OLD DOMINION UNIVERSITY

AUTONOMOUS SURFACE VEHICLE

TEAM: BIG BLUE

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Abstract

For the 8th Annual International RoboBoat Competition (IRC) competition held in Virginia Beach from July 6th through July 12th by the Association for Unmanned Vehicle Systems International (AUVSI), an autonomous vehicle was designed and fabricated by the Old Dominion University (ODU) Autonomous Surface Vehicle (ASV) team of engineering students. ODU students were able to create a robotic boat capable of navigating through multiple obstacles and meeting the prescribed requirements conveyed in the 2015 Final Rules. Equipment recycled from previous competitions, an improved computational platform, and various sensors types mounted to a previously fabricated aluminum pontoon inspired hull facilitated the ODU ASV team towards the goal of attempting competition challenges.

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I. Introduction

The autonomous functionality of the vehicle is based on motion control logic. Navigation of the vehicle rests on changes to individual propeller thrust. Sensors are required to ~~detect~~ locate objects, ~~that output~~gather distance information, and determine the vehicle's location with relation to the objects. This information is used to determine how much thrust is needed by each motor to avoid the obstacle. Computer vision is critical in observing the environment and determining a path based on the competition obstacles. The computer vision programing is written in C++ and Python utilizing OpenCV and (DLIB) libraries. The vision code incorporates YCbCr threshold color detection and HOG SVM detectors. Ultrasonic Sensors and LiDAR are used for object detection. Ultrasonic sensor data is output through Arduino and is coded in C++ programming language. The LiDAR data is output to the navigation code and is coded in C+ programming language.

II. Design Criteria and Methodology

The ASV is designed around the limitations and competition guidelines. Weight measurements are kept in mind when designing the hull structure of the vehicle. Pontoons are chosen to provide a necessary buoyancy force and support the weight of the electronics accompanying the ASV. The ASV uses a two pontoon design to equally distribute payload weight over the length of the frame, increase design flexibility when placing components and the availability of storage space. The material for the hull form is aluminum; its density and strength optimized weight, buoyancy, and rigidity. The frame of the ASV can be modified or machined evenly without affecting the stability of the boat. The rigidity of the hull allows for easy transport and mounting with no concern for structural compromise. The aluminum allows for a hollow hull design which reduced the weight of the structure.

A. Frame Compartmentalization and Waterproofing

The frame of the vehicle connects the two pontoons and hosts a deck where components may be placed. The center of gravity lies in a plane on the deck of the ASV. The frame, also made of aluminum, is equally rigid and easily machined. The deck is designed around weight limitations. The components placed atop the platform do not require a solid metal material; therefore, a perforated plastic was chosen as the solution to the design requirements. The platform provides enough stiffness to support the motion controller while eliminating unnecessary material.

Water sensitive components inside the pontoons requires that the open compartments be waterproofed. The obscure structure and form of the transverse bulkheads limited decisions of methods to seal the pontoons. Design considerations included: the use of a lightweight cover over the entire structure, a waterproof case for the water-sensitive components to rest inside the pontoons, and sealing the overhead of the compartments with a malleable material. The lightweight malleable material, EVA foam, serves the purpose required to seal the hollow pontoon and is of optimal weight. The hollow design allows the electrical components to be safely housed inside the pontoons, safe from environmental damages. The flexibility of the material contoured to the shape and curvature of the hull and increased surface contact. A redundant coat of water sealant spray and DEHCO putty tape was applied to ensure the exclusion of water.

Concerns about accessibility arose with the compartments sealed. There was very little support structure inside the cavity that could support the weight of an external force; an external force has the potential to compromise the seal between the EVA foam and the hull of the pontoon. The ideal case is permanently storing components inside the cavity. The compartment only needs to be accessed to change batteries through a cut out hatch. The wires connecting multiple components inside are connected to the electrical box on deck. This allows the motion controller to be dis-attached from the vehicle. The quick disconnect eases transportation of the vehicle and supports substitution of different modules.

B. Propulsion

The propulsion system of the ASV are variable thrust, fixed propellers. Each propeller provides thrust in one direction. The steering utilizes variable thrust through each motor. A turn is executed by decreasing the voltage received by one of the propeller motors while increasing or keeping constant the other propeller voltage. This method, as compared to one propeller with a rudder, is simpler. Motor voltage is easily controlled with differing Pulse Width Modulation (PWM) signals. The PWM signals regulate the voltage into each of the electric motors. A lower

PWM value decreases voltage and motor thrust while higher PWM values increases voltage and motor thrust. The maximum available motor thrust can be limited by setting a maximum value PWM signal; this is desired to limit vehicle speed. The processing capabilities limit the vehicle's ability to detect objects and maneuver around obstacles at very high speeds.

C. Power Distribution

The power source and fuse block provides all power to components associated with the ASV. The power source is universal 12 volt batteries that provide power to the fuse block. The fuse block opens or closes a circuit to power on or off sets of electronics. Switches on the motion controller permit the connection of power from the computer and motors to the power source. Most sensors and electronics draw power through the computers USB ports.

The weight of the batteries that power the motion controller and electronic components are significant in comparison to the weight of other critical components. This concern necessitated the decision to house the batteries inside the pontoons. One benefit to storing the power source in the pontoon is the natural cooling from contact with the hull wall. The hull delivers the capacity to cool the batteries by conduction through the pontoon.

