Chapter 1: Introduction to Robot

1.1 Definition

An automatically controlled, reprogrammable, multipurpose, manipulator which can be programmed in three or more axes, and can be either, fixed in place or mobile for use in industrial automation and domestic applications.

1.2 Basic components of a Robot

1. **Manipulator or Arm:** The arm is the part of the robot that positions the end effectors and sensors to do their pre-programmed business. Most working robots today have 6 degrees of freedom

2. **End Effectors:** This is the part which is connected to the end of the arm constituting the robot hand .They are different for different applications like spray gun, a welding electrode holder , part gripper, glue applying device or special purpose too.

3. **Controller:** The controller functions as the "brain" of the robot which controls and coordinates the activities of the robot. They are run by programs - sets of instructions written in code.

4. **Sensor:** Sensor is a device for detecting or measuring a physical property. Robotic sensing is a technology to endow machines with a greater degree of intelligence in dealing with their environment.

5. **Drive:** Is a prime mover which actuates or energizes all the functionalities of the robot. Some type drive mechanisms are Hydraulic, Pneumatic, Electric & Often combination of different drives are used.

1.3 Types of Robots

1. Cartesian coordinate Robot: Arm moves in 3 linear axes, easy to visualize, rigid structure, easy to program.
2. Cylindrical Coordinate Robot: Arm rotates about the base, moves in and out, and up and down, can reach all around itself, reach and height axes rigid, rotational axis easy to seal
3. Polar Coordinate Robot: 1 linear, 2 rotating axes, long horizontal reach, Can't reach around obstacles, short vertical reach.
4. Jointed Arm Robot: Joined-arm or revolute-coordinates robot: 3 axes rotational, can reach above or below obstacles, largest work area for least floor space.
5. SCARA: Rotates in 2 axes in the horizontal plane and moves linearly up and down, height axis is rigid, large work area for floor space.

1.4 Application of Robots

1. Industries
2. Space exploration
3. Medical field
4. Domestic purposes
5. Archaeology
6. Military purpose

Chapter 2: About Robotic Fish

A robot fish is a biomimetic robot deriving its design inspiration from aquatic fishes. For long researchers have been interested in the highly efficient propulsion of fish and now have attempted to apply it to underwater robots for fish-like swimming mechanisms. Underwater applications are one of the areas where biomimetic robots can potentially perform better than conventional robots. Underwater robots are widely used in the fields of ocean development, ocean investigation, and marine environmental protection. Requests for underwater operations to be carried out more efficiently have become pressing. In response, autonomous underwater robots have been planned. In fact several test robots have already been developed. The need for higher efficiency and propulsive performance essentially requires fish-like performance. Swimming methods of fish are various and interesting. They have many specialized modes of movement. For example, an eel swims waving the whole of its body and is highly adapted to an enclosed environment. A flat fish, on the other hand, swims by waving long fins in special patterns, allowing it to hover, backup or turn quickly in any direction. Robotic mimic of shark fish is shown in figure below.

Figure 1: Shark Robot

Chapter 3: Fish Swimming Patterns

Different fishes use different methods for swimming. As the well-known categories for the swimming fish, a zoologist, C.M. Breder classified into the following three general categories based on length of a tail fin and strength of its oscillation.

(a) Anguilliform: Propulsion by a muscle wave in the body of the animal which progresses from head to tail like the Eel.

(b) Carangiform: Oscillating a tail fin and a tail peduncle like the Salmon, Trout, Tuna and Swordfish.

(c) Ostraciiform: Oscillating only a tail fin without moving the body like the Boxfish.

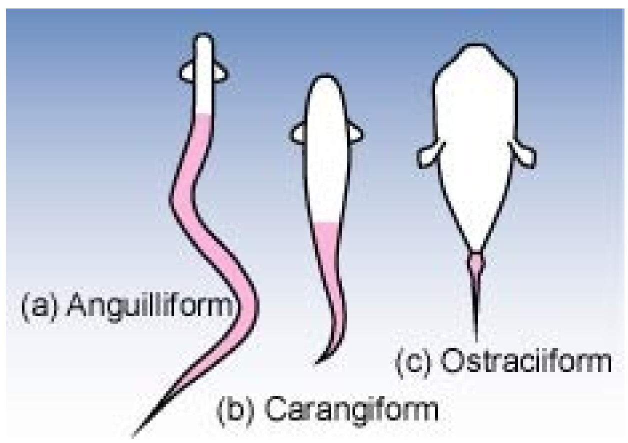


Figure 2: Fish swimming categories

3.1Constraints to swim underwater

To be able to swim, fish need to

1. **Overcome drag**: Drag normally exists in two types
    a) Pressure drag is the force needed to push water out of the way to swim forward. Streamlined body shape of the fishes reduces pressure drag
    b) Frictional drag can cause turbulence, making it harder for water to flow smoothly across an object. The slime coat over the fish provides a smooth surface that allows laminar flow and minimizes frictional drag

2. **Maintain their vertical position in the water column**: Neutral buoyancy is the condition to be satisfied to maintain vertical position. The swim bladder in fishes acts just like a balloon – with the ability to control the amount of gas. The primary gas in a swim bladder of fish is oxygen. To maintain a lower position, the swim bladder must release some of the oxygen. Deflating the swim bladder is a passive process. Higher pressures inside the swim bladder force oxygen to diffuse into the blood stream in surrounding capillaries. This allows the fish to sink to a lower depth. More gas is added to the swim bladder to move to a higher level in the water. Gas is released from the swim bladder to move to a lower position in the water. Inflating the swim bladder is an active process that generally involves a gas gland. The gas gland is rich with capillaries and acts to concentrate oxygen until the pressure of oxygen in these capillaries is greater than in the swim bladder. Oxygen will then diffuse from capillaries associated with the gas gland into the swim bladder, causing it to inflate, and allowing the fish to rise

3. **Maintain an upright position:** Fishes use their fins to control pitch, roll and yaw and hence maintain an upright position. The various fins of an angelfish is shown in the figure below

