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Development of Autonomous Robot for Underwater Applications

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ABSTRACT

Underwater Gliders are generally used in oceanographic research, marine, biological and commercial underwater applications. An underwater glider is a type of autonomous underwater vehicle (AUV) that uses small changes in its buoyancy. The glider which is driven by buoyancy change have proven quite effective for long-range distance. For buoyancy purpose, a suction chamber available which can suck the water in and also pump the water out will shift the center of gravity of the glider to make a parabolic up and down dive pattern in the ocean. In this paper, the research involves developing an underwater glider for its horizontal path like Autonomous Underwater Vehicle (AUV) by providing a small propulsion unit at its tail part to provide pull or push force during the dive pattern. Also this autonomous robot (GLIDEBOT-S) is built with the standard available parts which are low in cost without considering sensors. CFD analysis is done for analyzing lift and drag forces at different angle of attacks varying from 0º to 45º. Matlab simulation was done for analyzing the torque of the selected motor. Gyro sensor is used for controlling the motors of rear propulsion and buoyancy engine. Based on the experimental results, it is found that the developed underwater robot functions as expected and can carry up to 1.5kg payload which can be used for implementing advanced control systems or to carry any systems within the payload limit. Further, an underwater camera is used for surveillance purpose.

Keywords: Underwater glider, AUV, buoyancy, propeller, thruster, controller, service robot.

1. INTRODUCTION

AUV is an unmanned self-propelled vehicle with a mission-control which is preprogrammed that are deployed from surface vessel in real time [1-2]. In the last 15 years, AUVs (Autonomous Underwater Vehicles) have rapidly developed as a vital tool for marine geoscientists, particularly those involved in seafloor mapping and monitoring. It also made a vital role in the field of ocean research [3]. From last two decades AUV are transformed from heavy and expensive equipment for academic research as a tool for solving theoretical and practical issues [2-3]. But these AUV's are very expensive and overweight, with more time for manufacturing. There are different types of AUVs available like screw driven AUV, Underwater Glider, Bionic AUV etc., underwater gliders best for academic research based on literature survey [3]. The buoyancy driven underwater vehicles have proven to be quite effective for long range oceanographic research [4]. An underwater glider is a type of AUV that uses small change in its buoyancy in addition with wings to convert vertical motion to horizontal, and thereby propel itself forward with very low power consumption. Currently operational gliders, such as sea glider, Spray and Slocum glider uses an electronic displacement actuator, piston and pump are used to change the weight of the glider [5]. The concept of underwater glider was proposed initially by Henry Stommel in 1989 [6]. Other three gliders are designed by Office of Naval Research (ONR) having same functionality and objectives [5-6]. Gliders typically move horizontally at 0.3m/sec compared with propeller driven AUV's which are driven at greater than 1.0m/s. the low speed capability differs at higher water currents which exceeds maximum forward speed [7]. Hence the integration

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of sea glider and AUV have research scope. The trajectory of glider is like a saw-tooth profile. Also the glider works with low power consumption and produces low sound. These gliders are used to stay underwater for a number of weeks and months depending on their battery capacity. During initial stages of design the vehicle is usually kept as a variable to meet various design requirements [8]. The concept of underwater glider is simple and elegant [9].

From literature survey, ballasting purpose in underwater glider, uses electronic displacement actuator, piston and pump, buoyancy engine for submerging. From these buoyancy driven type ballast is easy to build and have minimal errors. The model is selected based on L/D ratio and the rudder designed is followed by aircraft modelling. The mathematical equations are analyzed for performing hydrodynamic forces. In this paper, the research involves developing an existing underwater glider for its horizontal path like Autonomous Underwater Vehicle (AUV) by providing a small propulsion unit at its tail part to provide pull or push force during the dive pattern. Also this glider is built with easily available parts which are low in cost without considering sensors. A new control system is designed in MATLAB for simulation and validated with experimental model. Sensors will be used to detect temperature, pressure, altitude, position and obstacles in the water. This glider will be completely autonomous and will be navigated in a pattern once it is deployed in the water. Here the actual hydrodynamic parameters is not yet determined since the hydrodynamic efficiency is not a primary design. Using the hydrodynamic parameters studied from [4, 6], the glider motion is simulated and compared with experiments.

2. CONCEPTUAL DESIGN OF AUV

The vehicle is designed for meeting its goal like low cost, less weight and should be autonomous. It uses common lightweight materials and durable components and an easy inexpensive manufacturing process. By considering these goals the vehicle design and its overall structure is divided into sections like hull body design, rudder design and hydrodynamic surfaces. For propulsion, it consists of buoyancy engine, control system and power system.

