



## Design and Fabrication of Under Water Remotely Operated Vehicle

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### ABSTRACT

Underwater Remotely Operated vehicle is a tethered mobile vehicle most often used to monitor underwater oil and gas drilling inspection, telecommunications and homeland security. The main focus of this research is to design a vehicle at low cost which is safe, portable, and easy to use while increasing the maneuverability and efficiency to reach a depth of 5 meters. While conducting research a unique design is selected based on a novel fin propulsion mechanism rather than propellers. Propellers though have high speed but cannot work on low flow rates and their blades can be damaged if jelly fish or other material is struck in its shaft. Two shapes have been considered to remove above difficulties i.e. Fish and Turtle. Due to higher stability, larger area and greater hydrodynamic efficiency Sea Turtle has been selected, as it can easily overcome the forces like buoyancy, pressure and thrust force. The results extracted from this research shows that the underwater vehicles based on the biological locomotion principle can perform very well than other propeller counterparts. The research concludes with the performance of a working system that validates motion capabilities related to speed, depth and hydrodynamic efficiency which can be further improved by using sophisticated control systems, outer shell and highly integrated processors.

## 1. Introduction

The design and implementation of underwater robot will be discussed in this paper. Rather than the conventional based propulsion by propellers, a novel bio-inspired propulsive mechanism similar to sea turtles is actualized. The main motivation of this research is to meet the round the clock underwater surveillance, sea exploration, scientific search and diving assistance.

An underwater remotely operated vehicle (UROV) is considered best approach to achieve above objectives. One of the main trends for UROVs is "autonomy" for some specific tasks, such as position tracking, dynamic positioning (or station-keeping), auto-heading and auto depth control. The ROV system is highly maneuverable unmanned which is operated by a person using tethered cable or by sensors through remote. It is connected to the vehicle by a tether or known as an

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umbilical cable. Under water vehicles are becoming useful source for commercial uses, mine hunting and sea. The underwater vehicle raised its cost effectiveness due to greater sea diving extreme environment conditions and maneuverability.

Lygouras *et al.*, [1] developed unmanned underwater remotely operated vehicle (ROV) called THETIS, which is used for measuring the water pollution in ocean environments. It is composed of remotely operated vehicle, a cable wire for power supply optical fibers and four DC motors, pivoting exceptionally outlined propellers for controlling profundity, location on the level plane, and caption of the vehicle. The DC engine propeller framework will be eluded as the thruster. AC or DC motor is adjusted to the vehicle as thrusters-First, click on the View menu and choose Print Layout. Yamamoto and Terada [2] adapted a propulsion control system on a robotic fish. They proposed an oscillating fin propulsion system. They arranged different types of tests on fins. As mentioned in this research that there are two types of fins (rigid and flexible). They work on flexible fins because it has more advantages than rigid ones to push out any text that may try to fill in next to the graphic. First, they generate a controlling algorithm for controlling the fin oscillating system.

Pan-Mook *et al.*, [3], the Ocean Exploration System Research Division of KORDI-MOERI "Korea Ocean Research & Development Institute" improved the arrangement of a 6,000-meter profundity appraised unmanned submerged vehicle (USV) for oceanographic inquire about in Korea. The USV framework consists of two vehicles: a "HEMIRE" remote vehicle and a "HENUVY" dive initiator had collaborated with the remotely operated vehicle. In 2006, Hu *et al.*, [4] designed and developed an autonomous robotic fish which swims like a real fish mechanism. The thrust for swimming is generated by bending or moving their one half or one third body. The body of fish is made up of 3 or 4 tail joints. These 4 joints connected with each other by Linkages.it consist of four servo motor and two DC motors. The four servo motors are used to bend the tail at greater angle with minimum time. A team of six students Tan *et al.*, [5], Michigan State University developed an autonomous underwater robotic fish for mobile sensing. Firstly they made a working prototype that could be operated with remote with the help of radio controller. After prototype, they built a circuit in which a GPS system, sensor, autonomous navigation, communication are installed and these are sealed with silicone adhesive. Shao *et al.*, [6] investigated cooperation control group of micro robots which are implemented by fish like propulsive system. The purpose of this work is; first to designed a fish like robot and realized; Secondly to use these multi-unit robots for underwater transportation.