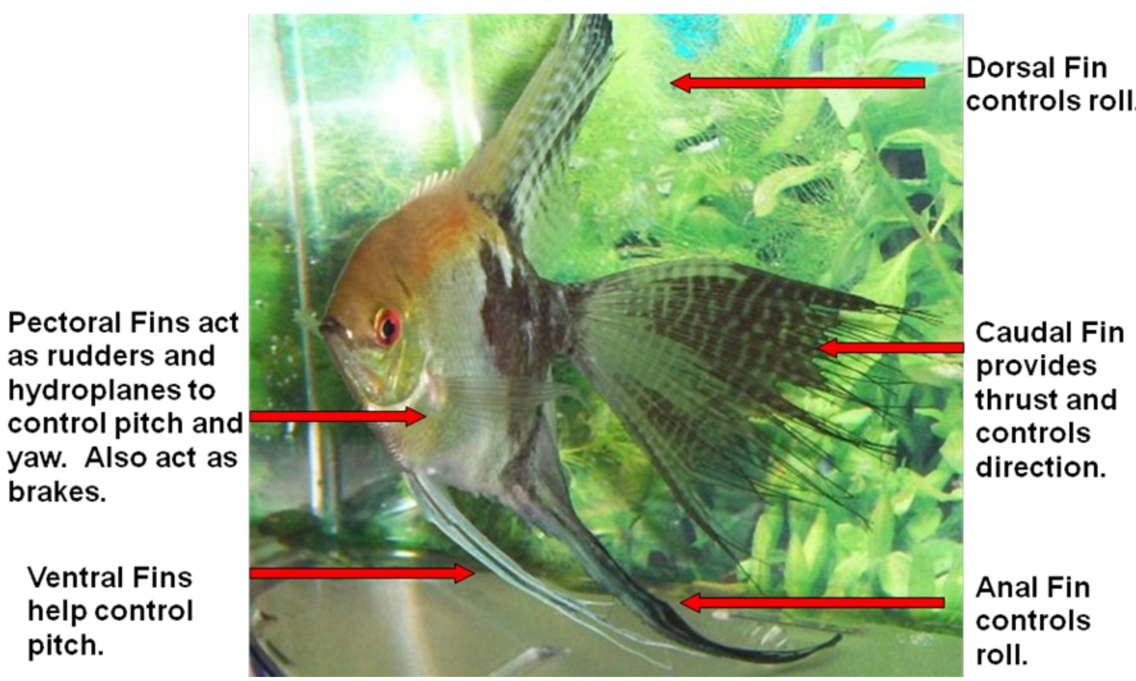


Figure 3: Fins of an angelfish

4. **Move efficiently:** The muscles provide the power for swimming and constitute up to 80% of the fish itself. Muscle blocks are arranged in multiple layers (myomeres) arrayed in several directions that allow the fish to move in different directions. Fish swim by contracting and relaxing a succession of myomeres (muscle blocks) alternately on each side of the body. The alternate shortening and relaxing of successive myomeres bends the body first toward one side and then toward the other, resulting in a series of waves traveling down the fish's body. This action starts at the head and progresses down toward the tail. The skeletal system acts as a fulcrum for the muscles. Fish create vortices (cause the water to spin) with the motion of their body and fins. This provides something the fish can push against to propel itself forward. The spin of these vortices is strong enough that they stay in place long enough for the fish to push against them.

3.2 Swimming Speed of different fishes

The swimming speed of fish is determined by its shape, size and build. In addition, fish generally cruise at a different speed than their all-out full attack speed. The following are typical values for various fish. The table includes the speed (m/s), and also typical values for body length L (m), and the ratio of velocity to length V/L.

Table 1 Swimming speed of fish

Fish	Speed	Length	V/L
Herring	6 km/h	0.3 m	5.6
Pike	6 km/h	0.5 m	3.3
Corp	6 km/h	0.8 m	2.1
Cod	8 km/h	1.2 m	1.9
Mackerel	11 km/h	0.5 m	6.1
Salmon	45 km/h	1.0 m	12.5
Bonito	60 km/h	0.9 m	18.6
Small Tuna	60 km/h	3.0 m	5.6
Black Tuna	80 km/h	3.0 m	7.4
Sword fish	96 km/h	4.0 m	6.7

Chapter 4: Challenges in building a Robotic Fish…

Major difficulties in the robotic fish design are caused by the water media, since water is an incompressible fluid with high density and practically offer difficult environments for mobile robots, including waterproofing issues, great viscous or friction drag and water pressure drag, etc. This project is to focus on three main challenge issues as follows.

Challenge 1: Swimming mechanism and mathematical models.

The fish's swimming mechanism and mathematical models are not very mature. In 1930's, Gray made an assumption about the swimming mechanism. He estimated the power requirements for a cruising dolphin, assuming that its drag can be approximated by that of a rigid model and considering turbulent flow. The calculations indicated that the power required exceeded the estimates of muscle power output by a factor of seven, thus the "Gray Paradox". Later, the reversed Karman vortex-street was observed. To explain it, many researchers proposed their own theories such as "vortex peg" mechanism, undulating pump mechanism and vorticity control mechanism. These theories explained the problem how the fish obtains its energy to move forward in some extent. The mathematical models to describe the kinematics of fish are based on many assumptions, including the resistive hydrodynamic models, 2D waving plate theory, and later wake theories of oscillating foil propulsion. These theories provide great help for the design of artificial propulsion systems and the robotic fish body. For the static water environment or quasi-steady fluid flow, current wake theories work well. But as far as the unsteady water is concerned the above theories will be reformulated to derive dynamic models of the oscillating foils.

Challenge 2: Motion control methods.

The second challenge is the motion control methods for the robotic fish. There are three main motions for robotic fish: cruising, maneuvering and hovering. Cruising is referred to the swimming in constant speeds. Maneuvering is to accelerate, decelerate, change direction, turn and swim up-down, etc. Hovering is to stop or stabilize at some position in water.

Challenge 3: Mechanical structure and sensors.

In general, the selection of mechanical structure, sensors and navigation technique are important factors in the design of a robotic fish. Firstly the mechanical structure of a robotic fish is diversified according to the different biological kind of robotic fish. For example, if the robotic fish mimics an eel, its body may have more joints than the robotic fish that mimic a tuna. There is no uniform basic principle even for the same biological kind of robotic fish due to the immature mechanism of fish swimming. Due to the waterproof requirement, limited space in a robotic fish and other special features of water, most of navigation sensors used in air would not work well in water. Some researchers focus on the bio mimetic fish skin to protect inside circuits and to provide free undulation capabilities. The artificial muscle or other rubber materials belongs to this kind. Other researchers develop the new material that could act as bio mimetic actuators to create undulation movement and provide forward energy for a robotic fish. In summary, it remains a big challenge to realize fully autonomous navigation on robotic fish, where this project aims to make a break through.

Chapter 5: Principles of Robotic Fish Swimming

5.1 There are four categories of mechanical design of fish robot based on analytical and biological observations.

1. **Changing Wave**

   Fish using this method are propelled by a muscle wave in the body of the animal which progresses from head to tail. This causes the fish to be propelled by the action of its body upon the water. In order to get propulsive force, it is needed that velocity of the wave is faster than forward speed of the fish, and amplitude of the tail part is bigger than that of the head part. We find that most of these fish can reverse this wave motion, thereby enabling them to swim backwards in a similar fashion. Normally, these fish have a long body or a long fin like a ribbon.

   A fish robot using this method needs smooth motion of the whole body with many hinge joints and so much complex control system for the joints. However the fish robot can realize delicate motion, and work well in narrow water area like a coral reef, when a high quality control system is completed.

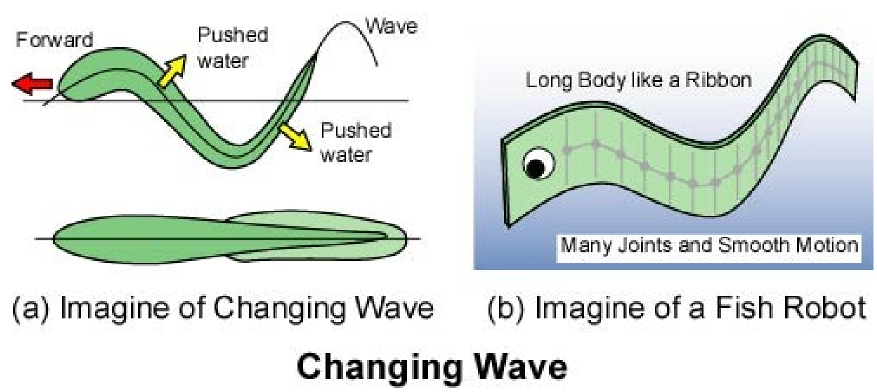


Figure 4: Changing wave design

2. **Body Foil**

Trout and Salmon are fish typical of those using this swimming method. These fish push water away behind them with using both oscillation of a tail fin and motion of a body. (a) of the figure to the right shows pressure distribution by the motion of body conceptually. There are positive and negative pressure gradients, or we may have to say them action -reaction force, their total force then becomes propulsive force.

