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Design and Fabrication of an Unmanned Underwater Vehicle

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ABSTRACT
This paper describes the construction of an unmanned underwater vehicle. The UUV was developed to provide the access of underwater for exploit the environment of water and the surroundings of that particular area. The construction of the submarine was done with aluminum to reduce weight and overcome high pressure. About all the components used is water protective, so that, these can give service as submersed. The body is 22 inch long with 10 inch diameter torpedo shaped. Four submersible pumps are used in two ballast tanks for water intake and exert through two solenoid valves. External shapes mount one propeller, one rudder behind the propeller, two elevators and an antenna at the top of the body for receiving signals. The power is derived from two onboard batteries, one for the rudder and elevators, and the other one is for other components. The thrust force generated by the propeller gives forward motion to the vehicle. The machine is equipped with necessary features that would be able to provide service for a long time. In the present research, an UUV is developed and experiment is conducted. It provides an excellent platform for further development of the underwater vehicle as well as can be used in various fields like underwater research, military and civil purposes.

Keywords: Submarine, Unmanned Underwater Vehicle.

1. Introduction
Unmanned underwater vehicles (UUV) are remotely operated Vehicle (ROV) that requires minimum intervention of human operator from a remote distance. ROVs are usually mobile, small in size & highly efficient in performing tasks with unreachable depths of the sea. These are used extensively in offshore industries due to their higher advantages over human carrying submarines. Submerged sea-mines and submarines can be identified with the UUV and secure the harbor.
The first conceptual design of submarine was made in 1578. The first UUV was constructed in the form of a self-propelled torpedo in 1868, but this torpedo did not run [1-2]. The U.S navy developed UUVs in 1960. Later on, around 1980 it became popular to the oil and gas industries [3]. UUVs become essential for underwater photography, 3D image reconstruction, deep-sea mapping and imaging for geo-studies and marine researches [4]. Since, 1817 most of the UUVs were given the torpedo shape to reduce the drag [5]. Due to advancement of material science ROV becomes smaller, lighter for better stability. In this research, the unmanned under water vehicle is designed, manufactured and automatic control system is developed to control it.

2. **Design and Construction**
The design and detailed drawing of UUV is developed by CAD software (SolidWorks), Fig. 1. The structure of the UUV is composed of five main parts: two ballast tanks, blunt shaped front part for navigation and weight balance, housing for the electric control system with attached hydroplanes and rear part supporting propeller, rudder and elevator. The UUV is 22.0 inches in length and 10.0 inches in nominal diameter. The length of two ballast tanks is 12.0 inches.
A 3D model of the UUV is developed in SolidWorks (Fig. 2). After that, the UUV is constructed. To make the front and rare shape, a mold is made with wood (Fig. 3). Then the sheet is cut and put upon the mould and bent to get the shape. Finally, four individual sheets are welded together to get the front and rear blunt structure. Then the main cylinder chamber of the UUV is constructed. After that the top and side (left and right) covers are made. Some holes on the frontal, rare and the

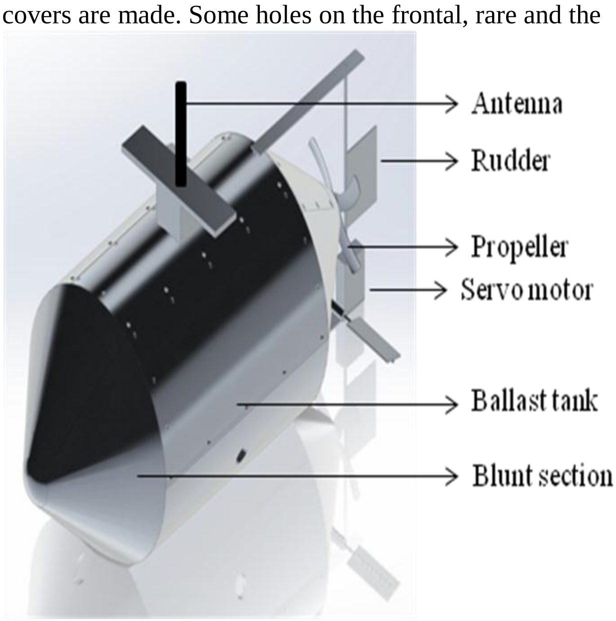

Fig. 1 Final design

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Fig. 2 Wooden mold

sideways are cut for the control systems. The control systems are attached individually according to the weight balance ratio to their respective places in the submarine. By installing all the components like rudder, impeller, elevator, antenna we get the final shape of the UUV (Fig. 3).