Ye *et al.*, [7] developed a remote-control centimeter-scale Robotic fish. There works is related to design a robotic fish. Though so many scientists, researchers have done more work on robotic fish, they are all worked on larger scale but only few were done on small scale autonomous robotic fish. Because when the length, width and height is decrease of its actual size than its overall size will also decrease. They use infrared sensor for operating the remote control function. Font *et al.*, [8] adapted a design and implement a propulsive Autonomous Underwater Vehicle Hydrofoil that is similar to the turtle's hydrofoil. They selected the hydrofoil NACA 0014 (National Advisory Committee for Aeronautics) because it gives a good relationship among drag and lift force. The profile selected is biomimetic ally to the sea turtle. In this there are 4 different phases' upstroke, upstroke, supination, and pronation. They use ball and socket mechanism for generating this type of hydrofoil which gives three degree of freedom and it is so compact. Aras *et al.*, [9] worked on low cost four degree of freedom remotely operated vehicle which is integrated with (IMU) and the pressure sensor. The purpose of this robot is to reduce the involvement of human activities under water because of high cost. To improve the efficiency and productivity, different industries develop a micro robot for their purpose. Martos *et al.*, [10] developed a remotely operated vehicle which is used in water for marine purposes. They just introduced a robot and also design a robot for general purposes. In this report they give about the idea of robot and also history of robot. They just made

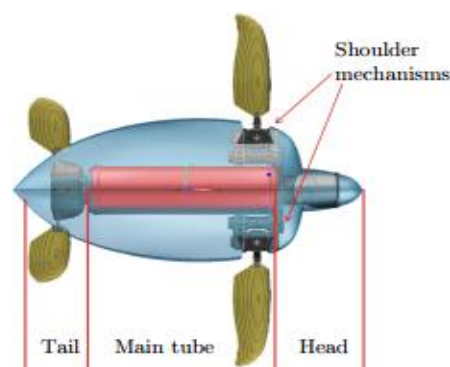
a robot which is fully equipped from video camera, propulsion system and lights. They designed a special type of robot called tuna shaped. There designed were also tested successfully.

Liu *et al.*, [11] provided a novel mechatronics plan for a 3D swimming automated fish, specifically MT1 (Mechanical Tail) mechanical fish. It has tail shape which utilizes just a single engine to create fish like swimming movement utilizing C-twists tail shapes. This outline empowers MT1 to wind up the primary little size mechanical fish (<0.5m long) and have the capacity to plunge more than 3 meters somewhere down in water. A successful control strategy with just 5 parameters is proposed to control its 3D swimming practices. Trial comes about are displayed to demonstrate the possibility and great execution of the proposed control calculations. The Tuna fish have a more prominent capacity to fish and swim with rapid. This property of Tuna angle pulls in the specialist, researcher to enhance the execution of Robotic fish. Zhuoyi *et al.*, [12] worked on the structure design of underwater vehicle which is made up of composite material. The structure of underwater vehicle depends upon buoyancy factor and gravity of the vehicle in water. Composite materials as good strength and also have stiffness, and stable against chemical reaction. Composite materials also have the ability to absorb sound. There work is related to reduce the weight of vehicle. For this purpose, they used carbon fiber for their requirements.

Anwar *et al.*, [13] fabricated and implemented remotely operated vehicle by using single thruster, this robot is design for surveying hollow tubes or shell has been done. It moves in 2 degree forward/backward with the help of thruster, and up/down with the help of changing density. For changing the density two water chamber on each side of hull is used. The density is changed by draining or filling this chamber, but all the main electrical components is attached to the main chamber. Chen *et al.*, [14] investigated Magnetically Actuated Miniature Robotic Fish is actualized. It works on law of electromagnetic induction. It consists of two magnets and a solenoid which is fixed with caudal. The two magnets generate their magnetic field and solenoid also generates its magnetic field when the pulse and frequency of electric current passing through the solenoid is changed or modulated. When the two magnetic fields is coupled than a force is developed which moves the fins of Miniature Robotic Fish. For controlling and power Bluetooth Low Energy (BLE) is used.

## 2. Mechanical Design

The project design phase was divided into four main parts: (1) Selecting a bio-inspired shape considering its stability, maneuverability and can contain many instruments within its structure, (2) Mechanism to move fin in 3 DOF motion, (3) Designing of fin, (4) Controls. Initial design inspiration took shape as shown in Figure 1.



**Fig. 1.** Selected Shape

Initial design ideas provided were then used in creation of the CAD model for the entire system for designing overall structure, mechanism and control of UROV. For specifying the shape of the UROV research paper gives us the previous work on the different shapes of the bio-inspired vehicles. The reasons are as (i) Due to its larger area we can place many components (sensors, motors, large battery) in it, (ii) Maneuverability, (iii) Hydrodynamic efficiency.

