Central Mechanical Engineering Research Institute

Mahatma Gandhi Avenue,

Durgapur – 713209,

West Bengal

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PROJECT REPORT ON: DESIGN & DEVELOPMENT OF A ROBOTIC FISH

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Yours Sincerely

....

Arnab Paul

Avik Halder

Avik Halder

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INTRODUCTION

AIM:

To design a robotic fish which can show concertina movement on ground surface and fishlike movement in the water. The task also includes Digital Servo Controller programming and interfacing using AT895C1 microcontroller.

THEORY:

In nature, fish has astonishing swimming ability after thousands years evolution. It is well known that the tuna swims with high speed and high efficiency, the pike accelerates in a flash and the eel could swims skillfully into narrow holes. Such astonishing swimming ability inspires the researchers to improve the performance of aquatic man-made systems. An example application is robotic fish.

Instead of the conventional rotary propeller used in ship or underwater vehicles, the undulation movement like fish provides the main energy of the robotic fish. The observation on the real fish shows that this kind of propulsion is more noiseless, effective, and maneuverable than the propeller-based propulsion. A Robotic Fish has the advantages over conventional marine vehicles powered by rotary propellers with the same power consumption. It enlightens researchers in robotics to develop biomimetic robot fish for the sake of performance improvement of AUV (Autonomous Underwater Vehicles). Biomimetic robot fish is a type of robot having fishlike figuration and swimming with undulatory body or/and oscillatory fins, which are driven by some motors and controlled by microprocessor. Biomimetic robot fish is a new orientation in AUV research.

Investigation on biomimetic robotic fish systems has provided significant insights into both theory and application of robotics in recent years, whose appealing nature involves higher efficiency, more remarkable maneuverability and quieter actuation. These advantages are of great benefit to applications in marine and military fields. Many theories are proposed to explore secrets of fish swimming mechanisms and summarize driving modes of fish motions. Based on these theories, many prototypes of biomimetic robotic fish have been developed .

LITERATURE SURVEY

1. The **Robotuna** project started in 1993 with the objective to develop a better system of propulsion for the autonomous underwater vehicles. The tuna was selected as model for its speed (a blue fin tuna can go up to 74 km/h) and its accelerations. It is a question of including/understanding how a fish can generate energy enough to reach such speeds.
2. After RoboTuna, another robotic fish was designed at MIT: **RoboPike** by John Kump , the robot pike (the pike interests the researchers for its fulgurating accelerations). RoboPike is not maintained in the aquarium by a system of pulley like its predecessor and can swim freely. But it is not autonomous: its navigation is directed by human and it is the computer which interprets the orders and returns the signals appropriate to each engine. At the time, John Kump studies the movements of fish thoroughly to be able to reproduce them. He also works on the form and the flexibility to be given to his robot. Thus, it equips it with a exosquelette in the shape of spring with spiral. RoboPike (81 cm length) can swim rather well but it is not equipped yet with sensors to prevent it from running up against the obstacles .
3. The **NMRI** (National Maritime Research Institute) developed many projects of robotic fish (series PF and series PPF) with a view to apply, in the future, the capacities of fish to our boats and submarines. The PPF-04 is one (all) small robotic fish of 19 cm and 400 g, remote controlled. Its size makes it possible to test it in a small tank (like a bath-tub). The study carried, inter alia, on the relation between the speed and the amplitude of the oscillations of the caudal fin.
4. **Robotic Eel, RobeaProject, multi-field team, CNRS, France**: The objective of the ROBEA-Eel project is to "design, study and produce a robotic eel able to swim in three dimensions". Whereas certain fish as tuna have a mode of locomotion based on oscillations of the body, the locomotion anguilliform(eel, lamprey...) is based on undulations of the body. Thus, the swimming of eel presents remarkable performances in term of maneuverability.
5. **Essex Robotic Fish, Jindong Liu, Huosheng Hu,Dept of Computer Science University of Essex, G.B.**: The goal of the researchers of the university of Essex was to carry out a robot-fish which can swim like a real fish and which is autonomous. A fish has various modes of displacement (speed, turns, accelerations, braking) and the challenge of the researchers of Essex was to obtain an autonomous robot-fish who can reproduce all these behaviors and not one or two in a more or less uniform way. They thus indexed the various behaviors in a library used by the computer to generate varied and unexpected trajectories of stroke. Robotic Fish (50 cm length) is for example able to curve its body according to a great angle in a very reduced time(approximately90°/0.20sec).