We can consider the characteristics of this propulsive method with aspect ratio which is often used to estimate the performance of a wing, defined the ratio of span of a wing, c and chord of a wing, b. When we consider the body to be a wing as shown in (b) of the figure boldly and extremely, the wing has low aspect ratio. Low aspect ratios are often associated with high lift devices, jumbo jet wing flaps, multi-purpose aircraft wings (utility, trainer), towing propellers, and multi-purpose boat propellers. Because it performs well at low and medium speeds and wide range of the attack angle, it is used to multi-purpose. It can travel far but needs a bit more fuel to go great distances. Also a wing 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

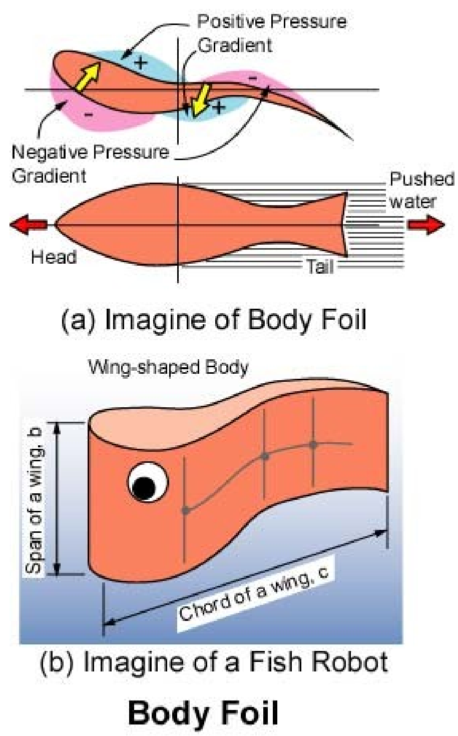


Figure 5: Body foil design

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. As the other excellent characteristics, it is expected to have good turning performance with changing the direction of the propulsive force, and it has no concentrated force at hinge joints with dispersing of the driving power to the whole body.

On the other hand, fish using this method such as Trout and Salmon have a triangular tail fin generally. The fish propel by the oscillation of the tail fin with the same principle of the Oscillating Wing described below. It is very interesting from the viewpoint of hydrodynamics that the triangular tail fin has lower aspect ratio than that of the Oscillating Wing.

3. Oscillating Wing

Fish using this method derive nearly all of its propulsive force from an oscillating wing-shaped tail fin. The motion of the oscillating wing is combined heaving motion and feathering motion of the tail fin, and has about 90 degrees of phase angle between the heaving and the feathering of the tail fin. Tuna and Bonito use this method. Cetaceans also use this method, although they wave their tails up and down, not left and right. These fish has a crescent and wing-shaped tail fin. As its span is long and its chord is short, the tail fin has high aspect ratio.

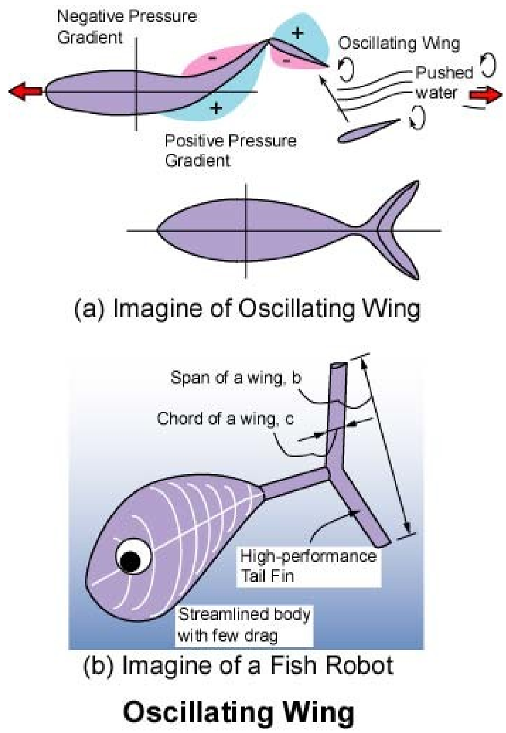


Figure 6: Oscillating wing design

` High aspect ratios are associated with very high lift performance in wings, propellers, helicopter rotors, high-speed motorboat propellers and hydrofoils. A wing with high aspect ratio has the great characteristics such as low drag and strong lift for a surface area of the wing. Thus, the Oscillating Wing gets the great performance, when a high performance tail fin in hydrodynamics, a streamlined body and a slim peduncle are combined. The body with few drag and strong propulsive force by the tail fin obtain high-speed swimming. The energy for driving the tail fin is a few, because the surface area of the wing is small for a size of the fish robot. Then the oscillating wing propulsion can get high propulsive efficiency. But the fish robot with this method does not expect to get good accelerating performance from stationary position, because the propulsive force is somewhat small for the size of the fish robot. It also is important that we should design the joint at the tail fin in careful, because the strong force is concentrated at the joint.

4. Oscillating Plate

Fish using this method oscillate only a tail fin alike a plate without moving the body. The direction of water pushed by the Oscillation Plate may disperse to left or right, not behind the fish. As the result, this propulsive method has weak points at swimming speed and propulsive efficiency. But the method is expected high mechanical efficiency, because it has a few hinge joint with small mechanical loss. Also from the simple structure of the mechanism, it is considered that the method is the most suitable for a small-size fish robot. In addition, it is considered the elastic tail fin of this method obtains somewhat stronger propulsive force, because the direction of the pushed water may become too behind similarly

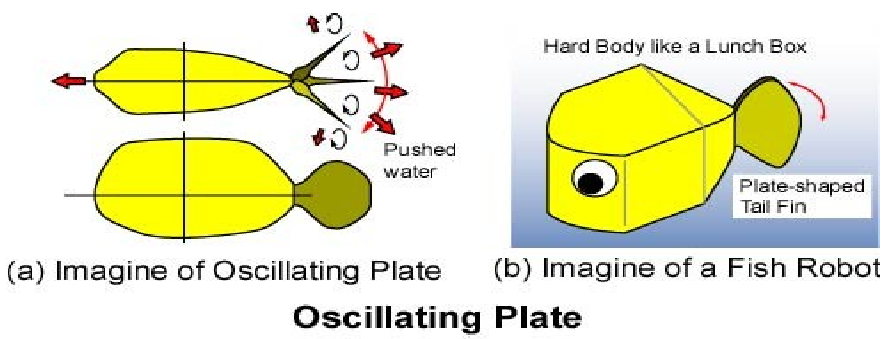


Figure 7: Oscillating plate design

Chapter 6: Up And Down Motion

For up-down motion, five kinds of the mechanisms are feasible

6.1 Up-down Mode A

In Mode A, a water tank (air bladder) and a pump are located in a fish robot. A balance of gravitation and buoyancy is changed by water in and out of the tank. After all, when the tank fills water, the gravitation becomes bigger than the buoyancy, then the fish robot moves down. When the tank fills air, the buoyancy becomes bigger than the gravitation, then the fish robot moves up. In this mode, the fish robot can move up and down vertically, and be controlled depth certainly and accurately. However, it is considered that this mode has problems such as delay of a response, handling of compressed air and getting large size by the tank and the pump.