Here the shape of hull body is taken as cylindrical shape based on l/d ratio. For underwater bodies the length to diameter (L/D) ratio is between 6 and 8, they are optimized for drag and are easiest to stabilize dynamically. Hence the design parameters are satisfied as per requirement. To balance the body in underwater the fixed wing is designed at center of hull body known as rudder. This fixed rudder acts as forward gliding for the glider. The end caps are designed for closing the hull body. These parts are drawn in solid works design software and assembled as single part. The conceptual design of the AUV is shown in the Figure 1. The design specifications are mentioned in Table 1.

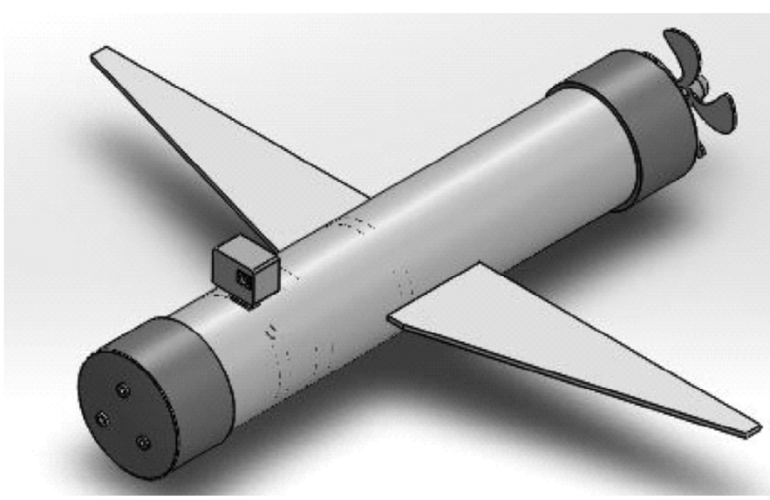

Figure 1: Proposed AUV model

Table 1
Design specifications of GLIDEBOT-S

Specifications of GLIDEBOT-S	
Dimension (m)	0.09 (d) * 0.55 (l)
Wingspan (m)	0.60
Wing width (m)	0.09
Total mass (kg)	4.5
Displacement (ml)	150
Maximum depth (m)	2.8

3. CFD SIMULATION OF AUTONOMOUS ROBOT

CFD analysis of the glider should be done in closed medium where the boundary conditions are defined. For this the water tank is created and constraints are defined as shown in Figure 2. The inlet velocity of the different angle of attacks is to be constant as 1m/s. For outlet, pressure outlet condition and for autonomous robot surfaces and other walls of flow domain is wall with no slip condition, symmetry plane uses symmetry boundary. Tetrahedral' and 'Pyramid' elements are normally employed for generating nodes and elements in the fluid domain. These elements are suitable for representation of a complex geometry such as a nozzle.

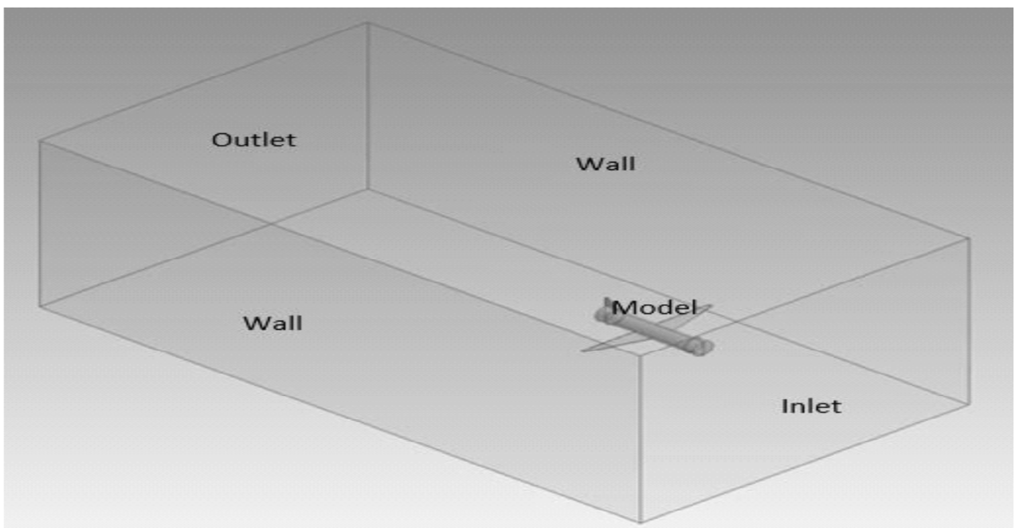

Figure 2: Boundary conditions of the glider

4. COMPONENT SELECTION

Based on the previous underwater glider design, three materials were selected for making hull body considering hydrodynamic surfaces, including wings and tail: PVC (poly vinyl chloride), acrylic and aluminum. These materials are easy for machining and also low cost. For hull body PVC is selected for easily machinable and low cost than acrylic because acrylic pipes machining is very tough. It easily produce cracks while making drills. If we need to visualize internal mechanism acrylic is preferable. The sizing of the hydrodynamic surfaces are done by using standard aircraft equations [12]. The swept of the wing tip also affects the drag. Hence the wing is designed such a way for producing low drag. So minimal sweep is added at the end of wings.

