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# Design and Depiction of 3D Printed Robotic Fish

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**Abstract:** ***Recently, fish robots have been widely used in various applications such as ocean exploration, military operations, and the preservation of marine circumstances. It requires high-performance autonomous underwater vehicles, especially for propulsion, and has great benefits with flexible invariability. Our paper focuses on the theoretical framework of the design, 3D modeling, and vertical and horizontal locomotion control of the robotic fish. The physical design of the robotic fish is obtained by trying to mimic the external anatomical features of a living fish. The structural design should mimic the fish's body structure. The body of a robotic fish should be compact and accommodate all sensors, actuators, and motors. By managing the amount of water inside the ballast tank, the fish can attain vertical motion and depth control.***

**Keywords:** 3D Printing, PLA, Arduinonano unit, Ultrasonic sensors

## 1. Introduction

A robotic fish is a type of bionic robot that has the shape and locomotion of a living fish. The basic robotic fish is made up of three parts: a streamlined head, a body, and a tail. Our project is to demonstrate the 3D printing of a robotic fish with higher efficiency and propulsive performance for under-water applications like mining applications, water pollution rate study, underwater oil pipe leakage detection, military reconnaissance, deep sea archaeology etc. Engineers and biologists have long been curious about how aquatic organisms can efficiently move themselves through water. As a result of breakthroughs in mechanical and mechatronic research during the previous few decades, bio-mimetic and biomechanics have been active research areas.

This study offers the notion of a robot in the shape of a fish that was designed to improve the effectiveness of the fish movement control system. The advancement of robotic technology has eased and resolved aquatic assignments to a greater extent. The advantage of robotic fish over submarines is that they are more efficient, have a more flexible structure, and can operate in dangerous conditions. It may be utilised as a spy robot in military applications because it is not just employed for underwater monitoring. A Poly Lactic Acid substance was used to create the fish, which was then printed on a 3D printer using the fused deposition modelling method.

Polyactic acid (PLA) and abstrone-type materials are used to create robotic fish. PLA is a lightweight and durable material. Four servo motors make up the robotic fish system. The movable joints are coupled to the servo motors. Two motors for the fish's right and left fins, as well as one for the body and another for the tail, For robotic fish locomotion, the body is made up of several jointed segments, and high torque servo motors are the major issue for position change and fast speed. It also provides the flexibility and stability required for stable movement.To detect objects, two ultrasonic sensors are attached to the fish's eyes, and a temperature sensor is attached to the fish's body. The robotic fish's drive circuit is designed on a PCB.Two lithium batteries are used to power all of these gadgets. The water intake process is controlled by the relay, which is connected to the Arduino and the water pump.

There are two types of sensors in the sensor unit: ultrasonic sensors and temperature sensors. These sensors are the system's inputs. The items are detected by the IR sensor, which sends signals to the microcontroller. Indirectly, the temperature sensor aids in the collection of a water sample for subsequent testing. The fish has servo motors linked to it for smooth mobility. The directional changes are aided by the connection of four servo motors. Bluetooth is a serial connection technology that allows the fish to move in either automatic or manual mode. If the fish is to move manually, there are three options: forward, left, and right. The microcontroller and the water pump are both connected to the relay. The relay will work in accordance with the controller's decisions, and it will collect the sample as a result. The fish has a weatherproof camera attached to it for monitoring the water bodies. This wireless camera will take photographs and movies in real time, which will then be saved to a computer.

## 2. Electronic design

The robotic fish is made up of a variety of electronic components. Sensors, a controller (Atmega 328), a motor driver circuit, and a communication device are all included in the PCB design.