The electrical components are installed inside the submarine. The electric circuit and the batteries operate the propeller, rudder, elevator and pumps and solenoid valves.

There are four submersible pumps (Fig. 4) which are used to suck and discharge water. Two is used to suck water from outside to the two water chambers when submarine is going to sink. On the other hand, another two are used to discharge water from water chambers to outside during floating. Head and flow rate of 12 volt submersible pumps are 300cm and 4 litres/min respectively.

Fig. 3 Final setup of UUV

Fig. 4 Submersible pump

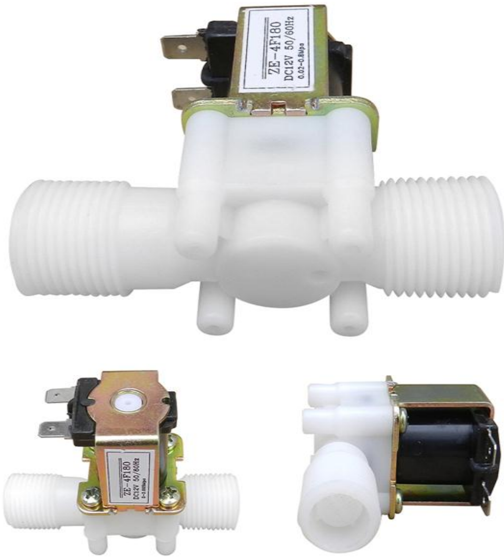

Fig 5 Solenoid Valve

Solenoid valves (Fig. 5) are used to prevent the unwanted flow of water between UUV and the water system. When water is needed to take inside the vehicle then the valve is opened with power supply and submersible pumps work to pump water inside the ballast tanks. Also when the ballast tank water need to excel, solenoid valve is powered to open and the other submersible pumps which work to exert water from the ballast tank start to pump out the water which assist the vehicle to float. Two individual solenoid valves are used for two water vessels. Orifice size, valve type and pressure range of the solenoid valve are 8.5 mm, diaphragm and 0.2-0.8 MPa respectively.

A brushless motor and a propeller are presented in Fig. 6. There is one brushless DC motor which is mounted on the rear side of the vehicle. The motor drives the propeller which results the forward motion of the vehicle. A high torque low RPM motor is used in this study. Shaft diameter, maximum current of motor are 3.17 mm and 20 A respectively. Because high torque motor is necessary for under water vehicle.

Servo motors are used to fulfill two different objectives: to control the vertical and horizontal direction of the

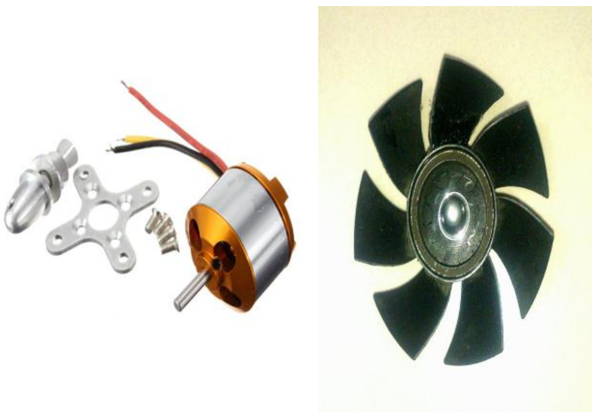

Fig. 6 Brushless motor and propeller

Fig. 7 Servo motor and rudder

submarine. A high-torque (10kg stalling torque) metal geared MG996R digital servo motor is used (Fig. 7). Two servo motors are assigned to uplift the vehicle by rotating the elevator. One servo motor is used to rotate the rudder to give the vehicle a turning movement so that, it can change its direction to move. The rudder is placed after the propeller so that the water can directly hit the rudder blade. Therefore, the vehicle turns faster.