D. Sensor Mounts

The sensitivity of the electronics requires protection from the environment and protection from force. Covers and mounts are essential in assuring the stability and survivability of the sensors. The sensors need to be fixed to the vehicle to properly perceive vehicle movement and true environment orientation. This challenge is solved through the use of sensor mounts tailored to the sensor or cover. The sensors are placed at points around the vehicle to maximize measurement coverage. Awkward shapes, bends, and corners make it difficult to mount sensor platforms directly to the frame; ideal placement uses the mounts on the boat.

E. Camera and LiDAR Gimbal

The gimbal is designed to overcome two degrees of freedom that the vehicle experiences while in transit. Wave motion subjects the ASV to pitch and roll movements that interfere with the orientation of the sensors. The computer vision relies on capturing image pixels and must stay somewhat level to the surface of the water to detect contours. Other mounted electronics must be able to obtain a steady reading of the objects surrounding the boat. The gimbal levels the electronics and stabilizes local dynamic movement to provide constant distance predictions. Two servo motors deliver the gimbal's 2 degrees of freedom. One servo motor overcomes pitch movement and the other overcomes roll.

F. Onboard Computer

In order for the ASV to successfully navigate a course without human interaction, all of the inputs from the sensors and cameras is collected and interpreted into useable data. This data is then processed to make the required navigational decision. These calculations require more processing than can be provided by the Arduino controllers alone. The vision and navigation codes require the use of a computer to be able to process the data and make navigation decisions in real time. A custom built computer made with desktop and automotive computer components, to increase processing speed, has been built. The new computer is faster in single threaded applications and has four available threads versus the previous computer's single thread.

G. Microcontrollers

Microcontrollers are a necessary component to the ASV's operation. These miniature computers handle a variety of inputs and outputs while running on a continuous programming loop. Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. This project uses several Arduino boards to handle sensory input and communication between the user and ASV. The Arduino allows the user to read and write analog, digital, and PWM signals.

1. State Arduino

The State Arduino collects data from a 9 Degree Of Freedom (DOF) Inertial Measurement Unit (IMU) sensor. This small sensor board with 9 degrees of freedom includes an accelerometer, magnetometer, and gyro. This information is used to drive the gimbal's servos used to level our camera and LiDAR. A separate State Arduino collects GPS information. The data is passed to the central computer for use in the navigation controller.

2. Drive Arduino

The Drive Arduino is the final step before motor commands are sent to the speed controllers. It is at this controller that the decision between user or computer control is made. The PWM signal from the RC Receiver is read and scaled for use. One channel from the six channel receiver is used as an on and off switch to set control mode. Two other channels are used to control the left and right motor. All of these values are carefully scaled to work with variable declarations in coding and system components.

H. Computer Vision and Navigation

Software, the heart of an ASV, remains under constant development to cope with new challenges and technologies. To improve upon previous competitions, existing software has been completely overhauled to improve performance and incorporate new technology. These updates have improved navigation in the form of object recognition through semi-automated color space translation and HOG classifiers. Color spaces represent collections of colors where specified input parameters will produce a given color; ranges of inputs produce ranges of colors. A common example of this is the Blue, Green, Red (BGR) color space, which takes three input colors. These inputs are blended based on ratio to produce other colors. Previous ASVs used a color space known as Luminance, Chroma-blue, and Chroma-red (YCbCr). This color space shares a similarity with the BGR space: more than one input is color based, so blending inputs to select a desired color or range proves difficult. For example, a bright red object is easy to match in BGR space by inputting red, but the same object cast in a shadow becomes the combination of three input colors. The process of selecting input ranges to identify a range of output colors is called thresholding.

Thresholding using color blending is not always intuitive, such as when two or more colors blend heavily; therefore, thresholding becomes time-consuming due to constant guesswork. Other color spaces are easier for approximating outputs, accelerating thresholding processes. Hue, Saturation, Value (HSV) color space places hues in polar coordinates around an origin. Hue is perceived as the approximate color, Saturation is intensity, and Value is its lightness. Objects can be isolated by perceived characteristics and by selecting the hue starting from red at zero degrees and blending through the visual spectrum before returning. An automated threshold object selection tool has been developed that allows the user to select the object to be detected and obtain threshold values. This will potentially lower the time spent obtaining color values in the finicky color threshold detection and allow for future automatic threshold determination from boxed images.

The navigation software interprets information gathered from the computer vision, ultrasonic sensors, and LIDAR to set the value of the motors PWM signals. Navigation for the boat is under constant development as time permits. Whereas previous systems are based on movement relative to the detected objects, the new system is based on mapping areas where the boat cannot go. This allows for more free movement of automated vehicles and the possibility of using more complex algorithms on the mapped area. This also allows for a visual representation of the theater of operation and visual cues to the operator for troubleshooting.

III. Summary

Given the competition rules and vehicle requirements, the challenges involved with fabricating a vehicle has been overcome. Keeping the craft within a six-feet long, by three-feet wide, by three-feet height determined the size of the pontoons, the height of the components on the platform, the depth of the propellers, and where the deck of the boat is placed. The use of strong and lightweight aluminum, plastics and composite materials cut weight while maintaining structural integrity. The dual propellers allow for tight, smooth turns using PWM signals from a drive Arduino to control vehicle position. Using a fuse box with two separate circuits enables the craft to connect the batteries from inside the pontoons to the computer and motor circuits. 3D printed mounts connect the ultrasonic sensors to the boat and a fabricated bracket connects the Gimbal to the frame. The Gimbal uses a state Arduino receiving inputs from an IMU to control two servos to level the camera and LiDAR for pitch and roll. The onboard computer processes the data received from the Arduino units, computes the distance of objects detected by the camera using OpenCV and navigates the ASV around objects and to target destination. With these design factors and the performance analysis during testing, the Big Blue craft is ready for competition.