Recent Development of Robotic Fish

1. Boston Engineering's GhostSwimmer autonomous underwater vehicle is preparing to enter the second phase of an 18-month Office of Naval Research Small Business Technology Transfer (STTR) program. Using a "bio-mimetic" model - a tuna fish robot has less drag than most underwater vehicles and the oscillating tail has up to twice as much efficiency as a propeller. The GhostSwimmer's fins can be changed out depending on mission needs and the vehicle has onboard autonomy. An operator can tell it to swim with maximum efficiency and it will calculate the best way to do that, or it can be told to get somewhere fast and flap its tail harder. Ultimately such a fishlike robot could operate offshore by itself or swim in a robotic school with other fish, conducting surveillance or taking measurements.

2. In the Center for Systems and Control, Department of Mechanics and Engineering Science, Peking University, Beijing, a multiple robotic fish cooperation platform has been developed, which is established by employing a group of radio-controlled, multi-link fish-like robots. This work is inspired by the observation from nature that the capability of one single fish is limited, as in order to survive the atrocious circumstances in the sea, fish often swim in schools. The analogical situations occur in the robotic fish case. In engineering applications, most missions are so complex that they must be accomplished by effective cooperation of multiple fish robots.

3. Robot fish developed by British scientists are to be released into the sea off north Spain to detect pollution. The carp-shaped robots, costing 20,000 pounds ($29,000) apiece, mimic the movement of real fish and are equipped with chemical sensors to sniff out potentially hazardous pollutants, such as leaks from vessels or underwater pipelines. They will transmit the information back to shore using Wi-Fi technology. Unlike earlier robotic fish, which needed remote controls, they will be able to navigate independently without any human interaction.

4. Scientists looking at the problem of overfishing have come up with a bizarre solution – giant robotic cages that would roam the oceans farming fish for human consumption. *National Geographic* magazine has reported that engineers and scientists in some of the world's top institutions are working on designs for the autonomous fish farms. Remote-controlled prototypes have already been built. Concerns over depleted natural fish stocks have meant that fish farming is increasingly seen as an alternative. A standard fish farm comprises a series of cages in shallow, calm coastal waters, but these are often susceptible to disease and poor hygiene. This is why the concept of 'smart' cages allowed to roam autonomously in deeper waters are being researched by institutions such as the Massachusetts Institute of Technology's Offshore Aquaculture Engineering Center (OAEC).

REAL FISH LOCOMOTION

The skeleton of a fish is the most complex in all vertebrates. The skull acts as a fulcrum, the relatively stable part of the fish. The vertebral column acts as levers that operate for the movement of the fish. The muscles provide the power for swimming and constitute up to 80% of the fish itself. The muscles are arranged in multiple directions (myomeres) that allow the fish to move in any direction. They look like sideways W's and contract from side to side and front to back. A sinusoidal wave passes down from the head to the tail. The fins provide a platform to exert the thrust from the muscles onto the water. Fins give a fish control over its movements by directing thrust, supplying lift and even acting as brakes. A fish must control its pitch, yaw, and roll.

A fish uses a number of fins for its locomotion:

Caudal fin-- provides thrust, and control the fishes direction. It is used for propulsion and steering. Fork shaped tails are suited for fast swimming, and they are also helpful for quick turning

Pectorals-- act mostly as rudders and hydroplanes to control yaw and pitch. Also act as very important brakes by causing drag.

Pelvic fins-- mostly controls pitch

Dorsal/anal-- control roll. The dorsal fin can be used to control height in the water and steering.

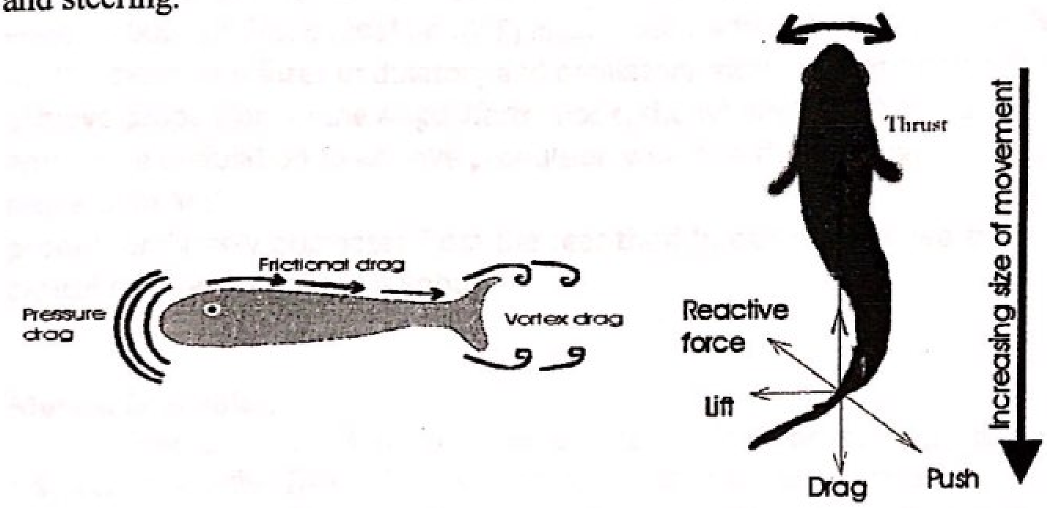


Fig.Diagram of forces when a fish swims.