Two Lithium-Polymer batteries (6000mA and 1100 mA) are used for power supply to the whole UUV (Fig. 8). Here, 6000mA 12 volt lithium polymer battery is used to support all the equipment like pumps, solenoid valves and propeller. We also used an 8 volt 1100mA DC battery for power to the micro controller board which supply power to the servo motors. It is used to reduce pressure on the main battery which will supply power constantly to the propeller to give the vehicle forward motion.

The general purpose of constructing the unmanned underwater vehicle (UUV) is to learn the principle of the vehicle. And another purpose is to explore the underwater environment. We have constructed the unmanned underwater vehicle through different design phases. After completion of the design phases the vehicle was constructed. Technical specifications of the designed UUV are presented in Table 1.

Fig. 8 6000mA and 1100 mA Li-Po battery

Table 1: Technical Specifications of the UUV

Parameter	Value
Depth	0.5 m
Maximum speed	0.1383m/s
Maximum Drag	1.062881 N
Dimension	
Total Length	22 in
Length of main vessel	10 in
Length of front and rear part	5 in
Radius of Main vessel	5 in
Weight	
Designed body	10.94 kg
Actual body	13.520 kg
With water mass balance	20.250 kg (max.)
Volume	
Vehicle	17.69×10^{-3} m^3
Water inside ballast tank after mass balance	5.16×10^{-3} m^3
Air	12.53×10^{-3} m^3
Power System	
Voltage	12V
Current	6A
Power	210 Watt
Control System	Bluetooth control via Arduino mega
Propulsion System	Brushless DC motor

3. Control Panel

The Arduino Mega 2560 is a microcontroller board (Fig. 9). It has 54 digital input-output pins of which 15 PWM outputs, 16 analog inputs, 4 Universal Asynchronous Receivers/Transmitters (UARTs), a 16 MHz crystal oscillator, a USB connection, a power jack, an In-Circuit Serial Programming (ICSP) header, and a reset button. The Mega 2560 board is compatible with most shields designed. In this research, 16 pins are used to control the UUV.

An eight channel relay interface board (Fig. 10) of 5V is used in this study. It is able to control various appliances with large current. It can be controlled directly.

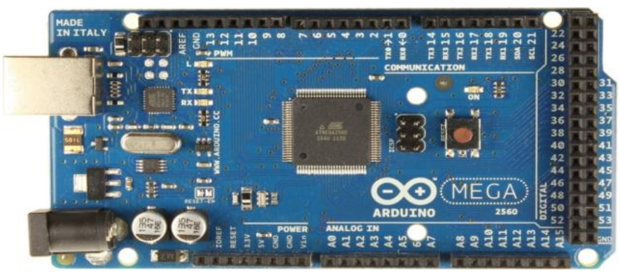

Fig. 9 Arduino Mega R3 2560

Fig. 10 Relay interface board

Fig. 11 Electric Speed Controller

Electronic Speed Controller (ESC) is the device to control the speed of the brushless dc motor. An ESC is shown in Fig. 11. It helps to vary the revolution of the motor which facilitate to vary the speed of the vehicle. It also helps to speed up gradually to give the propeller a gradually increasing torque for the forward thrust.

HC05 Serial Port Bluetooth is a device (Fig. 12) which works as the receiver of the signal. In the present study, submarine is controlled by a mobile phone. Bluetooth app is installed in the mobile phone. The signal is transmitted from a smart phone through Bluetooth technology. There are six pins of the Bluetooth device. Here, four wires are connected: two are for power to the device and another two are for receiving and transmitting data to the Arduino board. After receiving the data from the Bluetooth device Arduino identify the command and does the task by sending the signal to the components that should be operated.