To avoid water incursion inside the hull body must be sealed. Hence the end caps are used for sealing the hull body at both sides. The PVC end caps are used for proper closing of hull body. The end caps material is machined to taper shape for reducing drag component against water pressure. The butyl rubber tube is used in between pipe and end cap for complete proper sealing. For fixing components (like motor, sensors and control board) inside the hull body a flat surfaced acrylic plate is used. The width of the acrylic plate is equal to the diameter of the hull body.

For ballasting, a buoyancy driven engine was designed for in and expels of water. This buoyancy effects the change in density of the glider and produce saw tooth dive pattern. Similar glider designs are used inflate a bladder using oil pumps, increasing effective volume. Also fish like MUG use a hydraulic accumulator to store water internally. For the glider similar to GUPPIE, a set of three syringes are used for ballasting purpose in the buoyancy engine which resembles low cost and complexity is less. The force on each syringe is function of syringe surface area and depth of the glider.

Let us assume the glider should reach 3m of depth, the pressure exerts on each syringe with surface area of $5.07cm^2$ is 30.28kpa. The mathematical equations for calculating force and torque are as follows in Equation 1,

$$P = \rho g h \tag{1}$$

Where,

ρ = density of fluid ($1.03*10^3$ kg/m^3)

g = gravity (9.8 m/s$^{2)}$ h = depth (3m)

P = ($1.03*10^3$ kg/m^3)* (9.8 m/s$^{2)}$* (3m)

= 30282 kg/m^3 = 30.28kpa

The force required for single syringe is 15.35N and the ideal total force required is 46.05N. The torque required for producing 46.05N is 3.25N-m. To overcome this torque syringes are linked with circular mount consisting a nut. The motor acts as a screw mechanism for syringes like forward and backward motion. The geared motor of 12V is selected for acquiring the required torque. For producing horizontal gliding path a propulsion unit is arranged at tail part. The list components are shown in Table 2 and CAD model of the proposed underwater robot is shown in Figure 3.

Table 2
Components specifications

S.No	*Parts*	*Specification*
1	Tube	500mm
2	End cap	54mm
3	Syringes	60ml
4	Wing	640mm
5	Circular mounts	90dia
6	DC motors	60prm
7	Arduino UNO	ATmega 4328P
8	Li-Po batteries	14.3v
9	Gyro sensor	MPU6050

5. CONTROL SYSTEM

The control system for the glider based on controlling of buoyancy engine is shown in Figure 4. The suction and expelling of water into the buoyancy is based on stroke length of syringe and time. Initially the push button switches are used finding the position of stroke. The control algorithm is written for actuating the motor. Then to make complete autonomous the gyro sensor is used for operating the buoyancy engine. In earlier controller system design they used three controllers like Arduino variant, PIC controller and an NI

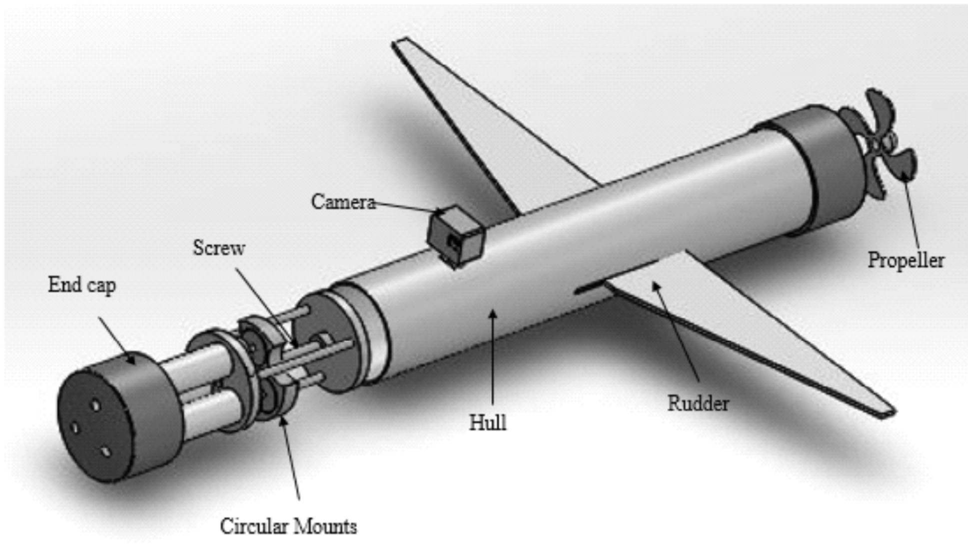

Figure 3: Schematic representation of proposed GLIDEBOT-S

SB-RIO [1]. Arduino variant and PIC controller are low cost and have similar specifications but Arduino control system is easily programmable for different tasks. Dc motors are used for producing linear motion in buoyancy engine and controlling rear propulsion. The Arduino UNO is selected for controlling system, as it is open source hardware for generating programs and also prewritten modules are available for integrating various sensors.

