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Structural Design of Underwater Drone using Brushless DC Motor

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Abstract

The concept of drones involves aerial surveillance from a specific height. Wh en constructing a Remotely Operated Vehicle (ROV) drone for underwater u se, it is crucial to carefully consider the various structural components to ensu re optimal performance and durability i n harsh underwater conditions. This ar ticle provides an overview of the struct ural design of an ROV underwater dro ne, including key components such as the frame, buoyancy system, thruster s, and others. The backbone of an RO V is the frame, which is often compose

d of lightweight, high-strength materials like carbon fiber or aluminum. The design of the frame must be optimized for stability, strength, and maneuverability in the underwater environment. The buoyancy system, comprising the ballast and flotation devices, is essential for maintaining stability and enabling maneuverability at different depths. This drone can be operated remotely from a distance of up to 70-80 meters.

Introduction

I. INTRODUCTION

Japan developed the first underwater drone in Asia, which was designed to lay and remove sea mines. India's first underwater robotic drone, "EyeROV TUNA," was launched and handed over to the Kochi-based DRDO lab, "Naval Physical and Oceanographic Laboratory (NPOL)[1]." The drone serves as the project's foundation and can be used for a variety of operations, including rescue and search missions.

In the coming years, seafloor observations using fiber-optic cables and satellites will generate vast amounts of data from coastal and deep-sea sites. This research aims to address the challenge of manually exploring the underwater sections of anchored ships to inspect cracks immediately. Underwater drones can help minimize risk and reduce the need for humans to perform dangerous or time-consuming tasks. Remotely Operated Vehicles (ROVs) are commonly used in deep-water industries like oil and gas exploration, telecommunications, geotechnical investigations, and mineral exploration.

ROVs are driven remotely by a surface operator through a series of wires that transmit signals between the operator and the vehicle. They usually have a video camera, propulsion system, and lights, with other equipment added as required. Manipulator arms, water samplers, and instruments that measure clarity, light penetration, temperature, and depth are among the additional equipment.

The structural design of an ROV underwater drone is crucial to its performance and durability in harsh underwater conditions. It must be optimized for stability, strength, and maneuverability to enable effective operation at various depths and under different underwater conditions. This paper aims to discuss the design and construction of key components of the ROV, including the frame, buoyancy system, and propulsion system. Specifically, it focuses on the selection and integration of BLDC motors, servo testers, and electronic speed controllers, and their role in achieving optimal performance and maneuverability in underwater applications. The importance of testing and validation of the structural design, including hydrodynamic testing and underwater trials, is also discussed to ensure that the ROV meets the required specifications and can operate safely and effectively in various underwater conditions.

II. LITERATURE SURVEY

Underwater drone technology functions like a crewless submarine and is primarily utilized for tasks such as search and patrol missions, rescue operations, and sea exploration. Typically, these drones are connected to a controller box on a ship or the shore by a lengthy tether or fastening belt. They are equipped with cameras and smartphones, enabling them to monitor underwater scenarios from the ground and collect water samples to examine the suitability of the aquatic environment for underwater life and rescue lost objects that have sunk. However, integrating wireless technology and a robotic arm into underwater drones would greatly enhance their ability to patrol the aquatic environment and produce benthic maps[2].

Benthic mapping is the process of creating a visual representation of different physical areas of the seafloor that are home to particular groups of plants and animals.

Traditional methods of benthic mapping such as SCUBA diving are not only hazardous for divers but can also limit the depth and area of the seafloor that can be explored within a given timeframe. However, the advancement of new technologies has enabled more detailed and accurate benthic mapping. For example, high-resolution multispectral imaging sensors have provided the ability to gather essential data on benthic habitats and water quality parameters [3].

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Inexpensive and widely applicable, a remote-controlled underwater video and photography platform can be used without requiring specialized resources or expertise. This study evaluates the advantages and disadvantages of utilizing cost-effective ROVs as a substitute for techniques like SCUBA diving in the creation of benthic maps within a reasonable timeframe.