A veroboard is used for different wire connections. The submersible pumps and solenoid valves are connected through the relay interface board from where 6 channels are used for our purpose. The relay is controlled by the microcontroller board. The servo motors which operate the rudder and elevator are also operated by the microcontroller. The propeller motor is connected to the main battery through the ESC. All the signals come to the Arduino board through the Bluetooth device.
Connecting the battery with the Arduino Mega and relay we got the power of the Submarine. Then Arduino Mega is connected with the smart phone via Bluetooth

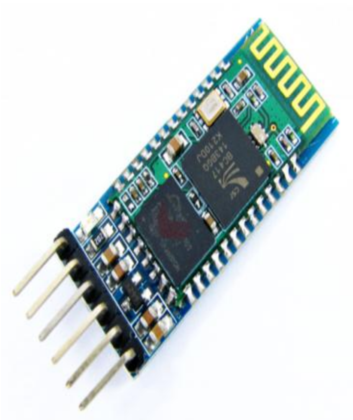

Fig. 12 HC05 serial port Bluetooth

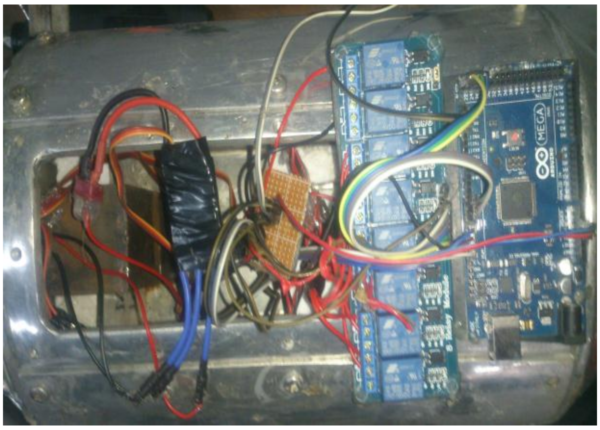

Fig 13 Setup of control panel

to operate the Submarine. Fig. 13 shows the electrical wiring of the control panel. A program is written and uploads to the Arduino board. At first we have to dive the submarine underwater. For the diving operation submerge the submarine under water was necessary. To drown, first the solenoid valve was opened and the intake pumps were start to let the water fill the blast tanks.
After fill in the blast tank, the BLDC motor started to give the propulsion of the submarine. The motor transfers power to the propeller. Then the servo motors are used for operations if needed. The servo motors are attached to control the elevator and rudder. The elevator gives the submarine vertical movement and the rudder gives the submarine directional movement. If the submarine needs to come to the surface of water, then controller send signal to the submersible pumps to force the water out from the blast tanks. Thus the submarine starts to float in water.

4. Calculation

Archimedes principal is quite useful to build the water vessels like ship and submarine. Archimedes principal is followed and a UUV has been successfully designed and prototyped with low cost. Mass and volume of the UUV is 13.520 kg, and 1.769×10^{-2} m^3 respectively. Therefore, density of UUV can be calculated by eq. (1).

$$D_{UUV} = M_{UUV} / V_{UUV} \quad (1)$$

Now the specific gravity of the UUV, can be calculated by eq. (2).

$$SG_{UUV} = D_{UUV} / D_w \quad (2)$$
$$= (764.27\ kg/m^3) / (1000 kg/m^3)$$
$$= 0.76427$$

Here, SG_{UUV} is less than 1. Hence, the UUV will float on water when the ballast tanks are empty.

5. Result and Discussion

The process of construction of an unmanned underwater vehicle is discussed in this study. Each components of the UUV is selected based on availability and low cost. The prototype has a complete set of components

including hull, propeller, rudder, elevator, speed controller, depth control, microcontroller board, batteries, and communication device.
During the experiment the revolution of propeller at different speed of the UUV is measured. It is found that the efficiency is 73%. The run time to go a distance of 170 m for various propeller speeds is estimated. From that, velocity of the UUV is calculated. Fig. 14 shows the velocity the submarine at different speed of the propeller. From the graph is seen that, the velocity of the vehicle increase gradually with the increase of the propeller speed.
At different speed the vehicle faced different amount of drag force. Here, for the blunt shape of the UUV, the coefficient of drag is 2.2. The frontal area of the submarine (A) is 82×10^{-3} m^2. For various speed of the vehicle, the drag is calculated by $F_d = 0.5\times\rho\times v^2\times C_d\times A$. Here, C_d is the drag coefficient, ρ is the density of the fluid, v is the velocity of the submarine Fig. 15 shows the drag versus velocity of the UUV. If velocity is increased then drag also increased.

