Design and analysis of controlling the robotic fish

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Abstract. Recently fish robots are widely used in various applications such as ocean investigations, military operations and marine environment protection. It requires high performance autonomous underwater vehicles especially for propulsion and great benefits with flexible manoeuvrability. In this paper focused on the fish propulsion mechanism, robotic fish overall design and dynamic model of robotic fish propelled by the pectoral fins and flexible tail. The tail part of the fish is attached to the active body segments which are connected in series through rotational springs and the hydrodynamic force will act on each segment. It can navigate efficiently over a given distance with a good balance of speed and manoeuvrability. Different mathematical propulsive waveforms are combined with an inverse kinematics-based approach for generating fish body motions. A prototype is built and is tested. The experiment results demonstrate that the kinematics of the robot fish can be predicted effectively. The above results indicate the proposed model is suitable for estimation of the behaviour, thrust and swimming speed of the fish robot.

1. Introduction

Underwater robots are mostly can do high performance movement in water. The robotic fish design is based on the mechanism of locomotion used in many applications such as ocean development, military operations and marine environment protection and it requires high performance automated underwater vehicle AUV. The most important thing is to develop the robot fish can control and navigate them to communicate with environment. The robotic fish movement is analyse the study of shape, dynamic model movements the main features are used in robotic fish are 3D navigation, path planning, and obstacle avoidance. The main advantages are including high efficient swimming, noiseless propulsion most researches have used two or three joints in fish robot. The flexible tail is used to give the better performance In terms of the propulsion and thrust efficiency. The kinematic study design based on the underwater experiments for motion analysis, comparative analysis. The fish robot consists of the joint propels and body by oscillating tail and pectoral fins locomotion such as lift, drag, acceleration. The fish can swim at constant speed with high amount of thrust, this is related to ships travelling for long distances. The pitch control is used to maintain the buoyancy control force to regulating the depth of the robotic fish and the buoyancy control is allows to the robotic set at neutral buoyancy force by adjusting the density with in a rigid volume.
Zu guang zhang [1] in this paper presents fully designed and fabricated by biologically inspired robotic fish. It can be propelling by its own through flexible tail they referred to use electrostatic film motor it consists of two pieces stator and slider through flexible power transmission system. This fish robot has mainly based on two types of swimming locomotion body caudal fin and medium paired fin. The principle is based on the electrostatic motor with six phase synchronous motor. Junzhi Yu [2], In this paper mainly focused on the controlling of a fish robot on multiple control surfaces to get the stable motions in aquatic environments. The fins are helpful in balancing for propulsion, steering, and paddling then the navigation sensor is used is in under water to get the location and CMOS camera is fixed to find the consists of three modules i.e the image capturing module, image processing module, and control module. Slightly improved by speed while turning operations in multiple hydro propulsion surfaces.