An idea for an underwater drone involves using a twin rotor system[5]. This system includes two motors that are controlled by a user outside of the drone. The motors create upward or downward thrust by rotating in a clockwise or counterclockwise direction, respectively. According to the center of mass theorem, the drone's PVC structure would be assembled with motors on both ends. It is important to note that this proposed design is only capable of vertical motion within a water column.

Different types of propellers used in aerial and underwater vehicles, such as helicopters and submarines, can impact the amount of thrust generated. Apart from the propeller parameters like diameter, pitch, and number of blades, thrust can also be influenced by external factors such as air density, air temperature, water density, and the vehicle's load[6].

III. EXISTING SYSTEM

The primary goal of the proposed design is to improve the horizontal movement of existing hybrid platforms in underwater environments by integrating the advantages of multirotor UAVs and RO

V systems. This will be accomplished by maintaining the conventional structure of an aerial quadrotor for air navigation and incorporating a modified version of the quadrotor-like thrust system suggested by other researchers to improve underwater performance. The vehicle's actuation system includes two types of thrusters: the first type includes an upper air propeller and a lower water propeller arranged coaxially to improve vertical movement, while the second type includes a horizontally positioned aquatic propeller that generates lateral propulsion in the underwater environment.

Although the proposed system has some limitations, such as requiring static stability and nonholonomic kinematics of motion, which require the use of nonlinear control methods, these are typical characteristics of underwater platforms and can be addressed during the design phase of the project. For example, an extra propeller can be added to the vehicle to facilitate movement along the y-axis of the body frame.

IV. IMPLEMENTATION

A. Block Diagram

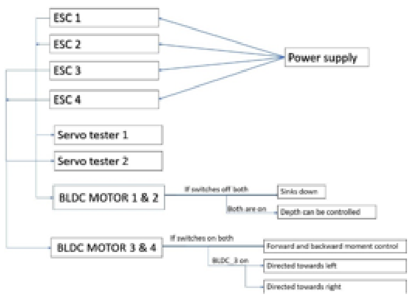

Fig 1.

- ESC (Electronic speed Controller)
- BLDC (Brushless DC Motor)

The diagram depicted in Figure 1 outlines the different constituents involved in designing a structural blueprint for an underwater ROV drone using BLDC motor, servo tester, and electronic speed controller. The propulsion system, which comprises the BLDC motor, electronic speed controller, and servo tester, is essential for attaining optimal performance and maneuverability.

The ROV's frame and buoyancy system support the propulsion system and other significant components, while the buoyancy control system guarantees that the ROV maintains the required buoyancy level at varying depths. The stability and maneuverability feature is crucial to ensuring that the ROV can operate efficiently and safely in underwater environments.

B. *Methodology*

1. *Design Requirements:* The first step in the structural design of an ROV underwater drone is to establish the design requirements. This includes the operational depth, payload capacity, and desired level of performance and maneuverability. These requirements will guide the selection of appropriate components, including the BLDC motors, servo testers, and electronic speed controllers.
2. *Propulsion System Design:* The propulsion system is a critical component of the ROV underwater drone, and the selection of appropriate motors

and controllers is crucial for achieving optimal performance and maneuverability. The design process should consider the following factors:

3. *Motor Selection:* The appropriate BLDC motor should be selected based on the design requirements, such as the operational depth, payload capacity, and desired level of performance. The motor should be rated for underwater use and have a high power-to-weight ratio.
4. *Electronic Speed Controller (ESC) Selection:* The ESC should be compatible with the selected motor and rated for underwater use. The ESC should be capable of controlling the speed and direction of the motor and providing feedback on motor performance.
5. *Servo Tester Selection:* The servo tester is used to test and calibrate the ESC and motor to ensure that they are operating within the required specifications. The servo tester should be compatible with the selected ESC and motor.
6. *Frame and Buoyancy System Design:* The frame and buoyancy system should be designed to support the propulsion system and other key components of the ROV. The design should consider the following factors:
7. *Material Selection:* The frame and buoyancy system should be made of lightweight, durable materials

that are resistant to corrosion and degradation in underwater environments.