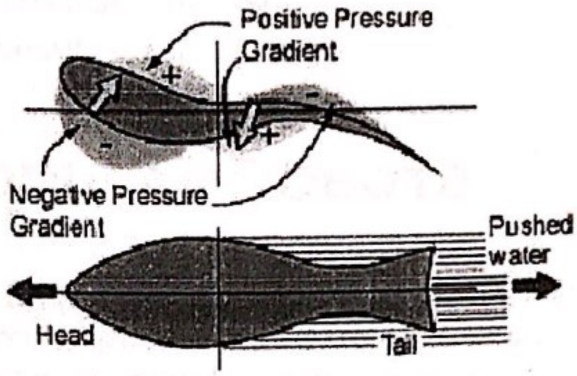
Here, Thrust- force in front direction ,

Lift- force opposite in right angles to the thrust (All lift forces cancel out over one complete tail stroke),

Drag- force opposite the direction of movement.

Start a forward motion

When the tail is whipped in one direction, the front part of the body tends to turn the opposite way. Water pressure resists the turning movement and changes it into a forward motion



Drag is minimized by:

1. The streamlined shape of the fish
2. A special slime fishes excrete from their skin that minimizes frictional drag and maintains laminar (smooth) flow of water past the fish.

When Thrust > Drag, the fish moves forward.

Each species of fish behaves differently in its environment and aspects such as body shape, body size and its swimming gait have all evolved from years of exposure to these specific environments. Modes of propulsion are generally based on how much of the fish's body undergoes undulation . The most common mode of propulsion in water is body and/or caudal fin (BCF) locomotion. A fish's swimming mode is based on the extent it utilizes undulatory and oscillatory motion of its body and fins to achieve propulsion. In the Anguiliform mode, the whole fish's body undergoes large amplitude undulation to achieve propulsion where in the Carangiform mode the movement and propulsion largely originates from the rear third.In our project, we tried to shape a typical carangiform fish like Rohu.

Motion Dynamics:

The tail is the key factor in the carangiform propulsion mechanism. The researchers on the fish behaviours point out that there is travelling wave, which travels from the neck to the tail implicit in the body of swimming fish. The wave appears as the curvature of the spine and muscle, gradually increasing amplitude, and it travels faster than forward movement. The carangiform propulsive wave curve starts from the fish's centre of inertia to the caudal link, which is assumed to take the form of

$$\mathbf{ybody\ (x, t) = [(C_1x + C_2x^2)]\ [\sin(kx + \omega t)]}$$

where,

ybody is the transverse displacement of body,

x is the displacement along main axis,
k is the body wave number ($k=2\pi/\lambda$),
λ is the body wave length,
$c1$ is the linear wave amplitude envelope,
$c2$ is the quadratic wave amplitude envelope,
ω is the body wave frequency ($\omega=2\pi f=2\pi/T$).

MODULAR ROBOTS

They consist of a set of identical robotic modules that can autonomously and dynamically change their internal geometric structure for locomotion, manipulation, or sensing purposes, in order to optimally carry out a variety of tasks. Self-reconfiguring robots are also able to deliberately change their own shape by rearranging the connectivity of their parts, in order to adapt to new circumstances, perform new tasks, or recover from damage. They can contain electronics, sensors, computer processors, memory, and power supplies; they can also contain actuators that are used for manipulating their location in the environment and in relation with each other. A feature found in some cases is the ability of the modules to automatically connect and disconnect themselves to and from each other, and to form into many objects or perform many tasks moving or manipulating the environment.
The modular building blocks usually consist of some primary structural actuated unit, and potentially additional specialized units such as grippers, feet, wheels, cameras, payload and energy storage and generation.
Modular self-reconfiguring robotic systems can be generally classified into several architectural groups by the geometric arrangement of their unit (lattice vs. chain). Several systems exhibit hybrid properties.

- **Lattice architectures** have units that are arranged and connected in some regular, space-filling three-dimensional pattern, such as a cubical or hexagonal grid. Control and motion are executed in parallel. Lattice architectures usually offer simpler computational representation that can be more easily scaled to complex systems.
- **Chain/tree architectures** have units that are connected together in a string or tree topology. This chain or tree can fold up to become space filling, but underlying architecture is serial. Chain architectures can reach any point in space, and are therefore more versatile but more computationally difficult to represent and analyze. Tree architectures may resemble a bush robot

Modular robotic systems can also be classified according to the way by which units are reconfigured (moved) into place.