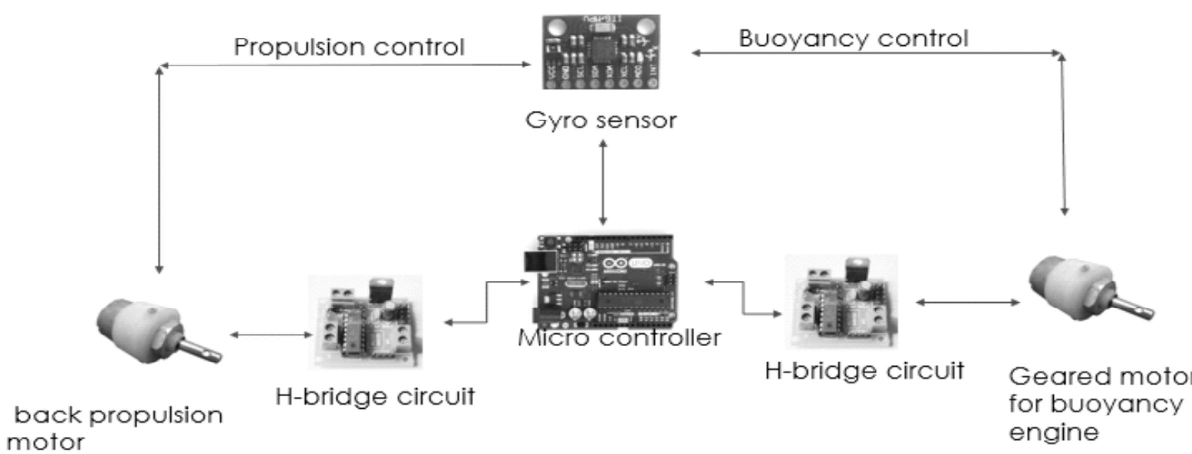

Figure 4: Control system

In circuit diagram as shown in Figure 5, the gyro sensor consists of SDL and SCl pins which creates I2c bus and give signals to analogue pins of the Arduino. From analogue pins, the pulses are transferred to motor driver (L293D microcontroller) which control the motor based on gyro behavior. The program is written into Arduino board to control the entire system.

The battery selection is based on low cost and low weight. Usually for underwater gliders a high powered battery pack are used for long range distances. But here the development of prototype long range is not considered. Hence the lithium polymer battery is used for evaluating the glider for 30mins and it was found to be low cost and it can be recharged for many times as per the requirement.

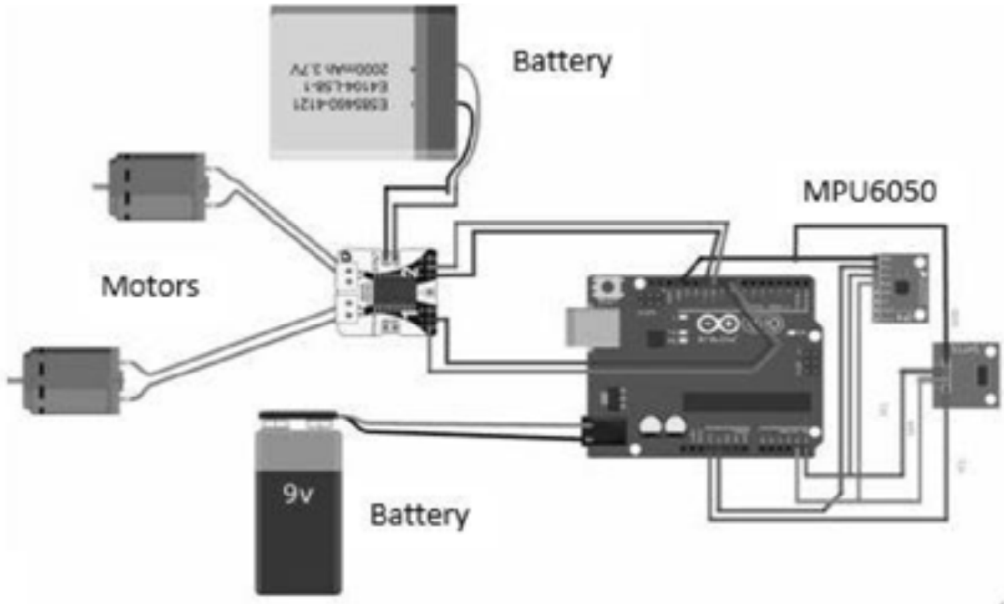

Figure 5: Circuit Diagram

5.1. Simulation

The glider dc motor is simulated in MATLAB to calculate the required torque for gliding. In MATLAB, the circuit is designed using dc voltage source, PWM block, H-Bridge module block, DC motor and Torque sensor as shown in Figure 6.