### 2.1Embedded system

As a controller, an Arduino Nano board is used. The At mega 328 is a microcontroller with a 32Kb flash memory. The robotic fish is powered by a 12V Li-Po battery. Servo motors with a predefined angle of rotation power the propulsion system. PWM pulses control the servo motor angles for the fish's mobility.The water collection is powered by a DC motor.The fish's speed is controlled by the changeable servomotor angles. LM35 is used for monitoring the temperature.The built-in ADC converts analogue signals to digital data, which may then be sent to the base station through wireless communication. The robotic fish has a camera attached to it. This camera aids in the monitoring and surveillance of the underwater environment.

### 2.2 Communication system

Use Bluetooth to send and receive data from the base station with the robotic fish. Robotic fish may be operated manually or automatically using an Android application and a Bluetooth communication module.Data transfer to the computer for live streaming is aided by the floating antenna.
The design of the robot, its movement pattern, hydrodynamics, control system, machine placement, mechanical qualities, and material properties should all be considered while developing robotic fish propulsion. The robotic fish consists of a microprocessor, which is permitted to acquire data from the sensors, process them, and transmit the output signal to the actuators. Here, Arduinouno is used as the microprocessor. It acts as a link between the sensory system and the tail actuation. To duplicate the real motions of a fish, the software substructure is outlined.

### 2.3 Electronic systems

The fish's two main portions are further divided into many sections, each of which is responsible for a different purpose. The sensor system, for starters, is made up of infrared sensors, gyroscopes, and a temperature sensor. All of these sensors are connected to a specially built printed circuit board inside the fish head. To limit the number of mechanical sensor mountings, the printed circuit board is designed to fit perfectly inside the fish head. The fish eye opening has two sensors: one on the left and one on the right. A microprocessor, servo motor driver, and power supply are all part of the control system. The control system hardware is integrated with the sensor system inside the fish head, allowing for easy troubleshooting without disrupting the tail drive mechanism. A high-torque servo motor with feedback capability, a central polycarbonate spine, skeleton discs, and a silicon caudial fin make up the tail actuation system.