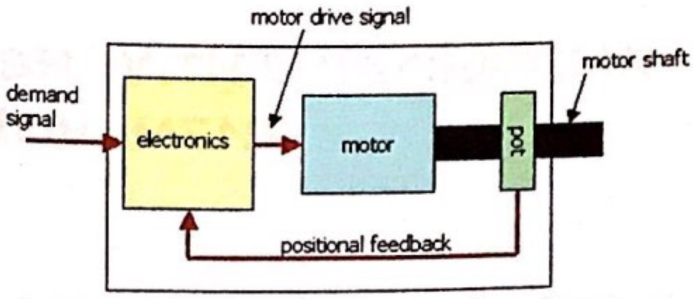
- **Deterministic reconfiguration** relies on units moving or being directly manipulated into their target location during reconfiguration. The exact location of each unit is known at all times. Reconfiguration times can be each unit is known at all times. Reconfiguration times can be guaranteed, but sophisticated feedback control is necessary to assure precise manipulation. Macro-scale systems are usually deterministic.

- **Stochastic reconfiguration** relies on units moving around using statistical processes (like Brownian motion). The exact location of each unit only known when it is connected to the main structure, but it may take unknown paths to move between locations. Reconfiguration times can be guaranteed only statistically. Stochastic architectures are more favorable at micro scales.

There is a growing number of research groups actively involved in modular robotics research. To date, about 30 systems have been designed and constructed(e.g. CEBOT, ANAT Robot, Uni Rover, M-TRAN II etc.)

MECHANISM OF SERVO MOTOR

A servo is a motor that is attached to a position feedback device. Generally there is a circuit that allows the motor to be commanded to go to a specified "position". A typical hobbyist servo looks like a rectangular box with a motor shaft coming out of one end and a connector with three wires out of the other end. Attached to the motor shaft is usually a "control horn". This is a plastic piece with holes in it for attaching push rods or other mechanical linkages to the servo. It generally consists of three basic pieces, a motor, a feedback device, and a control board. The feedback device is typically a potentiometer (variable resistor). The motor, through a series of gears, turns the output shaft and the potentiometer simultaneously. The potentiometer is fed into the servo control circuit and when the control circuit detects that the position is correct, it stops the motor.
Servos are controlled by sending them a "pulse" of variable width. When the servo is commanded to rotate, the DC motor is powered until the potentiometer reaches the value corresponding to the commanded position. The width of the servo pulse dictates the range of the servo's angular motion. The servo expects to see a pulse every 20 milliseconds (.02 seconds). The parameters for this pulse are that it has a minimum width, a maximum width, and a repetition rate. These values are not "standard" but there are conventions that are generally accepted. The convention is that a pulse of approximately 1500 uS (1.5 mS) is the "neutral" point for the servo. Given the rotation constraints of the servo, neutral is defined to be the position where the servo has exactly the same amount of potential rotation in the counter clockwise direction as it does in the clockwise direction.
Voltage ratings vary from product to product, but most servos are operated at 4.8 V or 6 V DC from a 4 or 5 cell battery.



Some terms related to servo motors:

Operating torque: The maximum amount of force the servo can exert is the torque rating of the servo. Typically this is about the equivalent of 1kg at 1 inch away from the shaft of the servo motor. When buying a DC motor, there are two torque value ratings which you must pay attention to. The first is **operating torque**. This is the torque the motor was designed to give. Usually it is the listed torque value.

Stall torque: This is the torque required to stop the motor from rotating. Servos will not hold their position forever though, the position pulse must be repeated to instruct the servo to stay in position.

Repetition rate: The maximum amount of time that can pass before the servo will stop holding its position is the command **repetition rate**. Typical values for the command repetition rate are 20 - 30 mS

Servo motor used in the project is: S3003 Standard Servo (Futaba series).

The specifications of the servo motor is given below:

Control System: +Pulse Width Control 1520usec Neutral

Operating Voltage: 4.8-6.0 Volts

Operating Temperature Range: -20 to +60 Degree C

Operating Speed (4.8V): 0.23sec/60 degrees at no load

Operating Speed (6.0V): 0.19sec/60 degrees at no load

Stall Torque (4.8V): 44 oz/in. (3.2kg.cm)

Stall Torque (6.0V): 56.8 oz/in. (4.1kg.cm)

Operating Angle: 45 Deg. one side pulse traveling 400usec

360 Modifiable: Yes

Direction: Counter Clockwise/Pulse Traveling 1520-1900usec

Current Drain (4.8V): 7.2mA/idle

Current Drain (6.0V): 8mA/idle

Motor Type: 3 Pole Ferrite

Bearing Type: Plastic Bearing

Gear Type: All Nylon Gears

Dimensions: 1.6" x 0.8"x 1.4" (41 x 20 x 36mm)

Weight: 1.3oz. (37.2g)

A Robotic Fish With Concertina Movement

It is our objective to build such a system which can show concertina movement on ground and fishlike movement in the water. So it is essential to know at first about the concertina movement.