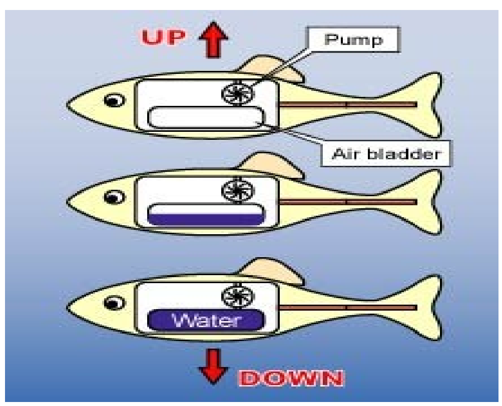


Figure 8: Up-down mechanism using air bladder

6.2 Up-down Mode B

In Mode B, a fish robot with fins (wings) moves up and down using their lift force. It is considered that the fish robot can realize various motions by location and operation of the fins like the main wings or horizontal wing of an airplane. It also is expected quick response and high dynamic performance in higher range of swimming speed. However, the fish robot is needed the higher swimming speed, because it utilizes the lift force of the fins. Thus it is not suitable for delicate control.

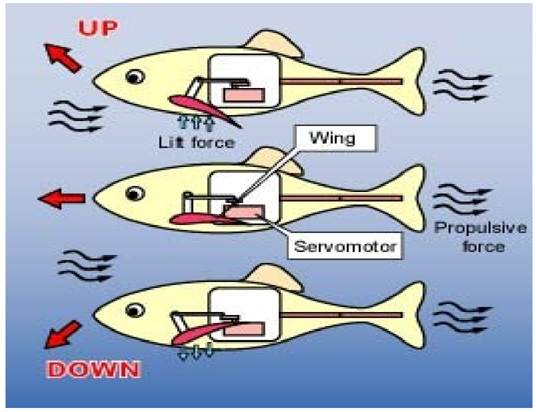


Figure 9: Up-down mechanism using servo motor

6.3 Up-down Mode C

In Mode C, a fish robot has a mechanism for changing angle of up and down direction at its head or tail. The fish robot changes its body to a shape of a wing, and moves up and down by the lift force. It is expected quick response and high dynamic performance in higher range of swimming speed alike the Mode B. But the fish robot is needed the higher swimming speed, because it utilizes the lift force.

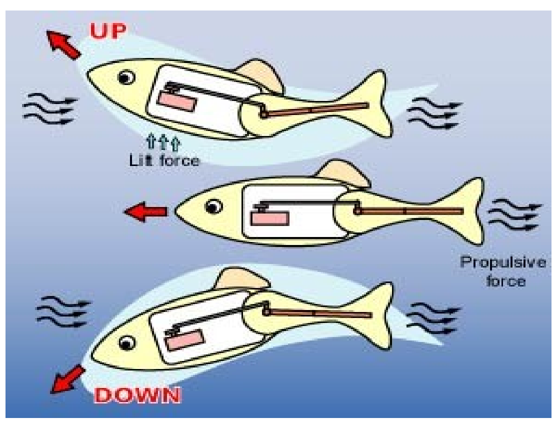


Figure 10: Up-down mechanism by changing head tip angle

6.4 Up-down Mode D

In Mode D, a fish robot moves up and down with changing a direction of tail fin which generates propulsive force. The fish robot has a mechanism for changing angle of up and down direction at its tail alike the Mode C. However the lift force of the body is not generated. It is considered that this mode can be used the fish robot which has a thin width of the body.

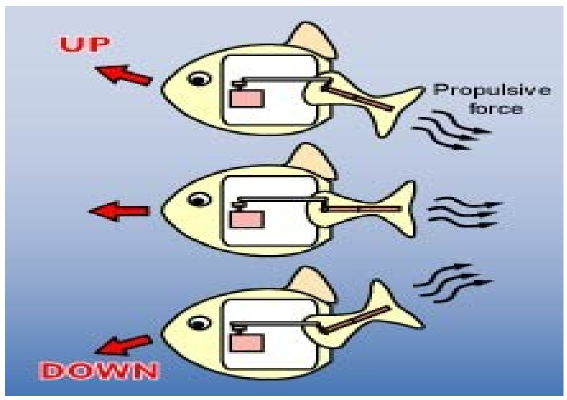


Figure 11: Up-down mechanism by tail fin propulsion

6.5 Up-down Mode E

In the Mode E, a fish robot has a mechanism moving a weight to forward and back direction. The fish robot moves up and down with changing a pitching direction by the moving of the weight. The mechanism is only set inside of the body, then the fish robot has a simple structure in a viewpoint of a seal device and mechanics. However, it is not expected quick response. And it is considered that an adjustment of gravitation and buoyancy is important for the suitable up -down motion.

On the other hand, in the case of changing a weight to the left and the right, the turning to the left and the right means the up -down motion. Namely, the fish robot utilizes a rolling motion and turning motion. But it is considered that the big rolling motion is not suitable in a viewpoint of the application and structure of the fish robot.

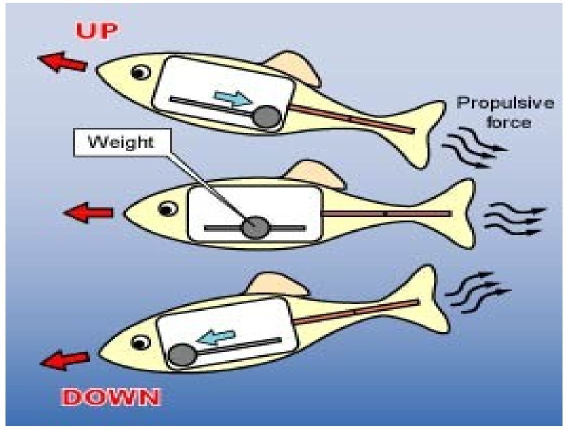


Figure 12: Up-down mechanism by moving weight

Chapter 7: Turning Modes of a robotic Fish

Though real fish turn skillfully using not only tail fin but also pectoral fins or ventral fins. But a fish robot can be designed, which turns with only swing of tail fin. As the tail fin is utilized both propulsion and turning, the fish robot gets simple structured and easy control for swimming. In the case of turning with only swing of tail fin, we consider three turning modes shown as follows

7.1 Turning Mode A

The figure below shows the case of Mode A. The fish robot swings its tail only to one side during a turning. It is considered that this mode is the most fundamental and important turning mode, because the robot can turn with various turning diameter and speed in this mode. In this turning mode, a head and a body of the fish robot are equivalent to a rudder, and the tail peduncle and the tail fin are equivalent to a screw propeller of the ship. If we attend to the resemblance of these functions, we can analyze this mode and control the robot easily