8. *Buoyancy Control:* The buoyancy system should be designed to provide sufficient buoyancy for the ROV at various depths, while also allowing for adjustment of buoyancy as needed during operation.
9. *Stability and Maneuverability:* The frame design should consider the desired level of stability and maneuverability, which can be achieved through careful placement of the motors and propellers.
10. *Integration and Testing:* Once the individual components are designed and selected, they should be integrated into the overall ROV design. The ROV should then undergo testing and validation to ensure that it meets the required specifications and can operate safely and effectively in underwater environments. This includes hydrodynamic testing and underwater trials to evaluate performance, stability, and maneuverability.

C. *Components Used*

1. *Thruster: Brushless Motor 1800kv*

A brushless DC (BLDC) motor is an el ectric motor that uses electronic comm utation instead of brushes and a com mutator to control the motor's speed a nd direction. The 1800kv rating of a BLDC motor refers to its constant speed per volt of input power.

The motor's operation is based on the interaction between the magnetic field of the rotor and the magnetic field generated by the stator.

The stator windings generate a magnetic field when an electric current is applied to it, which interacts with the magnetic field of the rotor to rotate it. In a 1800kv BLDC motor, the motor's speed is proportional to the input voltage. For instance, if the input voltage is 12 volts, the motor will rotate at 21,600 RPM (1800kv x 12V = 21,600 RPM). The motor's torque output is determined by the current flowing through the stator windings. BLDC motors have various advantages over traditional brushed DC motors, such as higher efficiency, longer lifespan, and lower maintenance requirements. They are extensively used in electric vehicles, electric bicycles, and drones.

To make the motor suitable for underwater use, it is typically designed to be waterproof and corrosion-resistant. The motor housing is made of materials such as stainless steel or plastic that can resist saltwater corrosion. The electrical connections are also waterproofed to prevent water from entering the motor and damaging the electronic components.

???????2. *Propeller*

Selecting an appropriate propeller is a crucial consideration when designing an underwater drone to ensure smooth movement and efficient propulsion. The size of the propeller is dependent on several factors, such as the weight and dimensions of the drone, motor power, speed requirements, and the operational environment. Typically, small propellers for underwater drones have a diameter ranging from 4-6 inches and a pitch of 2-4 inches, but the exact size and configuration will vary depending on the specific application and requirements. It is recommended to refer to the manufacturer's specifications and recommendations to determine the optimal propeller for the drone. The blade pitch is determined by the motor's rotational speed in RPMs and the diameter.

The blade width impacts the amount of water it can move and hence, thinner blades are utilized for higher speed applications. While these parameters can aid in selecting the most suitable combination, it is essential to consider other aspects as well.

???????3. *Electronic Speed Controller (ESC) 30amp*

An electronic speed controller (ESC) is a crucial component of an underwater drone's propulsion system, as it regulates the speed and direction of the motor by controlling the amount of power supplied to it.

Typically, in an underwater drone, the ESC is enclosed in a waterproof casing to safeguard it against water damage. The rating of the ESC, which is 30 a mp in this case, reflects its maximum current capacity and determines the maximum power that can be delivered to the motor. It is necessary to match this rating to the motor's power requirements to ensure the drone operates efficiently. With modern ESCs, a built-in feedback control system monitors the motor's performance and adjusts the power supply to maintain a consistent speed, preventing overloading or overheating.

???????4. *PVC*

The drone body is made of PVC material, which provides water resistance. A brushless DC motor (thruster) is mounted under the body of the drone to control buoyancy in the water. To achieve forward and backward movement, motors are mounted on both sides of the drone, while the direction of the drone is controlled using the side-mounted motors. The motor's speed can be managed using a servo tester.

5. ??????????????*Servo tester*

Underwater drones use servo motors to control their movement, and a servo tester is a tool that's used to calibrate and test these motors. This ensures that the drone moves smoothly and accurately in response to the control signals it receives. Meanwhile, the BLDC motor, which is also part of the drone's propulsion system, responds to control signals by adjusting its speed and direction. This allows the drone to move in a particular direction or change its speed as needed.

???????6. *Battery 11.1v*

The 11V battery is connected to four BLDC motors through ESCs. When the BLDC and ESC are connected directly to the remote control receiver, it is important to never switch off the remote control before turning off the power to the BLDC ESC. Doing so with certain remote control models may cause the motor to rotate at full speed. To prevent this, two servo testers are used for the paired motors to control their speed. Since a BLDC motor can rotate at 1300 RPM, which is high for a prototype, using excessive power and causing unnecessary jerks can be prevented with the use of servo testers.