Selection of a material for a process is based on its strength, application, availability, process and economically suitability. With reference to the product design the core objective of a material selection is to minimize the cost while meeting the performance goals. Systematic choice of the best material begins with cost and properties of candidate material. So, materials used and their properties are as follows

- Acrylic, PMMA( For front and back portions so that we can see if there is any leakage occurs)
- Unbreakable PVC( for internal components( electronics, motors...etc.) casing
- High carbon fiber/Epoxy.

Selected and implemented mechanism to achieve 3DOF (Degree of Freedom) is Combination of servo motors. This is the most flexible mechanism in which five servo motors are assembled together in such a way that this joint gives three degree of freedom system. Three out of five are high torque motors which give 3DOF at any maximum displacement. The requirement to design the flapper must meet the following conditions:

- Must move in 3DOF
- Have enough suitable strength to bear forces of water
- Have less drag coefficient and generates the maximum lift during the downward stroke

So, keeping these objectives in mind two hydrofoils are finally considered named as NACA0014 and RYAN BQM-34 FIREBEE AIR FOIL. So being on the save side NACCA 0014 is finally selected as flapper for underwater remotely operated vehicle. Mechanical components design of UROV is shown in Table 1.

**Table 1**  
Mechanical components Design

Vehicle Parameter	Value	Unit
Body Material	PVC pipe, PMMA, fibreglass	
Length of main hull	600	Mm
Diameter of main hull	165.1	Mm
Diameter of water chamber	76.2	Mm
Total mass of vehicle	12	Kg
Density of water (at 20°)	998.2	Kg/m <sup>3</sup>
Nominal Speed	1.0	m/s
Drag Force	1.579	N
Thrust Force	3.436	N

### 3. Design and Calculation

#### 3.1 Drag Force

In liquid progression, drag constrain is the power acting against the movement of a question moving in respect to the encompassing liquid. Torpedoes and submarines make them thing in like manner that is, they have a streamline body and a focal barrel that is utilized for lodging of a wide range of instrumentation, weapons, and valuable lives. In the majority of the cases, the body utilized is round and hollow fit as a fiddle because of its quality and capacity to agree to the dynamic powers following up on it. Despite the fact that, it is very productive in the auxiliary outline than different states of geometrical measurements, yet it gives less space to the frameworks

dwelling in it. This is because of the way that every one of the frameworks set in it are normally square or rectangular. So, drag is calculated as

$$C_D = C_{D,PRESSURE} + C_{D,FRICITION}$$

$C_D$ ,  $C_{D,PRESSURE}$  and  $C_{D,FRICITION}$  represent coefficients of viscous drag, pressure drag and friction drag respectively.

$$C_F = \frac{0.075}{(\log R_N - 1)^2}$$

$$R_N = \rho V L / \mu$$

Drag coefficient also depends on characteristic area. It is reported that frontal area is used as a characteristic area for cylindrical shapes.

$$F_D = \frac{1}{2} \rho V^2 A C_D$$

$\rho$  is the density of the fluid,  $V$  is the velocity,  $A$  is the frontal area (in this case) and  $C_D$  is the drag coefficient.

While moving downward towards the depth in the sea lift is also the unfavourable and opposing force acting on the body which was fine by

$$F_D = \frac{1}{2} \rho V^2 A C_L$$

### 3.2 Force Due to Weight

Apart from drag there is another force acting which has to be counter to move and this is force due to weight. It is calculated as

$$F = W = m g$$

### 3.3 Thrust Force and Torque

Thrust force is the driving force for the vehicle against any friction or drag. This force can be provided by many means. For this type of vehicle flapper-based mechanism is used

$$F_t - F_D - F_L = m \ddot{x}$$

Also, torque;

$$T = F \times r$$

### 3.4 Waterproofing and Sealing

Waterproofing is the most crucial part to be considered for the integrity of operations of vehicle. Motors are sealed by using grease and silicon cement/gel while cylinders are by use of PVC cement and glue. Waterproofing is the most important factor to be considered for the integrity of the operations of the vehicle. Two acrylic, transparent, disks are installed on both ends of the main hull. These disks are permanently sealed. These disks are installed for quick visual inspection of inner side of the main hull. Electrical plate is removed by opening the cap on the rear side of the main hull. Both the cap and the main hull have threads which provide mechanical seal. O-ring seal is also used with threads to complement the waterproofing of the main hull.