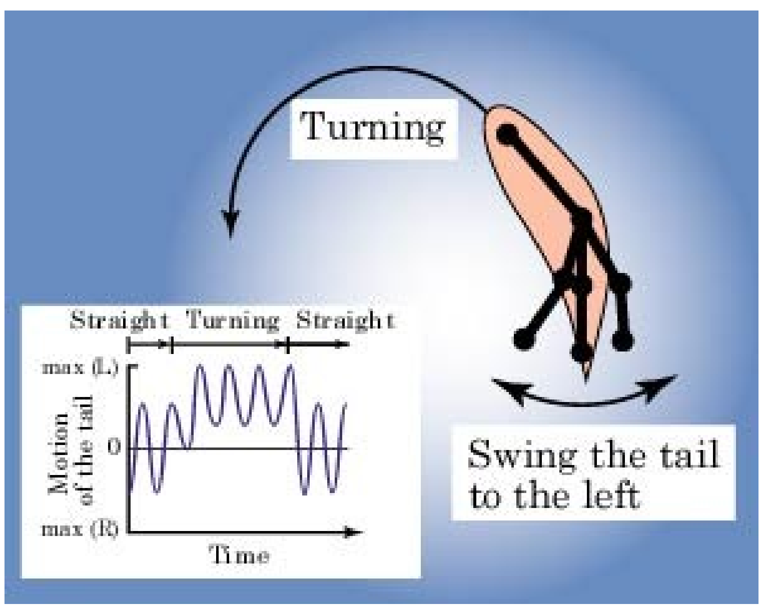


Figure 13: Turning Mode A

7.2 Turning Mode B

The figure below shows the case of Mode B. At first, the fish robot swims straight, and gets kinetic energy. Next, the fish robot turns its tail to one side, and keeps the posture to the side. Then the fish robot turns by hydrodynamics force. It is considered that this mode gets smaller turning diameter than that of Mode A

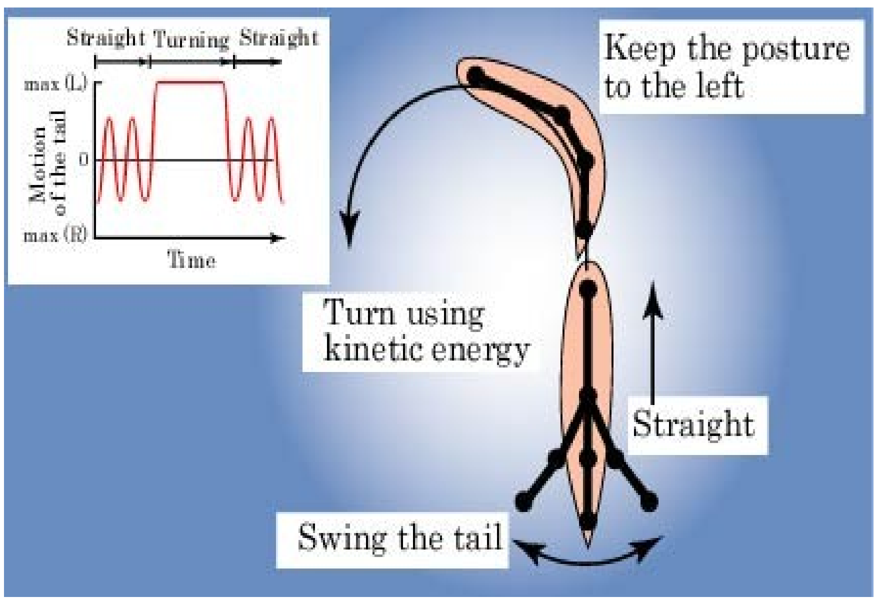


Figure 14: Turning Mode B

7.3 Turning Mode C

The figure below shows the case of Mode C. The fish robot swings its tail to one side rapidly from stationary state. In this turning mode, inertia force and friction force of the moving tail and the body are changed to the moment of rotation. This mode has excellent characteristics. It is possible to turn from the stationary state, and its turning diameter is the smallest in the whole modes. However, it is difficult to control turning speed and turning angle. Also, in order to get quick turning, it is necessary that the power source for tail swing should have sufficiently high torque.

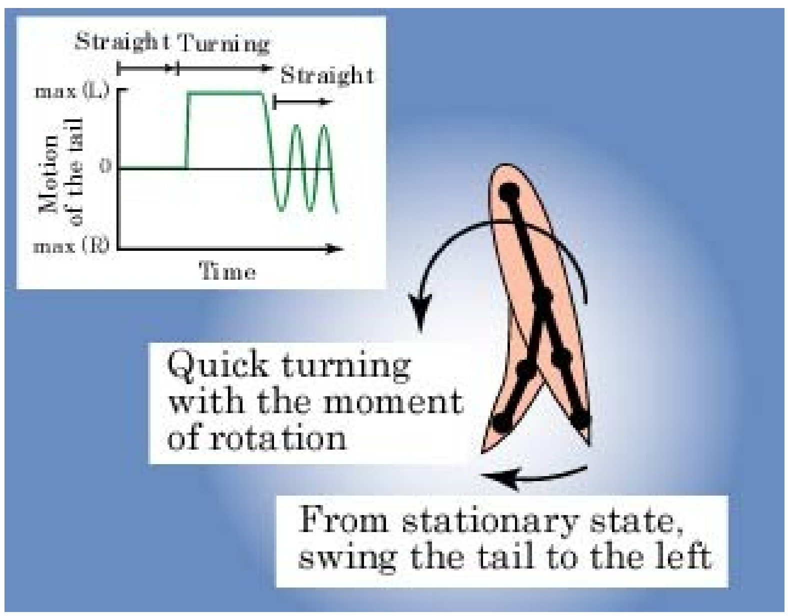


Figure 15: Turning Mode C

Chapter 8: Sensory System

Figure shown below depicts the block diagram for the design of the fish robot's sensory system. Also shown in the diagram is the robot power supply. This will power the sensory system as well as other electronics that are part of the robot.

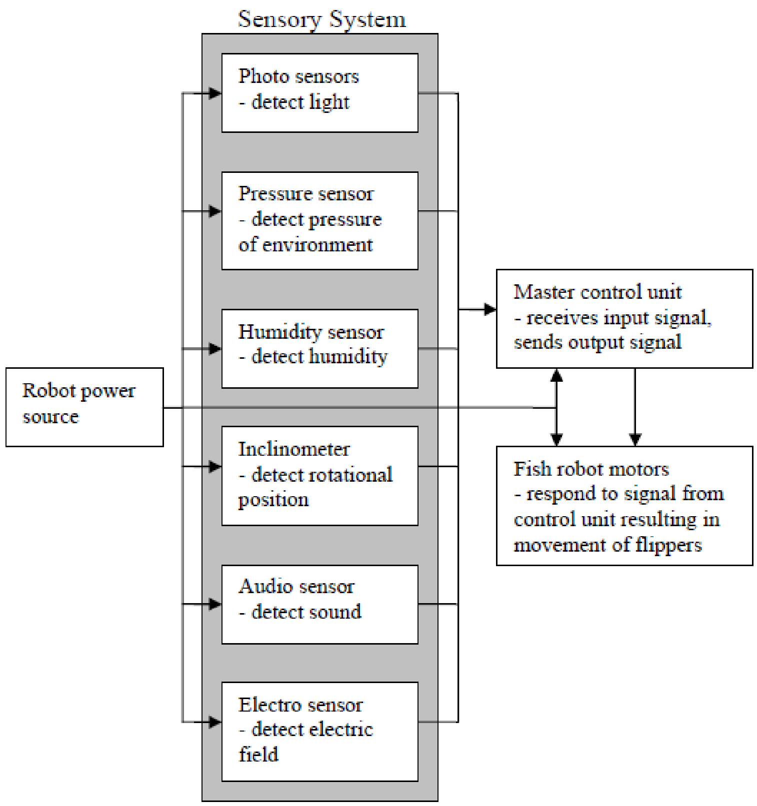


Figure 16: Block diagram of fish robot's sensory system.

8.2 Robot Power Source

The fish robot will get its energy from an internal power supply.. A few milliamps will be utilized to power a microcontroller, and this will leave remaining milliamps for powering the sensors. Therefore, the sensors should be chosen based on these constraints and on their functionality. Enough power should be supplied by the source to allow for the chosen sensors to function properly.