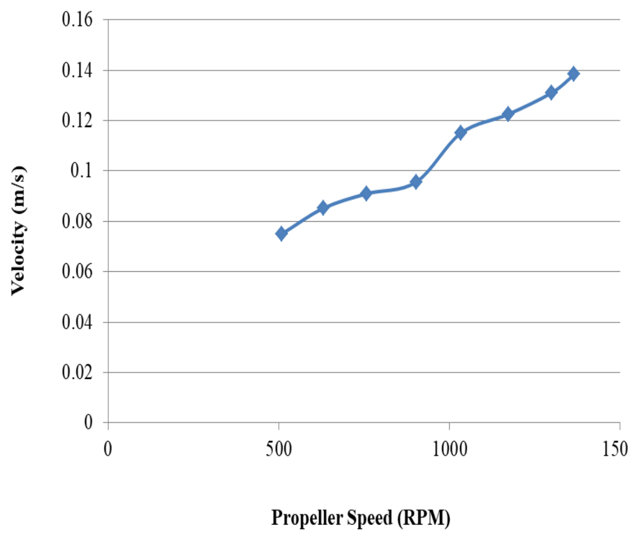

Fig. 14 Propeller speed versus velocity

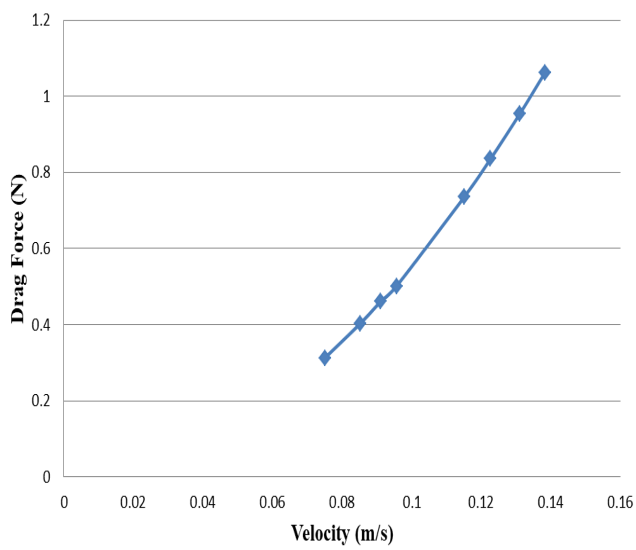

Fig. 15 Drag force vs. velocity of UUV

6. Conclusion

Objective of this research was to develop a prototype of an UUV with available facilities and to figure out its characteristics. With similar elements, by following the construction process one can build an entire submarine with full scale structure which can be operated through the water. No fuel will be required here. The efficiency of the vehicle largely depends on the perfect transmission system, load, hydrodynamic and the design of the propeller. The speed of the submarine depends on the propeller speed. There is a problem due to the leakage for which sometimes the system is dynamically unbalanced. Water leak is prevented by using gaskets, tape and gum. The biggest limitation of the setup: it is not perfectly water protected. The basic use of our unmanned underwater vehicle is to monitor the underwater environment of our water area. The unmanned under water vehicle can be used as the forward surveillance medium of Bangladesh Navy. As it is operated from a distance without a living soul in the vehicle, therefore, the risk of the loss of human's life being decreased in the war. UUV can inspect the submerged pipelines those are used to transfer crude oil and communication cable. In the present research, an UUV is made and experiment is conducted. In future, camera, light, and different types of sensors can be fitted with the UUV for different applications.

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NOMENCLATURE

D_{UUV} : Density of the UUV, kg/m^3
M_{UUV} : Mass of the UUV, kg
V_{UUV} : Volume of the UUV, m^3
SG_{UUV}: Specific Gravity of the UUV
D_w : Density of the Water, kg/m^3

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