???????D. *Design of Drone*

The drone has a cylindrical body made of PVC pipe with a diameter of 8cm and a length of 50cm. The body is divided into four compartments to hold the four BLDC motors. Each motor is connected to an Electronic Speed Controller (ESC) which is responsible for regulating the amount of power supplied to the motor. The ESCs are housed in waterproof enclosures to protect them from water damage.

Two motors are mounted on the left of the drone and two on the right. This configuration allows for precise control of the drone's movement in all directions. The motors are controlled by a remote control receiver which sends signals to the ESCs to adjust the speed and direction of the motors.

The drone also has two servo testers which are used to control the speed of the motors. This helps to prevent exce ssive power usage and unnecessary jerks. The 11V battery is connected to the ESCs to power the motors. It is important to ensure that the remote control is turned off after switching off power to the BLDC ESCs to avoid full throttle being applied to the motors.

E. Equations

1) When pressure is applied, hoop stress occurs along the circumference of a pipe, acting perpendicular to the axial direction. The tensile hoop stress is generated to resist the bursting effect resulting from the pressure application. Meanwhile, longitudinal stress is the stress produced when a pipe is exposed to internal pressure. It acts parallel to the longitudinal axis of the pipe's centerline, which means that the stress acts along the direction of the pipe's length.

In the dived condition, the cylindrical pressure tube undergoes longitudinal compressive stress, which is half the magnitude of the hoop stress or circumferential stress. To prevent buckling and failure of the pressure tube, the equation(1) is used to determine the required thickness of the tube and the scantlings of the stiffeners.

$$\sigma_H = \frac{p * r}{t}$$

$$\sigma_L = \frac{p * r}{2t} \qquad \text{...eq(1)}$$

Where,

sH = hoop stress,
sL = longitudinal stress,
R = radius of cylinder,
T = thickness

2)

svm = (s1)² - s1s2 + (s2)² ...eq(2)

Where,

svm = von mile's comparison stress
s1 = savg + R
s2 = savg – R
R = Mohr's Criterion radius

3) The regional stability of submarine sediments in the study area was evaluated quantitatively with the limit equilibrium method. The stability of an infinite slope is studied quantitatively with the safety factor (SF).

From equation(2),

$$SF = \frac{Yield\ strength}{\sigma_{vm}} \qquad \text{...eq(3)}$$

Where,

svm = von mile's comparison stress

F. Analysis of Material

BLDC motor, servo tester, and electronic speed controller is critical for ensuring that the ROV can withstand the harsh conditions of the underwater environment and operate safely and effectively. Here are some factors to consider in material selection:

1) *Corrosion Resistance:* The ROV will be constantly exposed to saltwater, which can cause corrosion and rust on metal components. Therefore, it's important to select materials that are corrosion-resistant, such as stainless steel, aluminum alloys, or high-performance plastics.
2) *Strength and Rigidity:* The structural design of the ROV should be strong and rigid enough to withstand the forces of water pressure and the weight of the components. Materials with high strength-to-weight ratios, such as carbon fiber composites or titanium, may be ideal for this purpose.
3) *Buoyancy:* The ROV should be neutrally buoyant in water, which means that it should have the same weight as the water it displaces. Materials with a lower density, such as high-density foams, can be used to achieve the desired buoyancy.

4. Compatibility with other Components: The materials used in the structural design should be compatible with the other components of the ROV, such as the electrical wiring and connectors. Materials that can withstand high temperatures and have good electrical insulation properties, such as certain plastics and rubber materials, may be suitable for this purpose.

5. Cost: To ensure cost-effectiveness and availability, materials for the structural design must be carefully selected. Although carbon fiber composites and titanium are high-performance, they can be expensive. Thus, more economical options such as aluminum alloys or high-density plastics should be considered.