8.3 Photo Sensors

These sensors require a minimum input voltage of 2.7 volts and up to 5.5 volts, allowing for them to be powered efficiently by the power source that will be used. The choice of sensor that will be used depends on the underwater tests. The more sensitive sensor is too easily saturated when capturing light through air, however, due to the effects of water on the attenuation of light, this sensor may prove to be the most effective in capturing light under water. A light filter will be used to decrease the sensitivity of the sensor if necessary. Figure 2 shows the three different models of photo sensors that were tested, as well as a diaphragm-type filter that can be used to limit the amount of light entering the lens. One photo sensor will not suffice in order to allow for the fish robot to follow a light source. Two photo sensors will be placed on the front of the robot's head module, at the same vertical level, but on different sides of the face. For the time being, this will allow the fish to follow a light source along a horizontal plane.

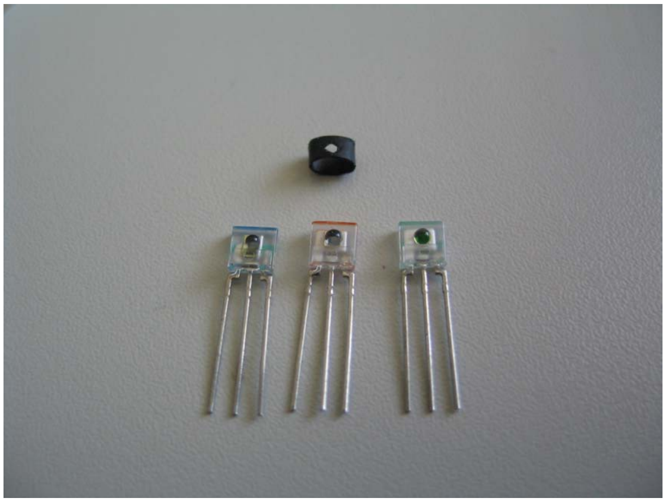


Figure 17: Photo sensors from TAOS. From left, models TSL250R, TSL253R and TSLG257. Above the sensors is a diaphragm-type filter that can be used to limit the amount of light entering the lens.

The idea being that the fish will turn in the direction corresponding to which sensor (left or right) is detecting more light. If both sensors are detecting the same amount of light, then this would indicate that the source of irradiance is straight ahead, and robot will move forward.

8.4 Pressure Sensor

These pressure sensors require between4.5 and 8 volts in order to operate properly, and therefore they will function properly when powered by the robot power source.

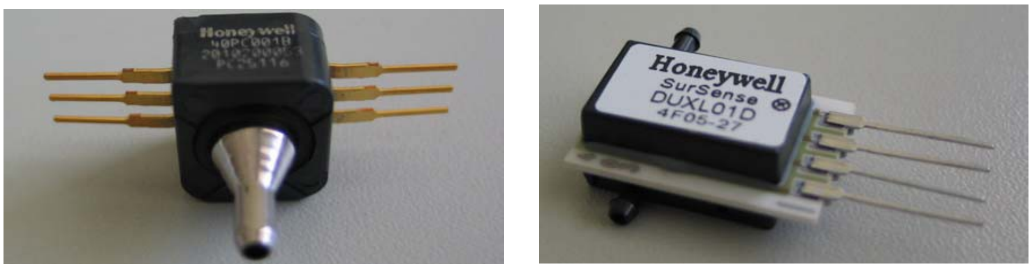


Figure 18:. Pressure sensors from Honeywell. From left, models 40PC100G and DUXL01D.

The choice of sensor will depend on the precision, the depth range, and on the shape and size of the sensor. The sensor must output a certain voltage for a certain depth, and this output must be consistent for all depths up to 60 centimeters. The output should always be the same (within 1 to 2 mill volts) for a certain depth. A more sensitive sensor would be desirable, the one which displays the greatest change in voltage per change in depth. This will help improve the resolution and make it easier to determine the depth more precisely. Also, there is not too much space in the fish module and for this reason the smallest sensor possible is desired and depending on the space available, the shape of one sensor might be easier to integrate into the module than another. The pressure sensors will be used to indicate to the robot the depth at which it is submerged, and may also be used to indicate any agitation of water within its surroundings.

8.5 Humidity Sensor

A humidity sensor is a useful device to use for detecting whether or not the robot is submerged in water. Since the fish robot is to function underwater, this sensor can be used indirectly as a type of on/off switch. For example, if the fish is submerged, this will be detected by the sensor and a command can be given to indicate to the robot to turn on (swim), and when it is removed from the water, using the same principle, the robot would turn off. Another idea can be a fish that is capable of moving on land. In this case the humidity sensor can be used to command the robot to change to a flipper motion that would allow it to move across land. An alternative method of indicating the condition of being submerged would be to use a simple circuit which contains an open circuit. The two ends of the open circuit would be exposed to the exterior, and in the case of a current being detected in the circuit, this would suggest that the robot is in a wet environment. This sensor can be used for other robots that are meant to function on both wet and dry conditions.

8.6 Inclinometer

For the time being there won't be an inclinometer or accelerometer installed in the robot's modules. Because of the weight distribution of the fish robot, it will naturally stay in the same position with respect to pitch and roll. Only the yaw will vary since it will be swimming along a specific horizontal, following a light source. Once development of the robot has advanced to the point where it can change its depth and control its rotational position, the concept of installing this device will prove to be very useful, improving the robots capabilities in more uncontrolled environments. The accelerometer will be useful in determining the position of pitch and roll of the fish robot, and this information can be used to better control the position of the robot if necessary. In order for these measurements to be registered, the sensor must have two perpendicular axes (one to measure pitch and the other to measure roll).

The sensor works by projecting the gravity vector on the two axes. Therefore, if the accelerometer is positioned so that both axes are horizontal, there would not be any projection of the gravity vector on either axes and this would indicate a neutral position.

8.7 Audio Sensor

A microphone can added to allow for detection of audio signals. In order to detect the location of the sound source, a larger surface area as well as many more microphones would be required. Using one or two microphones would allow for sending command/control signals using sounds waves, and could be used as an alternative to wireless communication via electromagnetic waves.

8.8 Electro Sensor

Some fish possess special organs for detecting electrical potential (voltage). A set of pits comprise the electro receptive system called the ampullae of Lorenzi. These are canals in the skin filled with a gelatin-like material that also contains sensory cells. Movements or disturbances near the fish change the voltage drop along the canals, which allows them to sense other organisms nearby. The fish's electro sensing system is oriented in the direction of displacement.

8.9 Master Control Unit

The control unit will receive inputs from the sensors via analog/digital converter, analyze the data that was received, and decide on what signals to give to the fish robot's motors.

For example, the light detected by the photo sensors will result in an input to the controller. If the photo sensor on the right side of the fish is detecting more light, then the control unit will output a signal that will indicate to the fish robot to turn to the right to follow the light source, and same goes for the left side. As stated above, if both sensors are detecting approximately the same amount of light (assuming that the fish robot is facing the light source), this would mean that that the light source is located straight ahead, and the fish would continue forward. The pressure sensor will indicate different voltage outputs at different depths. Since the fish robot will be moving along one horizontal plane and not changing its depth, the pressure sensor will be used to indicate to the master control unit how deep the robot is submerged underwater. Sudden oscillations in pressure may be used to indicate some sort of agitation of the water in the proximities of the fish robot.