### 3.5 Calculations

#### 3.5.1 Known parameters

For sea water

Density =  $\rho = 1013 \text{ kg/m}^3$

Salinity = 20 g/kg

Dynamic viscosity =  $1.043 \times 10^{-3} \text{ kg/m.s}$

Velocity of water =  $v_{\text{water}} = 0.8217 \text{ m/s}$

Temperature =  $20^\circ\text{C} = 293 \text{ K}$

Secondly the area of the overall body of robot without fin is calculated and is as follows

Area of the flapper =  $229\text{cm}^2$

Area of center body =  $990\text{cm}^2$

Area of the hind flappers =  $114\text{cm}^2$

#### 3.5.2 Drag calculations

Firstly, for the fin

$C_{D,\text{pressure}} = 0.7$

Area =  $229\text{cm}^2$

$V = 1.5 \text{ m/s}$

Overall  $C_D$  formula

$$C_D = C_{D,\text{PRESSURE}} + C_{D,\text{FRICTION}}$$

Where  $C_D$  = Viscous Drag

$C_{D,\text{PRESSURE}}$  = Pressure Drag

$C_{D,\text{FRICTION}}$  = Friction Drag

Skin Friction Drag is the function of Reynold's number which is defined by

$$C_F = \frac{0.075}{(\log R_N - 1)^2}$$

where,  $R_N$  = Reynold number and is defined by

$$R_N = \rho V L / \mu$$

where,

$\rho$  = density of fluid

$V$  = velocity of Vehicle

$L$  = diameter of vehicle

$\mu$  = dynamic viscosity of fluid

$$R_N = \frac{1013 \times 1.5 \times 1.5}{1.043 \times 10^{-3}} = 2185282.83$$

Viscous Drag Co-efficient is then computed to find the drag force and the expression is as follows

$$C_v = C_F \left[ 1 + 0.5 \left( \frac{d}{l} \right) + 3 \left( \frac{d}{l} \right)^3 \right], C_v = 0.7 [1 + 0.5(3) + 3(3)^3], C_v = 5.8$$

So, finally the Drag equation is

$$F_D = \frac{1}{2} \rho V^2 A C_D$$

where,

$F_D$  = drag force

$V$  = velocity of vehicle

$A$  = area of vehicle

$$F_D = \frac{1}{2} \times 1013 \times 1.5^2 \times 0.0229 \times 0.9$$

$$F_D = 12.932 \text{ N}$$

### 3.5.3 Drag for the hind flapper

$$C_D = 0.9$$

$$\text{Area} = 114.5 \text{ cm}^2$$

$$F_D = \frac{1}{2} \rho V^2 A C_D$$

$$F_D = 1.3389 \text{ N}$$

### 3.5.4 Drag of the body

$$C_D = 1.2$$

$$\text{Area} = 990 \text{ cm}^2$$

$$F_D = \frac{1}{2} \rho V^2 A C_D$$

$$F_D = 12.932 \text{ N}$$

### 3.5.5 Drag of fore limb flappers

$$F_D = \frac{1}{2} \rho V^2 A C_D$$

$$C_D = C_{PD} + C_{DF}$$

$$\text{As } C_{PD} = 0.45. \text{ So, } C_D = 0.45 + 0.02$$

$$C_D = 0.47$$

$$F_D = \frac{1}{2} \rho V^2 A C_D$$

$$F_D = \frac{1}{2} \times 1020 \times 0.7^2 \times 0.0229 \times 0.47$$

$$F_D = 2.68 \text{ N}$$

As,  $\theta = 70$ . So,  $F_D \sin \theta = 2.68 \times \sin 70 = 2.527 \text{ N}$ . Thus, on two flappers

$$2F_D = 2 \times 2.527 = 5.05 \text{ N}$$

So total drag is,  $D = 50.056 + 2.678 + 12.932 = 20.66 \text{ N}$

### 3.5.6 Lift coefficient

$$F_D = \frac{1}{2} \rho V^2 A C_L$$

$$F_D = \frac{1}{2} \times 1020 \times 0.7^2 \times 0.1035 \times 0.9$$

$$F_D = 14.27 \text{ N}$$

### 3.5.7 Force due to weight

$$F = W = mg$$

$$\text{As, } \theta = 20^\circ. \text{ So, } F = W = mg \cos \theta = \frac{12}{2} \times 9.8 \times \cos 20 = 55.25 \text{ N}$$