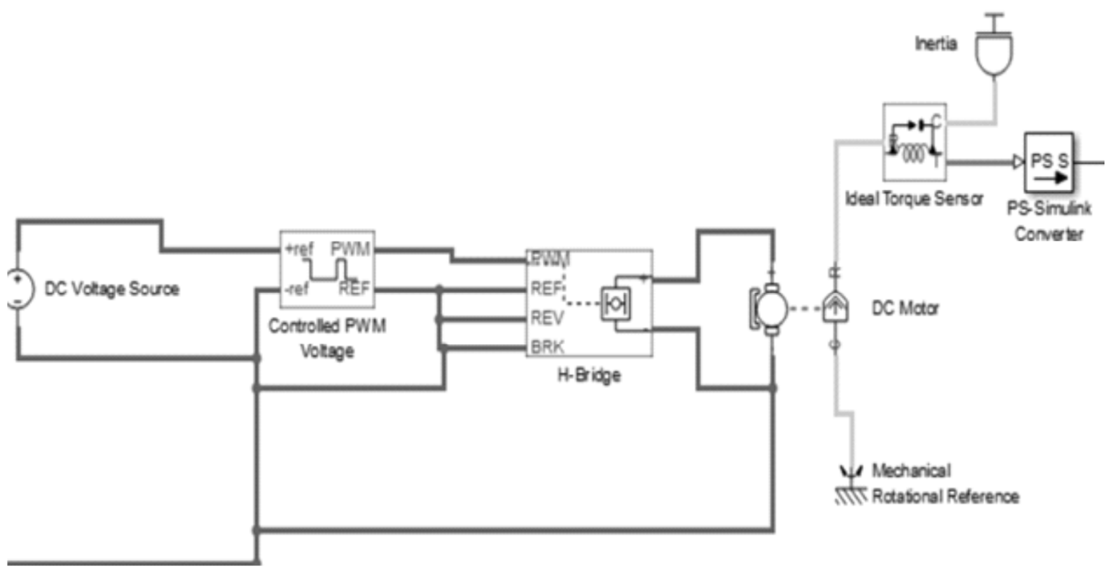

Figure 6: AUV's DC motor Circuit

Figure 7 is generated for selected motor and simulated at different time conditions using MATLAB. Based on the load conditions, the torque is varied and used in the control system.

6. EXPERIMENTAL SETUP

The developed AUV system are shown in Figure 8 and 9 and it consists of syringes, fixing mounts, motors, wires, battery, and control board etc.,. The three syringes of the piston are fixed to the circular mount at end side. The motor shaft is attached to the screw mechanism with nut. The 8mm long length screw is passed

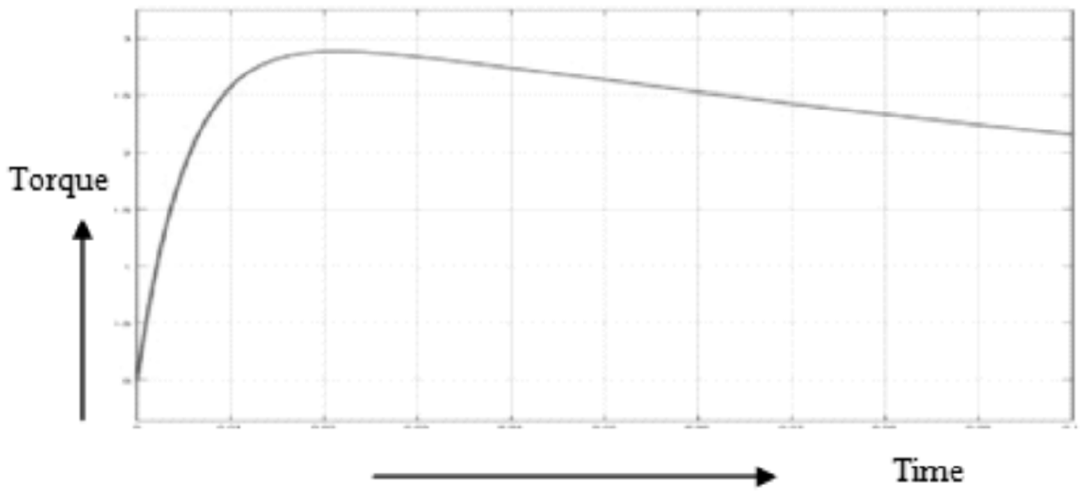

Figure 7: Torque Vs Time

through the nut and 2mm length is slotted in screw for fixing the motor shaft. The motor drive module is connected through gyro and Arduino. The end caps are drilled for mounting syringe heads and these holes are sealed with araldite solution for eliminating leakage into hull body. Rudder of the glider is fixed to the body of the system using synthetic tube glue to eliminate the water leakage into the hull body. The Arduino and motor is powered through batteries. Thus the entire setup is constructed and tested in 8 feet pool.

