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Controlling of Unmanned Surface Vehicle in Free Water

Assoc Prof. P. Sharmila Rani[1], A. Manisha[2], M. Sangeetha[3], G. Jaikanth[4]

[1]Mrs P. Sharmila Rani, Associate Professor Dept. of ECE, Teegala Krishna Reddy Engineering College
[2]A. Manisha, Department of Electronics and Communications Engineering, Teegala Krishna Reddy Engineering College, Hyderabad
[3]M. Sangeetha, Department of Electronics and Communications Engineering, Teegala Krishna Reddy Engineering College, Hyderabad
[4]G. Jaikanth, Department of Electronics and Communications Engineering, Teegala Krishna Reddy Engineering College, Hyderabad

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Abstract- Unmanned Surface Vehicles (USVs) are being developed across the world at a rapid rate. The objective is to make an operating model of an unmanned surface vehicle (USV) that's multi-modular in nature, i.e. makes use of multiple modules and sensors so as to sense and actuate the specified functions to suit our desired methodology of travel, conjointly keeping in mind a path-saving algorithmic rule, that takes into consideration GPS reference system to reach out heading and course modification angles. This, in order to capture the desired telemetry and data from the onboard sensors at the specified locations in the path, then return to base for the retrieval of the data for analysis.

Keywords – Unmanned Surface Vehicle, Mission planner, GPS, Brushless DC motors

1. INTRODUCTION

Unmanned surface vehicles (USVs) are autonomous marine craft that operate on the surface of a body of water without any personnel onboard. They are analogous to airborne unmanned aerial vehicles (UAVs) and subaquatic unmanned underwater vehicles (UUVs) USVs have been widely used to conduct scientific research in the fields of oceanography and meteorology and have their applications in the oil and gas industry also. Within the Defense sector, USVs are currently being developed for several roles including anti-submarine warfare and minesweeping.

One such USV is Halcyon which is currently being developed by Thales UK and ASV Global for autonomous mine clearing missions. The simulation model presented in this paper has been developed to aid in the development, testing and validation of Halcyon's autonomy management system. Using simulation for this purpose reduces the need to conduct time-consuming and expensive sea-trials and allows for greater flexibility over the environmental conditions in which the boat must operate.

This flexibility offers the additional advantage of being able to test and evaluate several guidance, navigation and control (GNC) systems using the same "random" wave environment. To aid in this, the simulator incorporates a novel sea-surface wave environment model which is an integration of several spectral wave models and is capable of simulating omnidirectional surface waves produced or affected by ocean swell, local wind, surface currents and finite water depth.

2. PROBLEM STATEMENT

The Unmanned Surface Vessel (USV) that can be used for observatory purposes. It would travel along a set of given way points and can be utilized to observe a given terrain. Due to its small size and as there are no human lives involved in the process it's a relatively safe method to operate especially during military operations.

During the Sri Lankan civil war Navy vessels carrying passengers and supplies to the Northern peninsular of Sri Lanka were constantly attacked by suicide vessels carrying explosives and controlled autonomously.

The traditional procedure was to dispatch a Navy boat to patrol along the course of the ship before it begins the trip and observe the terrain. However, this could be very dangerous as the patrol boat is highly prone to get attacked by terrorists. Since the protection of the ship which carries many civilian lives and essential supplies to the northern peninsular of the country was at stake the Navy had no option but risk the lives of its sailors in order to save the lives of civilians. USV is developed to provide an effective solution to this problem and save the lives of many civilians and navy personnel and reduce the damage caused to the property. USV will travel on a predefined path with the aid of GPS and digital compass. Since this observatory USV is small in size a better understanding about terrorist activities could be obtained in this way and allows the boat to travel in relatively small areas which could be impossible otherwise. Also, as its unmanned the threat caused to the lives of sailors is also nullified.

3. OBJECTIVE

- To integrate all brush less motor and servos to main controller and run the vehicle in free waters with all allowed controls in manual mode.
- To travel the boat given a set of way points given by the user with the guidance of GPS autopilot and the digital compass with automation mode.