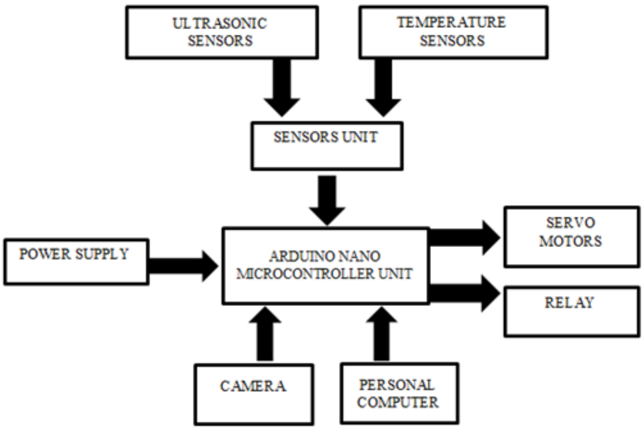

**Figure 1:** Block diagram

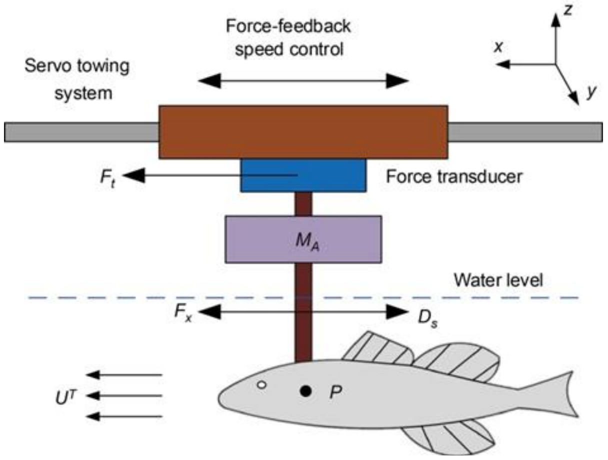

**Figure 2:** Mechanism of fish movement

## 3. Methodology

Our methodology involves the identification of problem statements and a literature survey of accessible resources. Followed by the selection of appropriate components. A block diagram and flow chart are prepared, forming the Arduino programming language. Finally, electrical connection of components takes place, followed by designing and 3D printing of robotic parts using Solid works. For modeling, we are using Solid works, and for printing the parts, a Creality Slicer is used. Then assembly of electrical components into 3D printed robotic parts. Here As the microcontroller, an Arduinonano was used. The analogue signals from the sensors were processed and turned into states. It also analysed gyroscope data and adjusted the required centre of gravity for each swimming pattern. It then created output signals to control the servo motor after analysing all of this data. The tail is controlled by a servo motor, which has a rotation of 0 to 180 degrees. This is a smart servo with a 0.325o resolution that can detect internal changes like temperature and power supply. It can also provide information about its current location, speed, load, and temperature. For the vertical motion, we are using a water pump and a ballast tank.

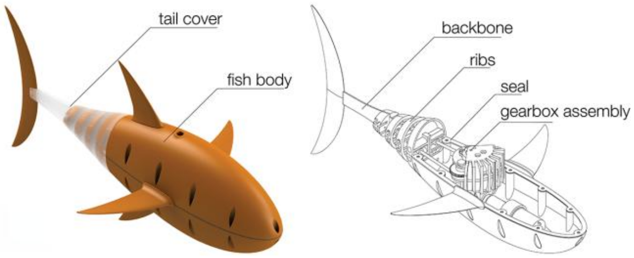

**Figure 3:** CAD-Model of the Robotic fish with an indication of its main components

## 4. 3D Printing

Engineers have been able to develop new approaches, deal with new species, and increase the impact of outreach activities as a result of this strategy, we believe. Our goal is to use a 3D printing machine to create a robotic fish that enhances experimental methodologies, increases flexibility, lowers costs, and promotes open science. The 3D printing process turns a whole object into thousands of tiny little slices, then makes it from the bottom-up, slice by slice. Those little layers adhere to one another to form a solid entity. 3D printers can generate moving pieces like hinges and wheels as part of the same product since each layer may be quite intricate.3D printing has so many advantages, like reduced speed and lead time, risk mitigation, and cost reduction.

### 4.1 Fused deposition Modeling

Fused Deposition Modeling (FDM) is the 3D printing process used to create robotic fish. Soft materials are printed using the FDM process in the form of a continuous filament, with a single layer placed at a time. A computer-controlled transformation step in additive manufacturing often transforms pattern-generating equipment, such as an ink-based print head or laser optics, to construct the required products in a layer-by-layer pattern. Patterned areas made of powders, inks, or resins are solidified during the additive manufacturing process to create the necessary 3D forms. The computer designs are physically realised in these 3D-printed products. Since the inception of 3D printing, several fundamental additive manufacturing printing processes have been introduced. Technology has advanced, from the development of simple prototypes to the construction of finished products.

The minimum feature size that can be attained and the types of printed soft materials that can be employed are determined by the explicit solidification and patterning approach used by a certain additive manufacturing methodology. Increased printing speed, improved printing quality, lower material consumption, and the use of different materials in the production of a desired 3D robotic fish are all advantages of the FDM technology. The benefits of 3D FDM include a greater choice of printed geometries, feature sizes, and ink patterns. In FDM, thermoplastic filaments are supplied by heating the extrusion head, then cooling below their glass transition temperature to harden them.

The famous printable plastic filament material used in this method is polylactic acid (PLA). The polymer filaments have the option of being loaded with carbon black particles to improve the functioning of printed products. FDM offers the extra benefit of being cost-effective, user-friendly, and very dependable, with minimal post-processing required. Primary construction materials, as well as sacrificial materials that support the spanning features, may be printed using both inkjet printers and FDM. Limited surface quality, low resolution, and wrapping are all disadvantages of FDM technology.

Figure 5 shows the flow chart of the working of the fused deposition modelling machine. The first step is the design of the model in CAD, followed by exporting it into STL file format. After export, import the STL file into the Creality Slicer software. After that, create the tool path in SML (Stratasys machine language) format. The data is then downloaded into an FDM machine and printed.