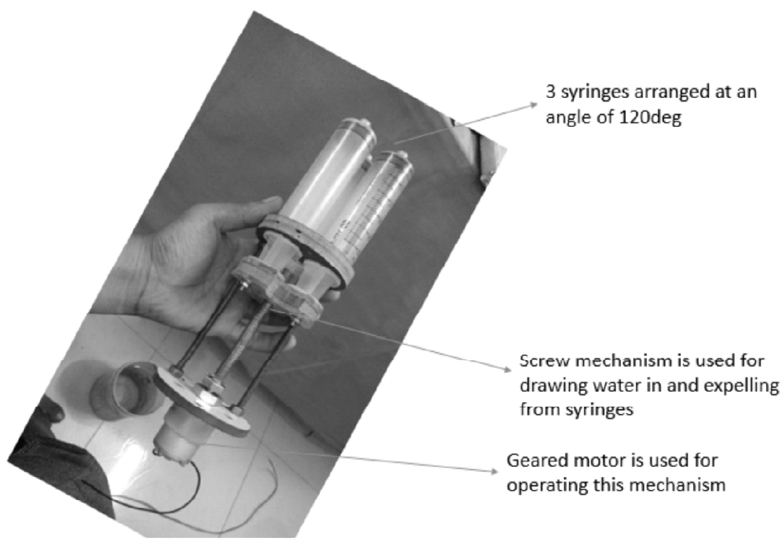

Figure 8: Internal Mechanism of GLIDEBOT-S

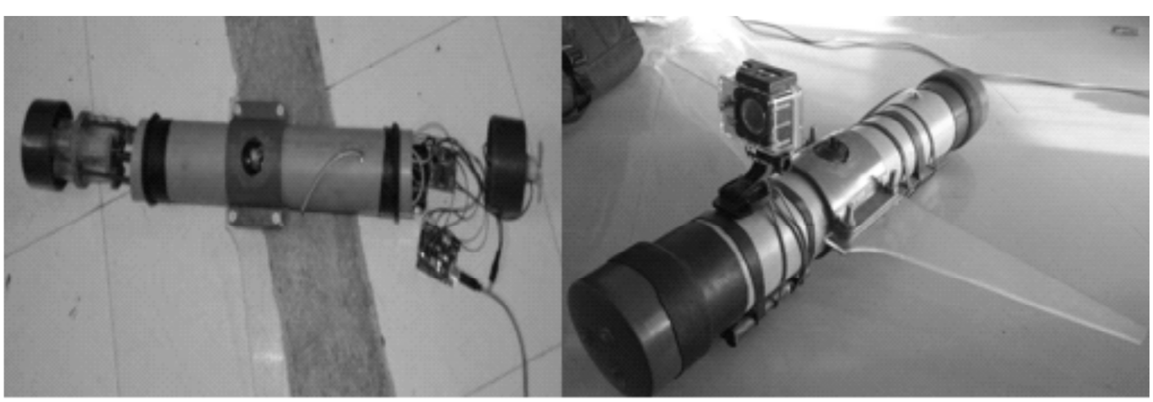

Figure 9: Prototype of GLIDEBOT-S

7. RESULTS AND DISCUSSIONS

The modelling, analysis, fabrication and testing of the autonomous robot is done and following results and discussions are made. The ITTC 1957 correlation equation was used to calculate the empirical estimation of the drag force. In steady condition the drag is calculated and found to be 0.7077N In CFD Fluent, the forces of lift and drag of the designed model is tested for various angle of attacks from 0º to 45º by making velocity constant as 1m/s. Also the pressure distribution is observed on the body. The variation of different angle of attack of the model is shown in Figure 10. And the forces of lift and drag are shown in Table 3.

Based on the results obtained it can be observed that as Angle of Attack increases from 0 the drag gradually increases. But in case of Lift it gradually increases and the lift starts dropping after +36 degrees and -36 degrees of AOA. So the maximum lift for the model of glider is 26.325 N at 36º angle of attack. The graph is plotted for the drag vs AOA in positive buoyant and in negative buoyant as shown in Figure 11. The maximum drag obtained at an angle of attack of 36º is 35.75 N. The graph is plotted for the drag vs AOA in positive buoyant and in negative buoyant as shown in Figure 12.

