destination point from the left, approaching it from the right, or going straight towards it. The program will recognize which situation the autonomous boat is currently in and output the corresponding message, approaching from left means turn boat right, approaching from right means turn boat left, and going straight towards it means keeps straight. The boat determines which way the autonomous boat should turn by comparing the slopes of each line.

Once the boat has evaluated the direction it will turn, it will use this to determine if the program will repeat. If the program needs to turn left, right, or go straight, the program will repeat (this repeat is going through a function called a "while" loop). However, when the program has reached its final destination, the C++ program will no longer retrieve information from the text file that was created by the Advanced NMEA Logger program. From here, another program will continue to operate the autonomous boat through the use of a vision system.

Conclusion

This project certainly presented a challenge. It was necessary to use the wide array of knowledge that was obtained throughout our studies during university, as well as learning new material in order to complete the project. The project incorporated everything from mechanical design, Strength of Materials, electrical, computer programming, and even project management. Despite having this challenge set before use, the team had the ablility to successfully conquer thus far. We still have a task that need to be completed to have a fully autonomous boat, but we are well on our way of achieving this goal.

With each system, the hull, propulsion, cooling, steering, vision, and GPS, effectively combined together, we developed a product that will be reasonably competitive in this year's ASV competition. The team worked hard and spent many hours on the project over two semesters, despite have to manage other classes during the time and having many holiday breaks. Time management was certainly a factor that helped produce such a product. The team met quite often despite other obligations, sometimes meeting as much as 3 or 4 times a week. However, the project did not go always as planned. Even though time management was great, if more time to design and build was allowed, certainly there could have been an ASV boat that would be superior to what was designed. Many team members are graduating, so time was a factor in design. Another short coming experienced during the project was the steering system. A design was initiated and fabricated, but was later discovered not sufficient for what was required of the boat. This design needed to be scraped and a new, better design took its place. This certainly shows that if more time was allotted, more thought could of gone into subsystems and a better engineered ASV boat could have been built.