Concertina movement is the movement occurring in snakes and other legless organisms that consists of gripping or anchoring with portions of the body while pulling/pushing other sections in the direction of movement. Each point on the snake's body goes through alternating cycles of static contact and movement, with regions propagating posterior (i.e. any point on the snake will change from movement to static or vice-versa shortly after the change occurs in the point anterior to it).

Matrix For Motion Control

It has been observed that to maintain proper synchronization among the servo motors it is essential to follow a square matrix while building up the program. It provides the most convenient way to change the digital servo controller programming loop and the speed of the fish as well.

We designed 5×5 matrix for the motion control of 5 servo motors.

The control matrix= N0 R1 N2 L3 N4
R0 N1 L2 N3 R4
N0 L1 N2 R3 N4
L0 N1 R2 N3 L4
N0 R1 N2 L3 N4

Programming Details:

```
org 0h
mov r4,#18h
here:acall neutral
        djnz r4,here

start:
    acall N0;
    acall RI1;
    acall N2;
    acall L3
    acall N4
    acall RI0;
    acall N1;
    acall L2;
    acall N3;
    acall RI4
    acall N0;
    acall L1;
    acall N2;
    acall RI3;
    acall N4
    acall L0;
    acall N1;
    acall RI2;
    acall N3;
    acall L4
    acall N0;
    acall RI1;
    acall N2;
    acall L3
    acall N4
ljmp start
neutral:setb p2.0
        setb p2.1
        setb p2.2
        setb p2.3
        setb p2.4
        acall delay19
        clr p2.0
        clr p2.1
        clr p2.2
        clr p2.3
        clr p2.4
        acall delay20
ret
N0:mov r7,#02h
next00:setb p2.0
  acall delay19
  clr p2.0
  acall delay20
  djnz r7,next00
  ret
```

```
RI0:mov r7,#02h
next01:setb p2.0
  acall delay24
        clr p2.0
        acall delay20
        djnz r7,next01
        ret
L0: mov r7,#02h
next02:setb p2.0
  acall delay14
        clr p2.0
        acall delay20
        djnz r7,next02
        ret

N1:mov r7,#02h
next10:setb p2.1
  acall delay19
  clr p2.1
  acall delay20
  djnz r7,next11
  ret
RI1:mov r7, #02h
next11:setb p2.1
  acall delay24
        clr p2.1
        acall delay20
        djnz r7,next11
        ret
L1: mov r7, #02h
next12:setb p2.1
  acall delay14
        clr p2.1
        acall delay20
        djnz r7,next12
        ret
N2:     mov r7,#02h
next20:setb p2.2
  acall delay19
  clr p2.2
  acall delay20
  djnz r7,next20
  ret
RI2:mov r7, #02h
next21:setb p2.2
  acall delay24
        clr p2.2
        acall delay20
        djnz r7,next21
        ret
L2: mov r7,#02h
next22:setb p2.2
```

```
acall delay14
        clr p2.2
        acall delay20
        djnz r7,next22
        ret
N3:     mov r7,#02h
next30:setb p2.3
  acall delay19
  clr p2.3
  acall delay20
  djnz r7,next30
  ret
RI3: mov r7,#02h
next31:setb p2.3
   acall delay24
        clr p2.3
        acall delay20
        djnz r7,next31
        ret
L3: mov r7,#02h
next32:setb p2.3
   acall delay14
        clr p2.3
        acall delay20
        djnz r7,next32
        ret

N4:     mov r7,#02h
next40:setb p2.4
  acall delay19
  clr p2.4
  acall delay20
  djnz r7,next40
  ret
RI4: mov r7,#02h
next41:setb p2.4
   acall delay24
        clr p2.4
        acall delay20
        djnz r7,next41
        ret
L4: mov r7,#02h
next42:setb p2.4
  acall delay14
  clr p2.4
  acall delay20
        djnz r7,next42
        ret

delay14:mov r1,#0ah;(1.12ms)
    next4:acall delay80
        djnz r1,next4
```

```
ret
delay19:mov r1,#0fh   ;(1.5ms)
      next5:acall delay80
           djnz r1,next5

ret
delay20:mov r3,#49h;(20ms)
      next2:acall delay80
                              acall delay80
                              acall delay80
           djnz r3,next2

ret


delay24:mov r1,#14h  ;(1.92ms)
      next6:acall delay80
           djnz r1,next6

ret
delay80:mov r2,#24h
      next1:djnz r2,next1

ret
end
```