Figure 10: Lift and Drag for different Angle of Attack

Table 3
Lift and Drag for different Angle of Attack

AOA	*Drag*	*Lift*
-9	6.86	13.11
-18	12.67	23.32
-27	17.24	24.67
-36	24	28
-45	30.04	25.63
0	2.33	0.0353
9	14.17	6.912
18	23.32	12.67
27	24.06	17
36	28.90	25.75
45	26.58	30.74

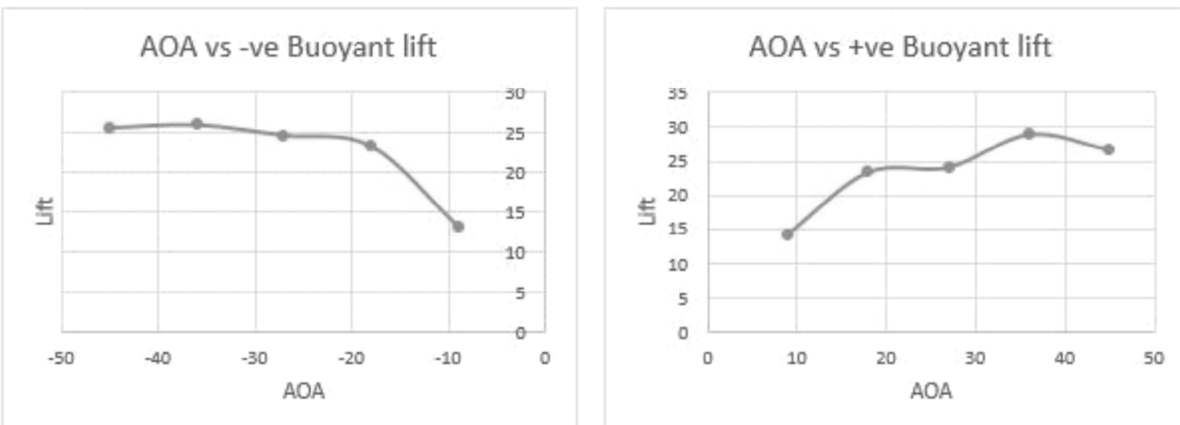

Figure 11: AOA Vs Lift

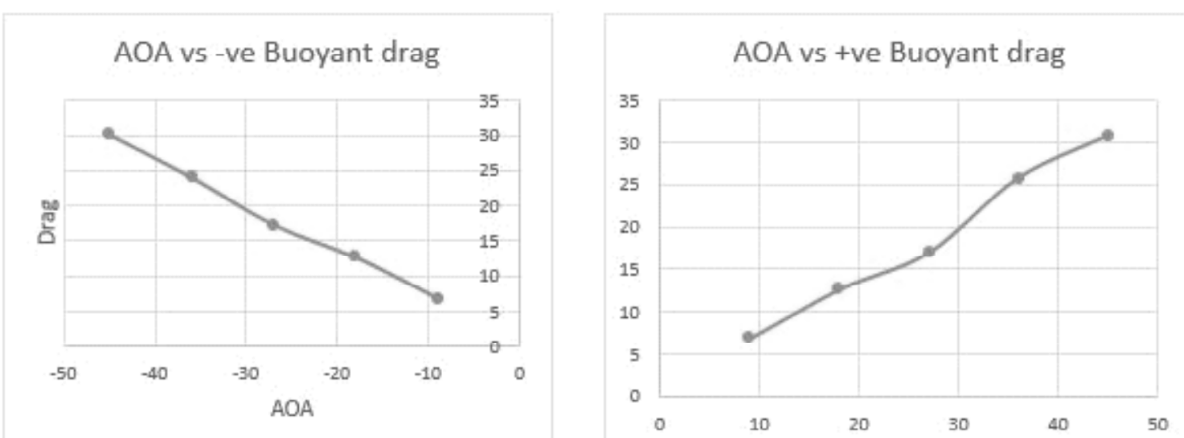

Figure 12: AOA Vs Drag

Figure 13 represents the pressure contour distribution over the autonomous robot. It is observed that the maximum pressure is occurred at the nose part of the robot is to be 5.35e2 N/m^2. This contributes to higher drag force.