4. LITERATURE SURVEY

Unmanned Surface Vehicles (USV) has found many applications in navy and other organizations for variety of missions and applications. USV has many different applications such as surveillance of coasts, port security and submarine protection. Many private and government firms use it for oceanographic purposes like ocean depth measurement, water sampling and monitoring. USVs are also used for hydrographic surveying. Hydrographic surveys help to as certain how the features of sea, river or any other water body would affect construction, oil or gas drilling, etc. USVs can greatly accelerate the hydrographic data collection.

Several articles which are related to the ASV design and control development can be found. An autonomous surface craft called ARTEMIS was designed by a research group in MIT for collecting the bathymetry data, [2]. ARTEMIS have two electric motors and a rudder for the propulsion system. It is equipped automatic heading and navigation control through the defined reference points that was used as the location of measurement point. Subsequently the catamaran was adopted for improving the intact stability and increasing the payload capacity.

In the other research, The DELFIM was developed as an Autonomous Underwater Vehicles (AUV), [3]. The ROAZ and ROAZ II was developed and designed for bathymetry survey, [4]- [5]. Furthermore, the development of autonomous marine vehicle was represented by the SWORDFISH, MESSIN and SPRINGER. The SWORDFISH is equipped with the modular sensor for payload and a gateway for data communication from air to underwater environment, [6]- [7]. The catamaran hull form was used by MESSIN for hydrological mapping and oceanographic survey, [8]. The MESSIN able to operate in very shallow water and the autonomous navigation system was able to follow the defined route efficiently. In 2004, the SPRINGER was developed for hydrographical survey and used as a test-bed for autonomous navigation and sensor system, [9]- [10]. The study of ASV hull form development can be found in some references. In [11], the author studies the modeling of twin hull for the USV known as SESAMO for data collection in the Antarctic region. In [12], the authors develop the catamaran hull form, propulsion and control system for the ASV prototype to survey the coastal region. The integrated system for sampling and monitoring of environmental parameters has been achieved.

5. DESIGN

When considering the design of the boat the most important factor is to consider the forces which act on the boat. It was identified that the following forces are acting upon the boat while its travelling on water.

1. Thrust from the boat
2. Drag forces of water and air
3. Roll, pitch and yaw

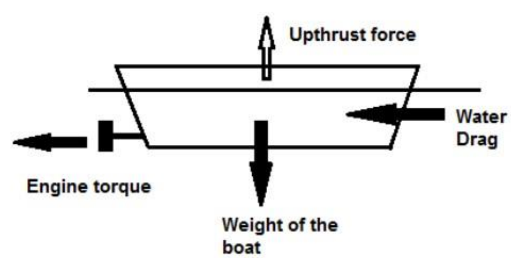


Fig. 1The forces which are acting upon the boat

5.1 Upthrust force

According to Archimedes Principle when a body is partially or totally immersed in a fluid there is an Upthrust that is equal to the weight of the fluid displayed.

mg = V ρg
V = Volume of the fluid displaced
ρ = Density of the fluid

5.2 Drag force

The drag force is the force which follows up on a solid object toward the relative stream velocity. Drag forces are reliant on velocity. Drag forces dependably diminish fluid velocity with respect to the solid object in the fluid's way.

Types of drag forces

1.Parasitic Drag
2.Lift-induced drag
3.Wave drag or wave resistance

Parasitic drag is generally used as a component of aero-dynamic and lift induced drag is just noteworthy when wings and lifting body are available. Wave drag happens when a strong object is going through a fluid at or near to the rate of sound in that fluid.

Drag depends on upon the properties of the fluid and on the size, shape and the rate of the thing. One way to deal with express this is by drag equation.

Drag Equation

$$\mathbf{Fd = 1/2\ \rho u^2 C_d A = ma}$$

Fd = Drag Force
ρ = Density of the fluid
u = Speed of the object relative to the fluid
A = Cross sectional area
C_d = Drag coefficient

A dimensionless number and for streamlined flows C_d =0.04
The drag co-efficient depends on the shape of the object and on the Reynolds number.

5.3 Roll, pitch and yaw forces

There are three axes in any vessel called vertical, lateral and longitudinal axes. The movements around them are known as pitch, roll and yaw.

Yaw axis extends from top to bottom, and its perpendicular to the other two axes. The yaw axis is perpendicular to the body of the boat.