DESIGN ARCHITECTURE OF FISH

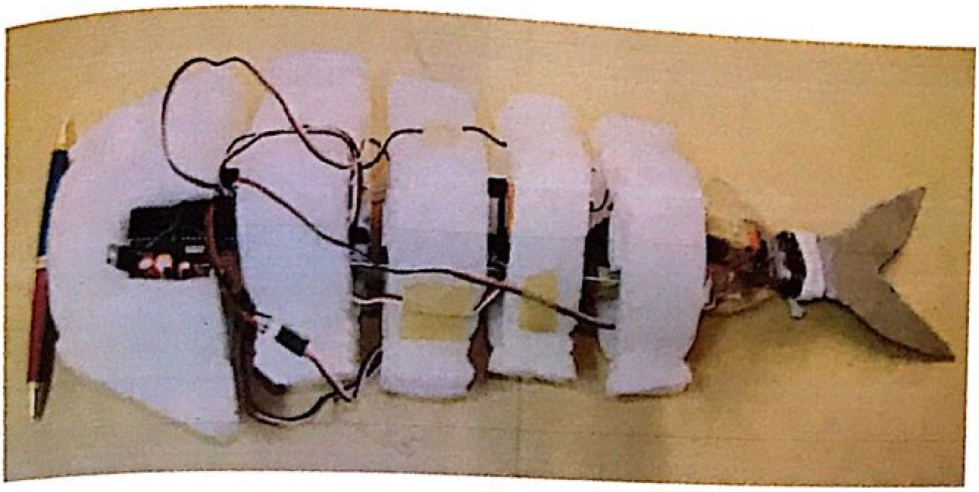


Fig. A Modular Robotic Fish Prototype

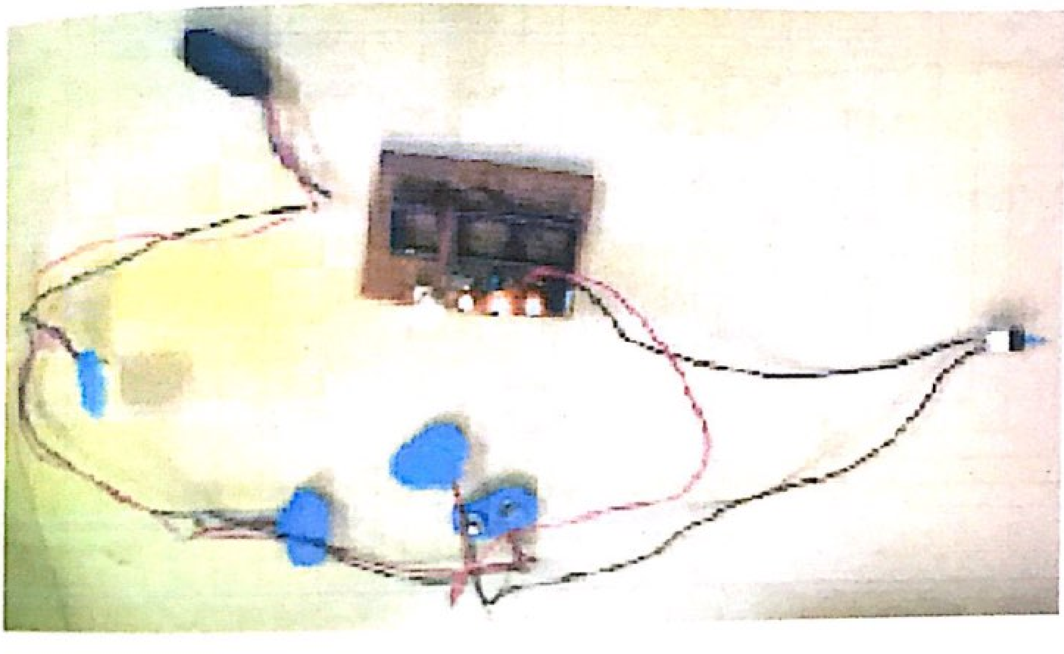


Fig. The complete circuit with battery connections and switch