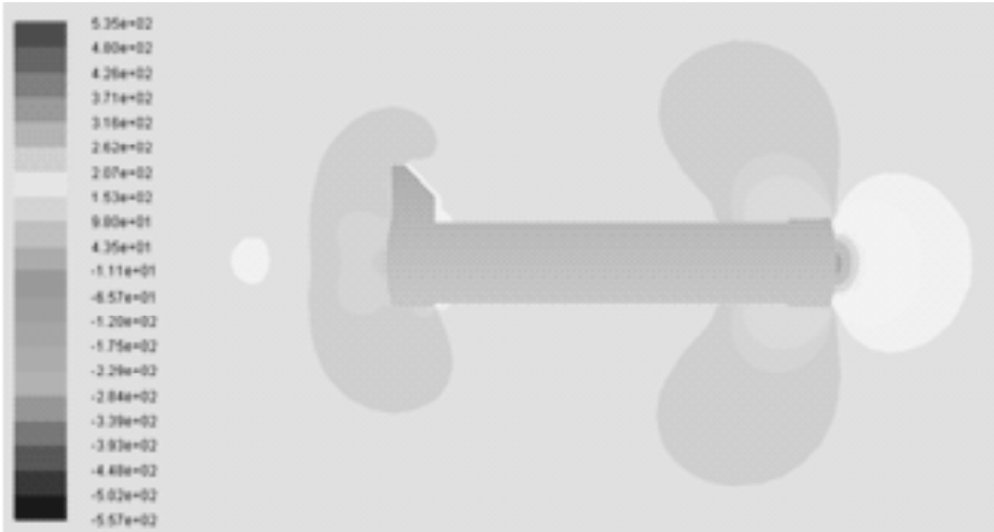

Figure 13: Pressure distribution over the autonomous robot

The observation was made in the water that the autonomous robot took 40s travel time from surface to negative buoyant as shown in Figure 14, at that position, the cylinder volume is completely filled with water. After reaching the maximum piston position, the robot stays idle for 20s inside the water and syringes started expelling of water into the tank and started rising up positively buoyant with same time 40s. The total time taken for completing one glide path is to be observed as 100s. Thus the both positive buoyant and negative buoyant are observed in the tank. Hence the buoyancy engine inside the glider is working efficiently in water.

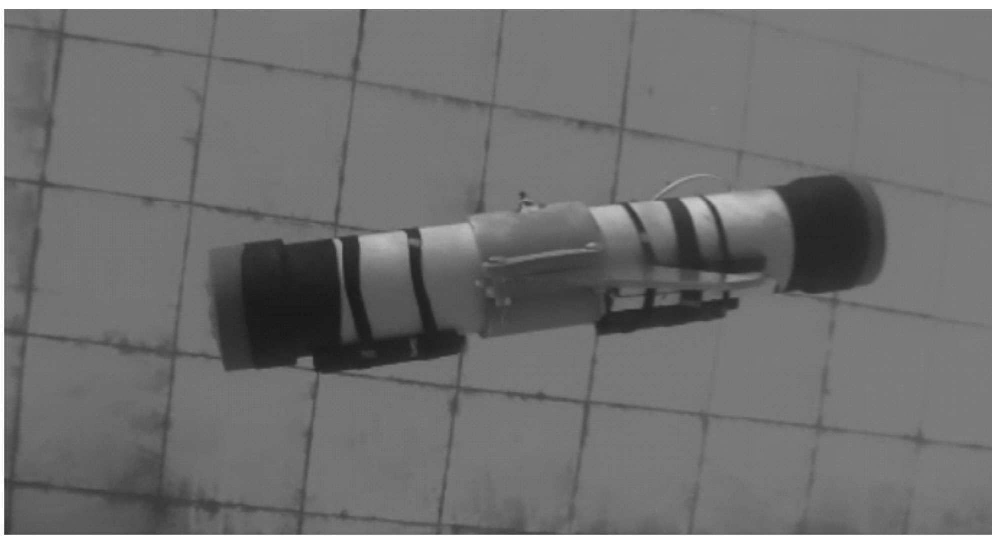

Figure 14: Experimental Investigation of the Robot in water

It is also observed the robot is completely sealed without any leakages. After testing, the rear propulsion unit and camera is integrated in the robot. As discussed in pressure distribution, at nose the drag is more but in practical the water suction and expelling is done through nose part of the robot which decreases the drag at nose part.

8. CONCLUSION

The autonomous robot is designed, fabricated and tested for underwater application. The robot is modeled and fabricated by the standard available parts. Based on the development of underwater robot for surveillance purpose, the following points are concluded,

- Compared to earlier underwater robot design mechanism, a simplified screw mechanism is used for actuating the cylinders or syringe pistons of the developed underwater glider.
- A rear proportional thruster is attached to the glider which helps the robot to glide with various speeds and also it gives additional push during its gliding.
- The developed AUV reaches the maximum depth of 2.8 m gliding in a parabolic path by shifting the center of gravity and buoyancy change.
- The parabolic path gliding is observed from negative buoyant to positive buoyant. The total travel time to complete one glide path is found to be 100s. The hydrodynamic forces are observed and maximum lift and drag is calculated.
- The developed underwater robot is capable of carrying 1.5kg payload which can be used for implementing additional sensors, monitoring systems etc.,

8.1. Future Scope

- The same working principle can be used by changing its volume of cylinder and size of the robot for ocean monitoring applications.
- The monitoring data can be transferred or viewed wireless by implementing sophisticated wifi control system.
- The travel path of the glider can be recorded and monitored through underwater camera and the data can be stored into micro SD card depends upon the requirement.
- The data can be transferred to cloud by using IOT interface and it can be controlled anywhere in the world.

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