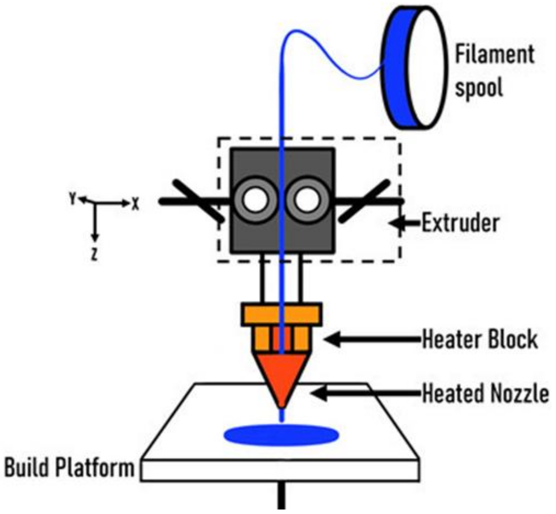

**Figure 4:** Fused deposition Modeling Printing Motion

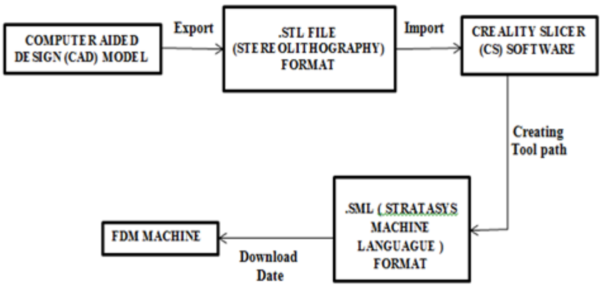

**Figure 5:** Flow diagram of FDM machine

## 5. Mechanical Design

Servo motors with a predefined angle of rotation power the propulsion system. PWM pulses control the servo motor angles for the fish's mobility. A DC motor drives the water collection system.The fish's speed is controlled by the adjustable servomotor angles. An LM35 is used to measure the temperature. The built-in ADC converts analogue signals to digital data, which can then be sent via wireless communication to the basestation. A camera is attached to the robotic fish. This camera serves as the undersea environment's monitoring and surveillance.

The robotic fish's body consists of two parts: head and tail. The head consists of a microcontroller unit, ultrasonic sensors, battery gyroscopic sensors, etc. The tail consists of a high-torque servo motor, a central spine, joints, and skeletal discs. The central spine is made of polycarbonate. The fish head and fish tail are connected together using high-power magnets, which enables the easy replacement of all parts.Fishes propel themselves underwater using the thrust generated by bending their bodies, producing a backward-propagating propulsive wave. The selection of mechanical structures, sensors, and navigation techniques is crucial for the design of a robotic fish. These considerations are diversified to a colossal extent according to the numerous biological kinds of locomotive properties.There are different ways to achieve this bending like Anguilliform, subcarangiform, carangiform and thunniform swimming. Subcarangiform, carangiform, and thunniform swimming only need the second half of the body, but anguilliform swimming requires several muscle contractions from head to tail.If the robotic fish wants to mimic the movements of an eel, it must have more joints connecting elements from head to tail than a tuna (thunniform), whose propulsion is mostly controlled by the posterior half of the tail, and so greater emphasis on buoyancy is required for the latter biomimetic kind.If the robotic fish wants to mimic the movements of an eel, it must have more joints connecting elements from head to tail than a tuna (thunniform), whose propulsion is mostly controlled by the posterior half of the tail, and so greater emphasis on buoyancy is required for the latter biomimetic kind. In fish, muscle fibres are responsible for the tail actuation, supported by a flexible central spine. The tail module of our robotic fish is inspired by this principle and is composed of a polycarbonate central spine attached by skeletal discs at equal spacing.