Chapter 9: Actuators & Motors

9.1 Actuator Selection

a) Selection 1: Two antagonistic linear actuators. Its drawbacks include the need for a distinct drive for each actuator, the presence of large forces due to actuator reloads and antagonistic design, and fatigue problems (depending on actuator technology used).

b) Selection 2: An actuator and a spring in competition. The drawbacks here include the asymmetry in the system's dynamics, and the demand for an actuator displacement that is double the one in Design 1

c) Selection 3: An actuator that provides alternating displacements. The actuator's displacement is converted into tail motion by a simple transmission. The disadvantage here is the increase in power consumption due to alternating accelerations and decelerations of actuator inertia

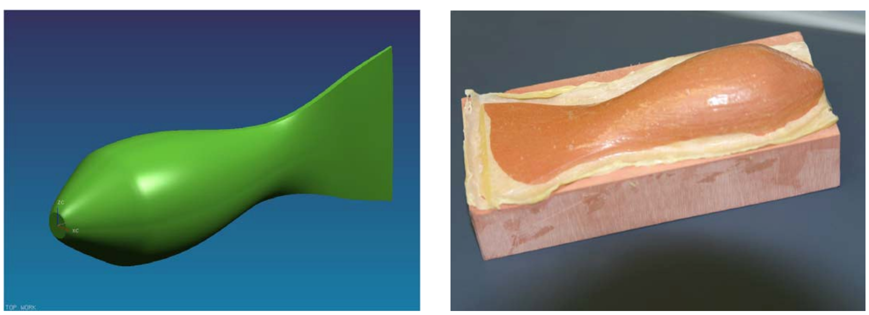
9.2 Fish Robot Motors

There are three motors contained within the fish robot modules. There is one flipper on each side of the robot (one on the left side and one on the right) and there is a tail fin. Each of these is controlled by a motor which receives as inputs control signals from the master control unit. Depending on the signal received, the motors may change their oscillation amplitude and frequency, or position themselves in order to follow the desired path.

Chapter 10: Structural Features

It is desirable for the swimming robot to have a real fish like appearance. In addition, a packaging scheme needs to be developed to protect all electronics onboard by water proofing, yet leaving easy access for battery replacement. Also the stream line design of the fish should not be violated.

The structural design can have three components, going inward from the outermost layer: a flexible, waterproof, fish-shaped outer layer as skin, a light inner filler to support the skin, and a structure to hold the controller/receiver board in place. Rubber latex is the most feasible material to adapt in robot fish skin because of its flexibility, chemical inertness and light weight. The rubber comes as a liquid stored in a plastic bottle, and it solidifies after painted on a surface and left to dry for about an hour. Multiple layers can be painted to obtain the desired thickness. A mold can be fabricated from a rapid tooling machine (CNC mill) for painting the rubber to make the skin follow a fish shape, as shown in Figure below, a polyurethane/epoxy board, is a desired mold material since it provides a nice rough surface for the latex rubber to grip to while in its liquid form.



(a) (b)

Figure 19. (a) The UniGraphics fish model for fabrication of the mold;
(b) **Rubber skin painted on the mold.**

The circuit board can be placed inside an insulation tube (typically used for copper pipes), and the open ends should be sealed using a silicone adhesive. An expanding foam, can be used as a filler material based on its ability to expand in an enclosed area and harden, creating a firm yet lightweight supporting structure.

Chapter 11: Final Assembly Structure

Structure of the PPF-09

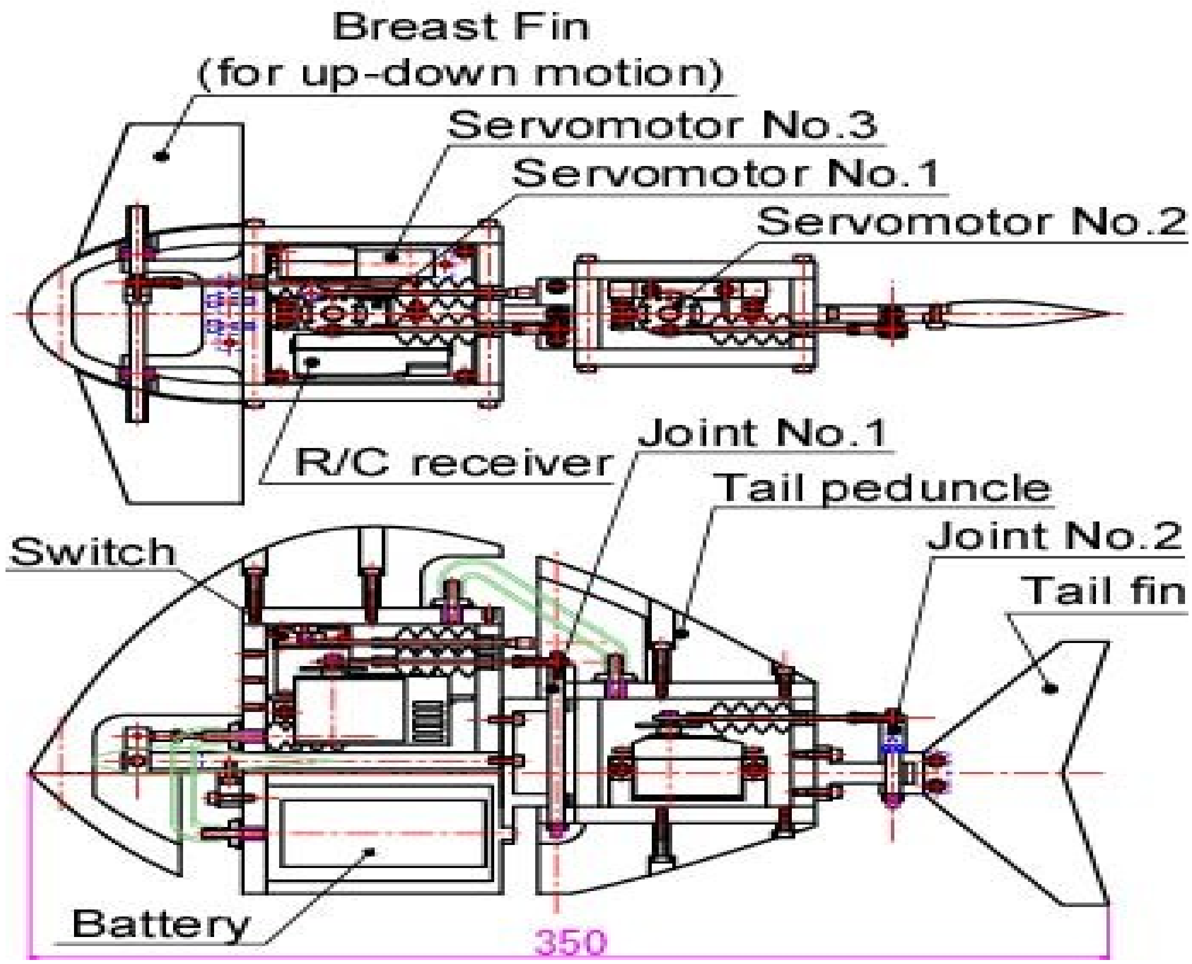


Figure 20: Basic Structure of a Robotic fish

The PPF-09 is a robotic fish developed by NMRI (National Maritime Research Institute) .The model fish robot; PPF-09 has two joints. It swims and turns with vibrations of a tail peduncle and tail fin. Also it can dive in the water with movement of the fins, which are located at the side of a head.