The objective is to determine the maximum safe depth that the Remotely Operated Underwater Vehicle (ROV) can reach while maintaining a safety factor of 1.5 (as per formula 1), while also identifying the most cost-effective material for this purpose. Different materials will be tested based on the size of the pressure vessel. This is a simplified version of the actual model, which is being used as a preliminary test to understand the effects of hydrostatic pressures on an object underwater.

Various factors were examined in this study, including safety factor, material, thickness, length, and diameter. The unmanned submersible will be constructed using a cylindrical housing that will contain all the necessary wires, circuits, and cameras. The cylinder's behavior as the depth increases will be the focus of the failure analysis.

The Table 1 incorporates all the materials acknowledged -

- 316 Stainless Steel (36X96 Sheet - Unpolished)
- 7075 Aluminum (48x72 Sheet)
- Titanium Grade 2 (24X36 Sheets - Ground Finish)
- PVC Schedule 40
- PVC Schedule 80

Table 1 : Safety factor of materials

PVC Sch. 40		Stainless Steel 316		Aluminum 7075		PVC Sch. 80		Titanium (Grade 2)	
Depth	FoS	Depth	FoS	Depth	FoS	Depth	FoS	Depth	FoS
50m	15.817	50m	15.887	50m	17.634	50m	24.403	50m	33.093
100m	8.636	100m	8.675	100m	9.628	100m	13.324	100m	18.069
200m	4.526	200m	4.546	200m	5.046	200m	6.983	200m	9.47
300m	3.067	300m	3.08	300m	3.419	300m	4.732	300m	6.416
400m	2.319	400m	2.329	400m	2.586	400m	3.578	400m	4.852
500m	1.864	500m	1.873	500m	2.079	500m	2.876	500m	3.901
600m	1.559	600m	1.565	600m	1.738	600m	2.405	600m	3.261
610m	1.534	610m	1.541	650m	1.606	770m	1.881	900m	2.186
620m	1.509	620m	1.516	690m	1.515	900m	1.612	1100m	1.793
624m	1.499	627m	1.499	697m	1.499	969m	1.499	1317m	1.499

PVC Schedule 80, although having a price that was slightly higher than that of PVC Schedule 40, had a better Depth to Cost Ratio. This means PVC Schedule 80 reached a depth of 969 meters, while PVC Schedule 40 only reached 624 meters. All the other materials had a low depth to cost ratio and used much more of the money than the two PVC tubes. In conclusion, the best material was the PVC Schedule 40, further testing will be done but this material seems to be the best choice to house the body of the ROV.

V. TESTING

The testing of the basic structure of the underwater ROV drone using four BLDC motors, ESCs, and servo tester has been completed. The primary focus of the testing was to assess the strength and stability of the drone's structure. The testing revealed that the basic structure of the underwater ROV drone was sturdy and capable of withstanding the harsh underwater conditions. The four BLDC motors were attached securely to the frame and provided enough power to move the drone efficiently in various directions.

The ESCs were also securely mounted and provided smooth control over the motor's speed, which helped in maintaining the drone's stability during movement. The servo tester played a critical role in ensuring precise control over the drone's orientation and position.

VI. RESULT AND DISCUSSION


Figure 2 : Prototype

Two upthrust providing motors worked well after making appropriate connections. 2 motors providing motors failed due the failure in the functionality of the servo tester. As only 1 battery is connected to all the motors the prototype is able to work continuously for 15 minutes.

VII. FUTURE SCOPE

1. Remotely operated gripper mounting on drone, with the help of remote pick up and handle underwater things.
2. With the help of machine learning algorithm drowning detection system can be installed in drone.

Conclusion

To achieve optimal performance and reliability in underwater environments, the structural design of an ROV underwater drone that employs BLDC motors, servo testers, and electronic speed controllers requires a meticulous approach to design requirements, component selection, and testing and validation. This paper presents a methodology that offers a blueprint for the design process, enabling the development of ro bust and dependable ROV underwater drones for diverse applications. The focus of the proposed model is on the design of underwater ROVs. After analyzing the material options, PVC pipe material was chosen for the outer body and wings due to its 1.5 safety factor. The drone\'s outer structure was constructed by assembling BLDC motors onto a wing-like structure. A circuit for three motors was created using a single servo tester, which functioned correctly after providing a power supply of 11.1V.

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