A yaw motion is a left-right movement of the hull. Pitch axis is perpendicular to the yaw axis and is parallel to the body of the boat. A pitch motion is an up or down movement of the hull.
The resultant force acting on the boat can be obtained as follows

FT − Fd = ma
FT = Force due to the torque of the motors
Fd = Force due to the drag force

$$\mathbf{FT - 1/2\ \rho u^2 C_d A = ma}$$

Finally, an equation for the torque required by the boat can be obtained by the below equation.

$$\mathbf{FT = ma + 1/2\ \rho u^2 C_d A}$$

Also, a number of additional factors should be considered when considering about the design of the boat.

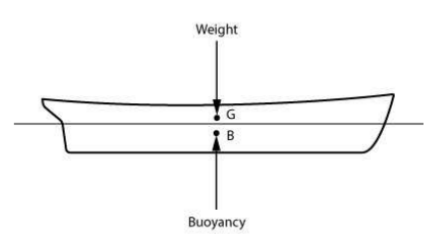
5.4 Center of Gravity

The center of gravity of a distribution of mass in space, is the point where the weighted relative position of the distributed mass sums to zero. The dispersion of mass is balanced around the average of the weighted position coordinates.

The center of mass is a useful reference point for calculations in mechanics that involve masses distributed in space, such as the linear and angular momentum of planetary bodies.

5.5 Center of Buoyancy

The center of buoyancy depends on the center of gravity. When an object is fully or partially submerged in a liquid, some of that liquid is displaced. This volume of this liquid displaced is equal to the volume of the object that is below the surface of water. Additionally, the shape of the volume of displaced liquid is same to the shape of the part that is below the surface of water.



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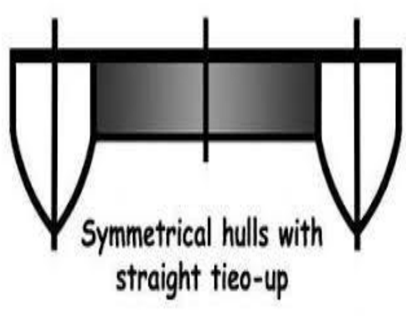

Fig.2: Center of gravity and center of buoyancy acting upon the boat

5.6 Initial Design

Fig.3 Initial Design

The initial design of the boat was to use a mono-hulled steel boat that has one propeller connected to a brush less motor for controlling the speed and a rudder for controlling the angle by which the boat should rotate. An ESC (Electronic Speed Controller) was used to control the brush less motor. The angle of the rudder was controlled by a servo motor. The mechanism was the angle by which the boat should rotate in order to adjust its course (angle) is controlled by the servo motor and the speed by which the motors should rotate in order to reach the way point is controlled by the ESC. However, this design was a failure and the boat drowned during the testing stage unable to provide sufficient Upthrust force to bear the weight of the components. Also, another reason for failure was the placement of the rudder aligned to the right side of the boat instead of placing the rudder in the center of the boat. This created a moment around the center of gravity of the boat that resulted the boat to topple during the testing stage.

5.7 Final Design

Fig.4 Top view Final Design

Fig.5 Final Design

The finalized design of the boat is much bigger in size with comparison to the initial design and it too is a double-hulled boat made of steel. This design includes two BLDC motors controlled by ESC's and they control the speeds by which the motors should rotate. The speed of rotation of motors are adjusted in order to navigate the boat to its intended heading from its current heading and to control the speed by which the boat is moving when it approaches a way point. However, this design does not include a rudder to change heading of the boat by an exact angle, but the two DC motors differentiate its speed to carry out a similar function. The speed controlling algorithm when approaching a way point however, is similar to the initial algorithm. This design is more balanced than the initial design and provides sufficient Upthrust force to balance the weight of the components.