Abrha roy Chowdhury [3], This paper focused on the fish propulsion mechanism this fish robot having 2-join, 3-link multi body vehicle model. The robotic fish model based on light hill (LH) mathematical frame work model. It is inverse kinematics-based mathematical propulsive waveforms generating fish body motions. The fish robot is allowed energy efficient to navigate a distance and balance a good speed and simulation of identified in kinematic parameters. Pichet Suebsaiprom [4], this paper is based on roll, pitch and yaw develops 6-degree of freedom mathematical model. It is based on barycenter mechanism and to provide the body stabilization to actuate an active control design. The kinematics and rigid body dynamics and fish tail mechanism are enable in the fish robot to freely move in three dimensional space. The simulation results are satisfactory performances and path tracking control. The 3D swimming tracking control conducted in three types are global velocity, yaw angle and LQR controller. Yong Zhong [5], This paper represents wire driven mechanism the compliant tail molded through multi pseudo link model it can simple in structure, easy to control and high speed swimming the compliant bodies are fabricated using soft elastic materials. The design and fabrication presented by kinematics of the robot fish the active and compliant propulsion mechanism is driven by one motor. Gonca Ozmen Koca [6], This paper represents the dynamic simulation model for carangiform fish robot with high flexible multi join propulsion and the fish robot provides great benefits with high propulsion efficiency, high flexible maneuverability and less noise considering in under water vehicles. In this two possible route planning scenarios in robotic fish model based on Carangiform motions are performed. Case 1 is the swimming its gives the permission to go straight forward and case 2 the fish is to reach the destination along the area of shortest path. Rahul Kumar [7], This paper focuses on the fish propulsion theory and fish robot overall design. Fish locomotion momentums are lift, drag and acceleration the forces are acting on fish robot in vertical directions and it can be stable because of buoyancy forces and hydrodynamic forces are acting on horizontal direction. By Paul Phamduy [8], In this paper fully focused on the remotely controlling the fish robot through Idevice application and represents the design and development of robotic fish. The iDevice application implements three types of modes control that offer a vividly colored, intuitive, and user-friendly theme. This fish robot having three degree of freedom tail along with buoyancy control system and pitch the communication protocols between the idevice, robotic fish and base station through Wi-Fi. Yahui hou [9]. In this paper generating the sine wave signals through CPG controller can also control the movement of robotic fish. This type of controller needs so many parameters such that fish body wave motion. CPG means that central pattern generator is used to test the effectiveness and feasibility test for simulation in three joints of robot fish and same time the CPG controller can reduce the number of parameters and controlling the locomotion modes. C Rossi [10]. In this research paper described on bio-inspired locomotion system using the structures and smart materials. This paper based on the design process of the bio inspired structure from the control and simulation process and this type of structural arrangement is bending the back of fish curvature of the body. The objective of work is to investigate new things of robots and capable of changing their continuous shape. M. abbaspour [11]. In this paper presents that the hydrodynamic model consists in a biomimetic robot fish based on quantitative and kinematic parameters. The digital particle image velocimetry and optimal coefficients of the motion equations and location of the joints are derived. The speed of the swimming process is adjusted by changing the oscillating frequency, amplitude and length of the oscillating part. Phi Luan Nguyen [12]. In this paper presented by dynamic model of the fish with non-uniform flexible
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Mainly focusing on the thrust and swimming speed whenever the driving changes. Derive the thrust estimation, performance of evaluation and equation of motion with non-uniform flexible tail. The results are compared for the maximum thrust and swimming speed around $f=1.4$ Hz the dynamic model is suitable for behavior of thrust and swimming speed. Andrea Ravalli [13]. This paper based on the focusing on designed by bio-inspired fish robot using the concentrated hydrogen ions can detect by electro chemical sensors. The signal is transforms to electronic signal to be used in robot controls electrochemically graphite screen is based on the PH sensors. The water quality parameters providing to changes the environmental condition and improving management decisions. Jianxun Wang[14]. This paper presents a develop dynamic model of robotic fish using a flexible tail. The tail is connected through the rigid segments using rotational springs and hydrodynamic forces in terms of steady state speeds and dynamic tail shapes. Young sun ryuh[15]. In this paper presents the multi agent system by robotic fish used environmental conditions. This fish robot has the five degrees of freedom for controlling the speed and depth. The body designs to enable it have high swimming speed and less disturbance. The mathematical model of the fish robot with the tail fin is 3 DOF link mechanism to develop the navigate autonomously in real environment.

2. Methodology

The fish robot methodology is the relative motion function between the buoyancy and hydrodynamic forces. The design parameters are assembled to do the fabrication. Then check the flexible tail moments in water and running speed also compared in the kinematic analysis then the control of a active body and tail body fins to move forward and backward using the water proof servomotor. The arduino uno is used to control the moving motions to give the 6.7 to 8 volts power.

![Figure 1. Electric components.](image)

The fish robot can do some inspection in water it’s like taking pictures in water and sending through the monitor using the wireless module of bluetooth and find the way of path using GPS.
Design the model using Pro-E

Manufacturing the parts using 3d printing

Fabricate all parts by follow the dimensions

Connect the servo motors to fins and tail through electric board using external power source

Calculate the frequency of sinusoidal wave at the end of fish tail and buoyancy force

Upload the arduino programming to run the robot in water

**Figure 2.** Flow chart.

### 3. Mechanical Design of Fish Robot

The design consists of head part, body part, tail part, these parts are combined and it includes the fabrication and finally assembly process.

#### 3.1 Head part

The head part is define to control the body motions by using the pectoral fins and moving forward and backward motions
3.2 Pectoral fins

The pectoral fins are used for fish robot to control the direction of head moment in the process of locomotion.