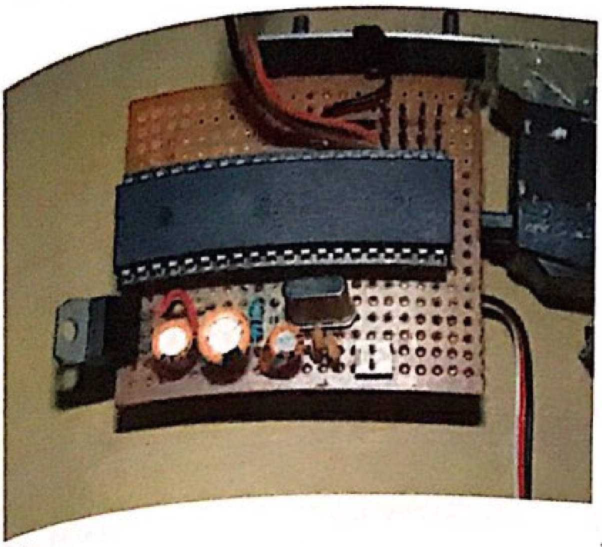
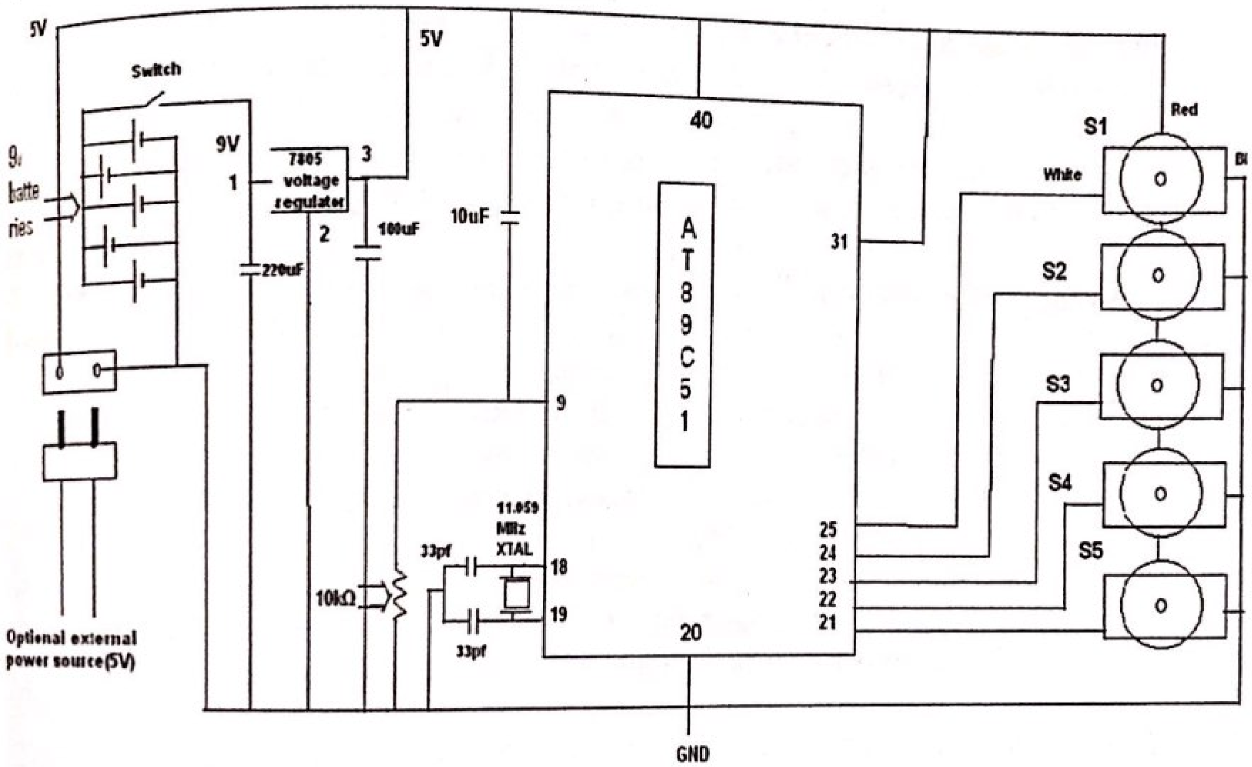


Fig. The Central Processing Unit of the robotic fish

The circuit diagram of the Central Processing Unit:



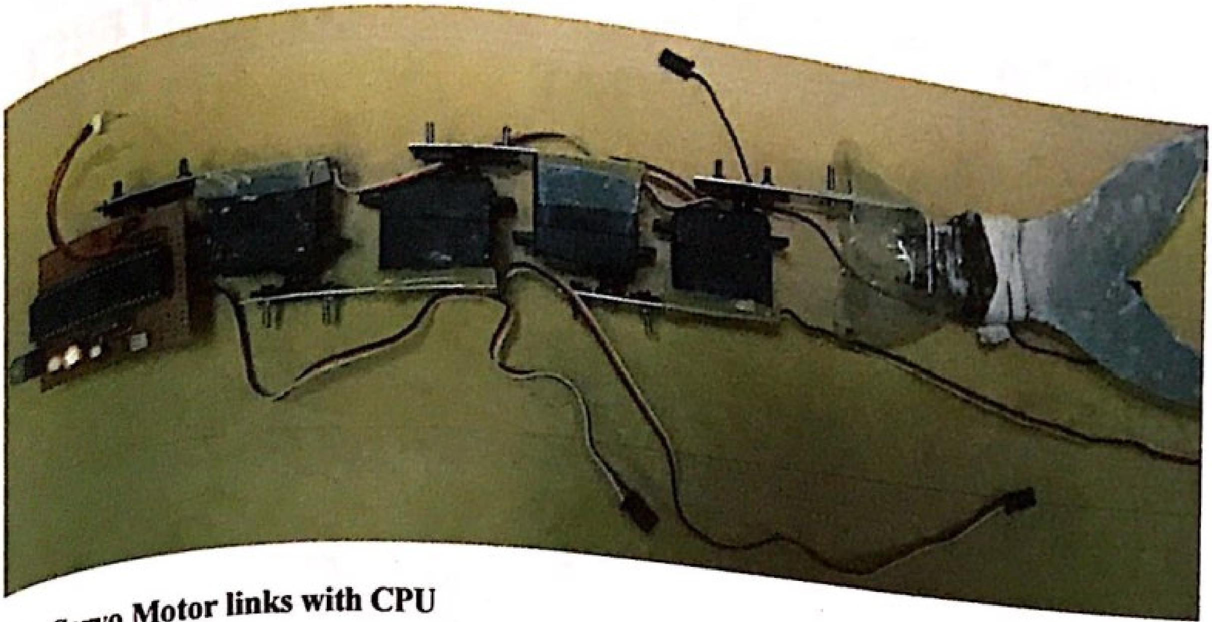


Fig. Servo Motor links with CPU

The prototype in this project has been modeled on the Carangiform swimming mode in order to achieve highly efficient swimming.

The servo motor links along with the CPU at the front and aluminum tail at the end is the basic structure of the Robotic fish. Servo motor is light in weight and the operating voltage is in the range of 4.8-6.0 V DC, which is easy to achieve. Hence it is used in its structure. Aluminum is chosen for linking the servo motors and fish-tail as well for its light weight and providing enough material strength to carry the successive force of the links while in motion.

To make the robotic fish more light, the segments are wrapped with a lightweight packing material in the similar fashion that of a fish would look.

The aspect ratio of the caudal fin plays an important role in propulsive efficiency. Aspect Ratio=b^2 /Sc, where, b=fin span, Sc= projected fin area. A caudal fin with low aspect ratio is not suitable for high speed and high propulsive efficiency, because it has large drag for a surface area of the wing. However the wing is expected to get huge propulsive force, because the wing has large surface area remarkably for a size of the fish robot. As the result, it is considered that the fish robot with the low aspect ratio can accelerate well from stationary position.

Fig. Caudal Fin(tail) of the Robotic Fish

In our robotic fish prototype, we have tried to keep the shape of the tail as far similar as that of a real fish.

APPLICATION POTENTIAL

1. Since the robotic fish in our project is capable to move both on ground and under water, it can be set in anywhere in the ground and may have immense application in military fields such as exploring enemy territories etc.

2. It can used for autonomous underwater vehicle(AUV) and hence can be used in many marine fields such as exploring the fish behaviors.

3. We know that electromagnetic wave cannot be used beyond the depth of 1 meter in the water. So to communicate far more distance in the ocean it can be an excellent medium.

4. Detecting the leakage of oil piping .

5. Sea bed exploration.

6. Mine counter measures .

CONCLUSION

The Robotic Fish can be further developed for Sharp Turning using motion control algorithm and velocity control algorithm. Many sensors such as infrared sensor for obstacle avoiding, ultrasonic sensor for terrain detection, pressure sensor for buoyancy control, GPRS module for communication can be implemented for more advanced applications.

The Robotic Fish can be modified in to a Miniature Robotic Fish also. Miniature Robotic Fish is cheap enough to be mass-produced, which may enhance the quality of the solution by communication among them. The Miniature Robotic Fish should be elaborately designed because all the mechanical structures, control units, sensors, communication module and power supply are integrated into a very limited space, which brings a new challenge.

In the process of completing our robotic fish project we have learned about different terms in Robotics, different types of Robots especially biologically inspired robots. We have also learned to make electronic circuits, microcontroller programming, servo motors and their applications, Pulse Width Modulation, Mechanical Structures and Linking and so on. So it is a good source of robotic education and we believe that it will make students more and more interested in Robotics.

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