6. PROPOSED SYSTEM DESIGN

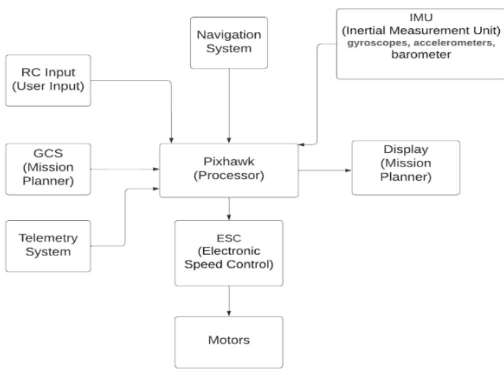

Fig. 6 Block diagram of proposed system

6.1 Working

In Manual Mode

1. One of the main controllers of the USV is the throttle controller for controlling the horizontal movement of the USV.
2. The propeller is rotated by the motor, where moment is generated in the direction opposite to that of propeller rotation.
3. The USV can move in four directions: throttle, roll, pitch, and yaw with the help of Joy stick of RC Remote. However, movement is possible only in two directions.
4. The Vehicle can be moved left or right by slow down the speed of any of the one motor.

In automation mode

1. The way point latitudes and longitudes are selected by using Google maps through Mission planner software (GCS)
2. which is connected via telemetry system (433Mhz) it uses messaging protocol of MAVLink protocol (MAVLink or Micro Air Vehicle Link is a very lightweight messaging protocol for communicating with drones/USV). for communicate with USV and the data will be transferred to the Pixhawk Flight controller.
3. The current position of the boat is given by GPS data in latitudes and longitudes. The current heading of the boat is given by the digital compass.
4. The boat takes into consideration the current position, current heading and calculates the speed by which the motors should rotate in order to maintain its course. If any deviation occurs from fixed route, the error is calculated and corrected by using accelerometer.
5. There are two BLDC motors in the boat which are used to navigate the boat along its path and to alter the speed of the motor when it reaches a way point. The speeds of the motors are controlled by two ESC's
6. first the GPS and the digital compass are initialized. Then depending on the data they acquire they BLDC motors are started to rotate
7. The GPS calculates the actual position and the digital compass calculates the actual heading of the boat. Depending on these data distance to the next way point and bearing to the next way point (β) are calculated.
8. Then the PID algorithm will consider to reduce the error of the measurement and depending on this the PWM value of the motors are changed in order to bring back the boat to its correct position by changing the bearing and to control the speed in order to reach the way point.
9. This process happens repeatedly until the error is minimized and until the boat is at its correct speed and heading. When the boat approaches the current way point values are switched to the next way point. This process is repeated until the last way point is reached and after that the PWM signal given to the motors are cut off and the boat will stop at the final way point.

7. SOME PHOTOS OF PROPOSED PROJECT

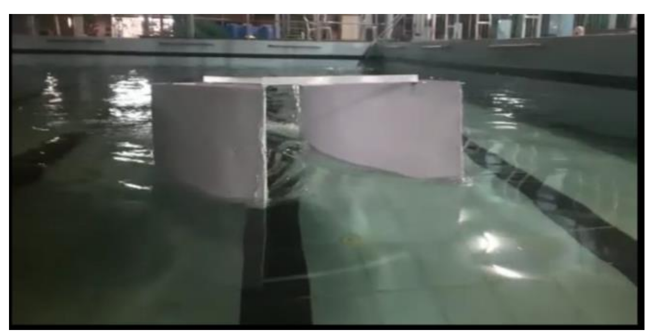

Fig. 7 a &b USV running on the surface of the water

8. CONCLUSION

The project titled **"CONTROLLING THE UNMANNED SURFACE VEHICLE IN FREE WATER"** has been successfully implemented by using Pixhawk controller. The circuit is designed by integrating telemetry system. This device serves as a technological demonstration for the capability of the given hardware, and allows testing of many navigational systems for various applications like surveillance, scientific data gathering and geological surveys. The Pixhawk provides ample connectivity to utilize the on-board array of sensors for navigation and light data processing, and allows for upgradation of the product with additional modules in the future for more advanced applications. In automation mode, this vehicle at least requires the 500m radius area of water to run in free waters.

9. FUTURE SCOPE

Modifying the boat hull and adding advanced components like an infrared camera, Ultrasonic Sensor, Compass can vastly improve the efficiency and capabilities of the vehicle. Different configurations of the cameras can help with underwater data gathering. This will enable surveys of lake beds, shore lines and can also help with finding ghost nets. The navigation system will be altered to enable locomotion within larger areas. A rudder can greatly improve the steering capabilities from the present differential thrusting system. The unmanned surface vehicle market is projected to grow within the forecast period attributable to driving factors like rising need for ocean data mapping and water quality monitoring.

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