A servomotor (No. 1) for movement of a joint No.1, a servomotor (No. 3) for the up-down motion, a R/C (radio control) receiver and an electric switch are located in an acrylic fiber body case. Rods of the servomotors and the switch are waterproofed by rubber boots.

An aluminum battery case is hung below the body case. In order to change the battery easily, a few bolts are used for the fins installation, and an O-ring is used between the case and its lid.

A servomotor (No. 2) for movement of the joint No.2 is located in an acrylic fiber tail peduncle case. A wood tail fin is set to the joint No.2.

Several parts of a wood body are screwed to the body case and the tail peduncle case. In order to balance between buoyancy and gravitation, several weights are set to the below side of the body case and inside of the head.

Electric wires between the body case and the tail peduncle case, and the body case and the battery case, are covered up by rubber tubes. Thus, the PPF-09 has nearly perfect seal performance.

Chapter 12: Current Models of robotic fish across globe

1. **RoboTuna I (robot-tuna), David Barrett, and RoboTuna II, David Beal and Michael Sachinis, MIT, the U.S.A**

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.

Figure 21: Robo Tuna II, U.S.A

It is a question of including/understanding how a fish can generate energy enough to reach such speeds. RoboTuna evolves/moves in the aquarium of MIT, suspended by a mast, itself fixed at a system which slides along the tank (see the white mast on the photograph). The mast is also used for to pass the cables which connect the robot to the controllers. Thus, the controllers receive information from the sensors in entry and return instructions to robot-tuna. This one includes/understands 8 vertebrae and a system of cables which is used of tendons and muscles. The envelope is made up of a fine and flexible layer of foam covered with Lycra to approach the flexibility and smoothness the tuna skin. RoboTuna and RoboTuna II:

2. **Manta Ray, EvoLogics, Germany**

Manta Ray - EvoLogics

Figure 22: Manta Ray, Germany

Evologics is a spin-off of the Technical University Berlin with Festo partnership. Due to the use of "Festo Fluidic Muscles" actuators, wings shape can adapt gradually to water movements around the body. 3 propulsion modes are used. First use wings movement for quiet, fast and efficient moving with high maneuverability. Second use buoyancy variation with volume adjustment to sailplane up and down. Third use hydro jet propulsion for add-on speed requirements or stable trajectory needed by sensors. This technology will be useful for deep sea exploration, offshore industry, sensible ecological research, environmental monitoring and marine security.

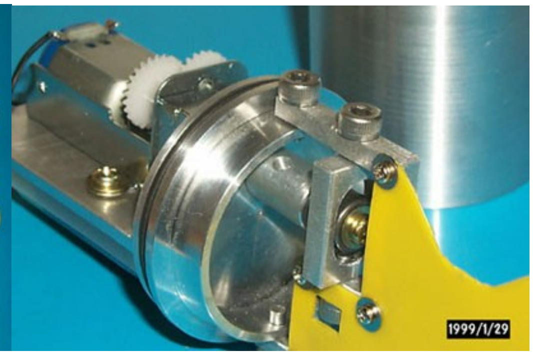
3. Tai-robot-kun, University of Kitakyushu, Japan

Tai-robot-kun, Univ. of Kitakyushu, Japan

Figure 23: Red Snapper, Japan

Engineers at the University of Kitakyushu have developed one of the most realistic biomimetic robot in the world. This red snapper is actually a robotic fish known as “Tai-robot-kun”. Tai-robot-kun weighs 7kg and mimics a real fish swimming silently in the water, and can go for as long as an hour with a full battery. It has a silicone body covered in realistically hand-painted scales, features a unique propulsion system that allows it to move its tail and drift silently through the water like a real fish.

4. Model Fish Robot, PPF-05



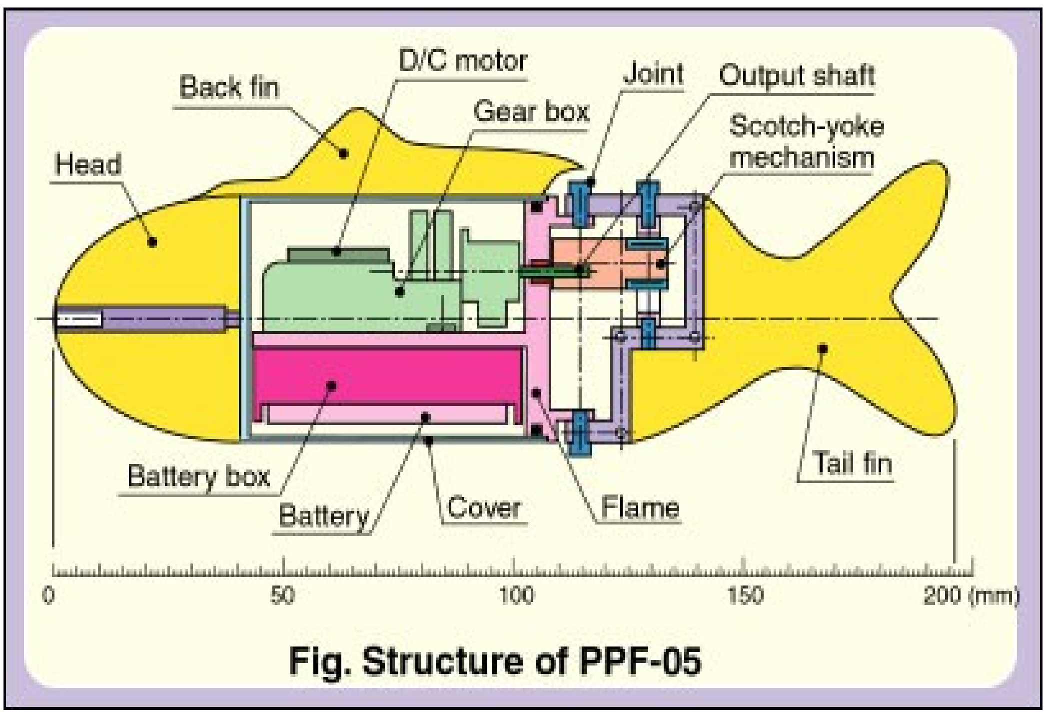


Figure 24: Structure of PPF-05

Length of the PPF-05 is 196 mm with a total weight of 245 g. A small D/C motor, a gear box and a battery box are located on an aluminum flame as shown in the structural figure above. The flame is covered and sealed by a O-ring. The output shaft of the gear box is sealed by a Teflon tube (ID: 2 mm) simply. The tail part and tail fin are made by one board of polypropylene (thickness: 0.75 mm).

Chapter 13: Application and Future Projects

13.1 Applications

Robotic fish could be potentially useful applications such as

1. Aquatic creature behavioral research : Investigating deep-sea fish behaviors
2. Mining Applications : Deep sea mining
3. Pollution Rate Study : Water pollution rate inspection
4. Industrial purpose : Underwater oil pipe leakage detection
5. Military Reconnaissance
6. Sea bed exploration : Abyss region
7. Deep sea Archeology

13.2 Future Projects

Future research will be focused on how to make robotic fish more robust and adaptive like a real fish.

1. Different types of fish swimming behaviors will be added gradually.
   Each fish has good performance application wise.
2. Robotic fish should be able to find a charging station as real fish look for food.
3. In order to get high quality work and high propulsive efficiency, there will be study on suitable sensors and the control technology.
4. Development of an efficient strategy for a team of robotic fish to cooperate for a common mission task.

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