3.3 body segment parts

Body segments are connected in series and tightening with the bolts the body segments are created through 2 parts. The links are freely movable with the use of servomotor. When the fish robot doing a task in complex underwater environments, then it needs to recognize the environment this purpose the multiple sensors are used to equipped with the robot fish in environmental data. The links moments are moveable and controlling the fish active body segments.
Figure 5. Body segment parts

3.4 Tail part
The tail fins are used in many ways mainly to swim the fish in different directions and turning operations.

Figure 6. Body segment part

3.5 Assembly part
The design of the fish robot is shown in below figure assembled with pectoral fins, tail fin, all rigid body segments and including head part.

Figure 7. Design of fish robot
The specifications of the fish tail is given below table 1

| SPECIFICATIONS                        | DETAILS             |
|----------------------------------------|---------------------|
| Number of body links                   | 2                   |
| Size of link 1(mm)                     | 70x100x98           |
| Size of link 2(mm)                     | 60x85x75            |
| Head(mm)                               | 85x102x100          |
| Body(mm)                               | 105x102x77          |
| Fins(mm)                               | 75x5x40             |
| Tail(mm)                               | 140x5x102           |
| Full design length(mm)                | 134x102x100         |
| Actuators                              | Waterproof servo    |

4. Fabrication of Robotic Fish

The robotic fish is made by ABS material each segment having the different dimensions and those segments are connected in series and also connected by the water proof servomotors which are going to be perform in water to get more hydrodynamic force.

![Fish robot](image)

**Figure 8.** Fish robot

The motion of the fish tail will be sinusoidal wave has to generate and propulsion force will develop. The propulsion force will push the object on forward motion.

\[
(x) = (c_1x + c_2x^2) \quad (1)
\]

\[
(t) = \sin(kx + wt) \quad (2)
\]

(x) and (t) are formed by the up and down motions those two equations write together.
\[ y(x, t) = (c_1 x + c_2 x^2) \sin(kx + wt) \]  \hspace{1cm} (3)

The above equation is used to get the sine wave in mat lab for the motion using body wave number that is called ‘k’

\[ k = \frac{2\pi}{\lambda} \]  \hspace{1cm} (4)

c1= wave amplitude, c2=quadratic wave amplitude, w=body wave motion, \( \lambda \) = body wave length

Figure 9. Fish tail

The robotic fish tail and fins are made by acrylic sheet with the 5 mm thickness as shown in above figure.

4.1 motor selection

In this tail it requires more torque for that chosen RKI-1248 (water proof servomotor) it can perform well in water getting sinusoidal wave and also easily control show the specifications table 2

| Motor                        | Specification                  |
|------------------------------|--------------------------------|
| Water proof servomotor       | Speed (6v) - 0.17 sec/60 degree |
|                              | Speed (7.4v) - 0.16 sec/60 degree |
|                              | Speed (8.4v) -0.14 sec/60 degree |
|                              | Torque(6v) – 15.5kg/cm          |
|                              | Torque(7.4v)-17kg/cm            |
|                              | Torque(8.4v)-20kg/cm            |
|                              | Weight – 60gm                   |
|                              | Dimensions – 40x20x40.5 mm      |
5. Experimental and Results
The test setup has been built for getting sine wave using 3 servomotors. The one servomotor is connected back end to get tail motion and two servomotors are connected front side to get fin motion as the set up for controlling the arduino uno and using external power source, arduino uno shield to get the propulsion mechanism move forward motion in water.

![Testing in water](image1.jpg)

**Figure 10.** Testing in water

The tail motion is generated using mat lab using equation (3) this is the kinematic analysis of fish tail

![Wave Motion in Mat Lab](image2.png)

**Figure 11.** Wave Motion in Mat Lab

6. Conclusion
This paper presents a fish robot with a complete design and follow the various designs in this robot having more torque and easily balancing the fish using buoyancy force and hydrodynamic force to move forward. The experimental results to get the motion of fish tail using waterproof servomotor and also get sine wave motion in mat lab.
Future work will be the simulation of the tail. Testing in water for taking pictures in water to add wireless camera lens and find out the path way to use GPS.

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