**Figure 6 :** Design of Robotic fish

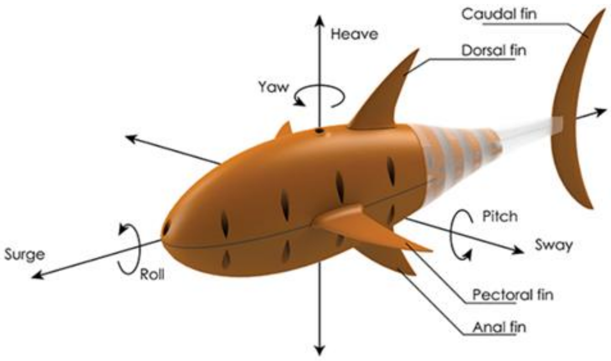

**Figure 7:** Explanation of the terms used for fish anatomy and fish stability

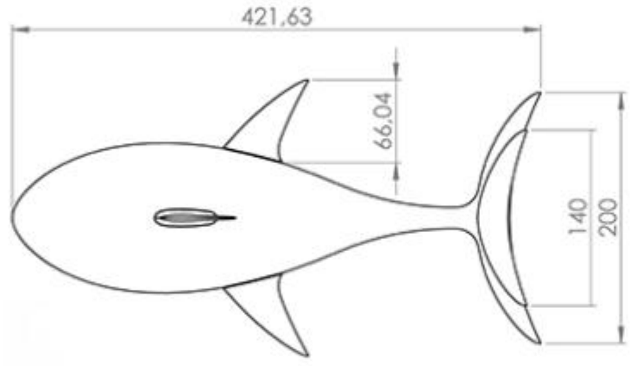

**Figure 8:** Sideview of Robotic fish with Dimensions

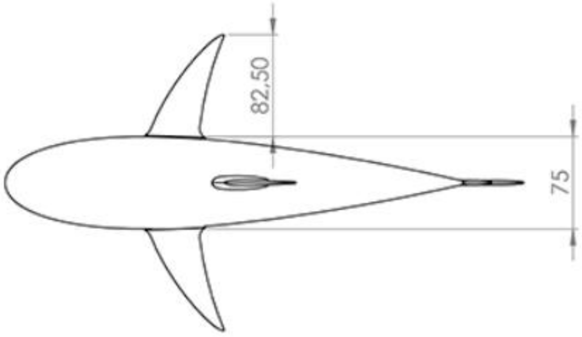

**Figure 9:** Top view of Robotic fish with dimensions

## 6. Vertical Motion of Robotic fish

It is necessary to construct a fish robot with a 3-D motion that includes forward, rotating, and up-down motion in order to develop a fish robot for an underwater application.In this fish robot, there is a water ballast tank (air bladder) and a pump. Water in and out of the tank alters the gravitational and buoyant equilibrium. After all, when the tank fills with water, the gravitational force becomes greater than the buoyancy force, and the fish robot sinks. When the tank is filled with air, the buoyancy overcomes gravity, and the fish robot rises.

The fish robot can move up and down vertically in this mode, and its depth can be precisely regulated.Turn on the pump to submerge the model in this principle of operation. Water will be pumped into the tank using a pump. Air inside the tank will escape through the tube. Thus, water is inside the tank and the tank is full, which leads to the downward motion of fish. To enhance the model, the battery terminals are interchanged. The pump is reversely working, and it will pump out the water and the air will get inside again through the tube to equalise the pressure.

A figure featuring the up and down motion of fish using a pump and ballast tank is shown below. If the ballast tank or air bladder is filled with water, then fish will move downwards. If the ballast tank is filled with air or without water, then the fish will move upwards. Like this, we can control the vertical motion of the fish.