So, for two flappers

$$2F_w = 2 \times 55.25 = 110 \text{ N}$$



### 3.5.8 Thrust calculations

$$F_t - F_D = m\ddot{x}$$

$$F_t = m\ddot{x} + F_D$$

$$F_t \times t = tm \frac{dv}{dt} - F_D \times t$$

Now,

$$v_F = v_i + at$$

$$v_F = 1.5 \text{ m/s}$$

$$v_i = 0$$

$$t = 3 \text{ secs}$$

$$1.5 = 0 + a \times 3$$

$$a = 0.5 \text{ m/s}^2$$

$$F_t = 12 \times 0.5 + F_D = 6 + 20.66 = 26.66 \text{ N}$$

For single fin,

$$F_t = 26.66 / 2 = 13.33 \text{ N}$$

### 3.5.9 Torque calculations

$$T = F \times r, T = 6 \times 0.130, T = 0.78 \text{ Nm}$$

Now, torque for drag

$$T = F \times r, T = 20.66 \times 0.307, T = 6.34 \text{ N}$$

So, Stall torque at 6 volts = 11kg. fcm

So, Stall torque at 6 volts = 1.07Nm

For 5 motors:  $1.07 \times 5 = 5.35 \text{ Nm}$

### 3.5.10 Torque for hind limbs

$$T = F \times r = 1.33 \times 0.130 = 0.1729 \text{ Nm}$$

For both hind limbs

$$T = 0.1729 \times 2 = 0.3548 \text{ Nm}$$

### 3.5.11 Current calculations

Fore limbs

Let,  $I = 700 \text{ mA}$  (From Data sheet of servomotors)

So, for 5 servomotors  $I = 700 \times 5 = 3500 \text{ mA} = 3.5 \text{ A}$

For both joints

$$I = 3.5 \times 2 = 7 A$$

For hind limbs,

$$\text{Let, } I = 700 \text{ mA (From Data sheet of servomotors)} = 700 \times 2 = 1400 \text{ mA} = 1.4 A$$

$$\text{Now total Current} = I = 7000 + 1400 = 8400 \text{ mA} = 8.4 A$$

### 3.5.12 Battery calculations

For 1 hour

According to calculations 8400 mAh battery is required. As our requirement is 7 hours, so for 7 hours =  $7 \times 8400 = 58800 \text{ mAh}$   $\approx 60,000 \text{ mAh}$

These are self-contained electric devices which rotate/push different portions of machine with high precision. Servos are found in numerous applications: from toys to home electronics to cars and airplanes. RC car, airplane, or helicopter, use a few servos.

As five servo motors are attached at each fin for the thrust, so the distances which the flapper covers in xyz direction are as

$$x = 1.5 \text{ cm}$$

$$y = 9 \text{ cm}$$

$$z = \pm 100^\circ$$

Assembly of UROV with flappers are shown in Figure 2.



Fig. 2. UROV Assembly with Flappers

## 4. Electrical System

The electrical system of UROV is divided into two parts. One part indicates the controlling elements like circuit board, camera, servo motors and sensors. Second part comprises the control given to the operator at the station. Arduino UNO was used for the controlling and communicating with the vehicle. Camera is connected by USB cable which directly comes to the base station to give output at PC. All the motors and sensors communicate signal by using a tethered wire which was 10 meters long. Tethered wire is best suitable solution for short distance operations but for deeper operations the voltage and signal drops and is vulnerable to a number of risks due to less strength.

Electrical components attached with UROV are presented in Table 2 and final assembly of UROV with all electrical components is shown in Figure 3.

**Table 2**

**Electrical Components**

Component	Parameter	Value
Electronic Speed Controller	Maximum Current	55 A for 10sec
Sensing Devices	Two sensors	Proximity sensor, Temperature sensor
Microcontroller	Arduino UNO	Digital I/O, 13 Analog Inputs
Joystick	Logitech Attack3	Programmable buttons, throttle button
Camera	USB 2.0	30 frames/second
Power bank	Li-ion battery	2x6V 4.0Ah rating



**Fig. 3.** Final UROV Model

## 5. Conclusion

This research concludes determination of the relationship between buoyancy forces, propulsion and thrust forces. The purpose is to design the project at low cost which is safe, portable and easy to use. Two shapes have been selected while making designs i.e. Fish and Turtle. Shape of turtle is selected as it has more stability and components can be placed easily due to larger area. However it has low speed then Fish. The major problem is identification about control system, coupling and maneuverability which has been discussed in detail. Also the force of buoyancy, coefficient of drag and thrust force on Fins and body are calculated. Desired depth of 5 meters and velocity of 1.0 m/s have been achieved. NACA 0014 is selected for fins and flappers as it has greater maneuverability and hydrodynamic efficiency. Drag forces acting on fins, hind flappers and body were found by using Reynolds number and drag formulas.

## 6. Future Recommendations

- Modifications could be made on design and shape of the fins to reduce drag and increase its speed.
- Tethered wires could be improved to reduce buoyancy effects.
- Servo motors failed on numerous occasions while testing, other methods such as ball and socket, four bar link mechanism could be used to achieve 3 degree of freedom.
- Underwater Remotely operated vehicle could also be used for study about the environment disturbances such as waves, tides, tsunami and unexpected changes in climate.
- Better communication systems could be used for UROV for wireless networking.

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