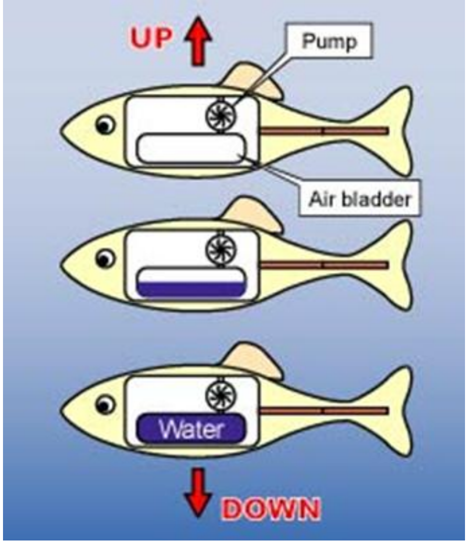

**Figure 10:** Up and down motion

### 6.1 Mathematical Calculation of Mass of Water Pumped Inside the Bladder for Vertical Motion

Simple model of dynamics of DC motor water pump is

$$M.\dot{V} + B.V = g.\mu$$

Where
M= Mass of the Robotic Fish
V = Vertical Velocity
$\dot{V}$ = Vertical Acceleration
B = Linear Drag Coefficient
$\mu$ = Variable water mass pumped inside the bladder
g = Acceleration due to Gravity

Values of parameters are,
Consider

- Mass of the robotic fish, M = 0.9025 kg
- Acceleration due to gravity, g = 9.8 m/s
- Linear drag coefficient, B= 0.7 Ns/m
- Time constant, $\tau = 0.2$ s
- Control input coefficient, K= 0.00385 Kg/Vs

The vertical acceleration is zero if the fish travels vertically downwards or upwards at a uniform velocity of 20 cm/s
Let the Velocity of the fish, V = 5 km/hr = 1.38889 m/s
Linear drag coefficient, B= 0.7 Ns/m
Acceleration due to gravity, g= 9.8 m/s
Mass of the robotic fish, M = 0.9025 kg

$$M.\dot{V}+B.V = g.\mu$$
$$0.9025 \times 0 + 0.7 \times 1.38889 = 9.8 \times \mu$$
$$0.972223 = 9.8 \times \mu$$
$$\mu = 0.972223 / 9.8$$
$$\mu = 0.09920642857 \text{ L}$$
$$\mu = 99.20642857 \text{ mL}$$

Variable water mass pumped inside the bladder for the vertical motion is **99.2064857 mL** for the taken velocity condition.

By entering this amount of water inside the ballast tank, then the fish sink downwards. If this water is draw out from the ballast tank, then fish will come upwards.

## 7. Material required for construction of robotic fish

1) Screws - screws are used to connect the top and bottom part of the fish
    - Number of screws required – 11
    - Dimensions of screws – Length = 1cm; diameter = 3mm;
2) DC Pump
    - Voltage = DC 6V to 12V
    - Working current = 0.5A to 0.7A
    - Power = 4W - 7W
3) Ballast Tank
    - Maximum volume of water can be occupied = 250 ml
4) Tube used for connecting the pump and ballast tank
    - Diameter = 7.5mm
5) Battery
    - Voltage = 9V
6) Rubber Washer – to place in between the top and bottom part to avoid the leakage of water.
7) Servo motor
8) Camera
9) Sensors unit
10) Arduinonano microcontroller unit.

## 8. Conclusion

This paper presents the design of an autonomous underwater robotic fish having horizontal and vertical motion that is highly modular and simple to deploy. The concept of design includes cable-based tail actuation, communication from head to tail , stability control, vertical motion and depth control, a sensory circuit, control of servo motor , and computer algorithms. The goal for future work will be to create better software that can adapt to the underwater environment. Furthermore, in order to develop more reliable autonomous robots, one of the primary goals for the next phase of design will be battery lifespan. The robotic fish takes use of recent advancements in multi-material three-dimensional printing, which allows for the integration of a variety of material qualities in a single print assignment. This capacity has been put to use in a new robotic fish design that incorporates waterproofing and kinematic functionality.

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