Body Construction of Fish Robot in Order to Gain Optimal Thrust Speed

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Abstract

In fish robot, hydrodynamic shape of its body determines the ability of the robot to swim. However, sometimes the swimming gait depends not only on the body, but also on the frequency of tail undulation and body angle when it attempts to achieve fast swimming. Thrust speed becomes the main objective in this research. Some variables which are suspected as important variables influencing the thrust speed were observed such as body shape, fin, frequency of tail, and acceleration of tail. Results of investigation show that there are some significant dependency among thrust speed, frequency of tail undulation and body shape. In some conditions it was found that there was some optimal condition for all parameters which pace the fish robot towards fastest thrust speed.

1 Introduction

There are some researches in fish robot like mad by MIT 1994, Japan Marine robot [1], Essex University of England [3] and so on. The basic idea of their research is to design their robot like fish. It can swim or floating in the water. The entire robots have unique ability. MIT fish robot has fast speed in thrust motion, fish robot made by Hirata [1] has many types of shape, which are closely to natural fish, and it has the ability to swim around. Recently, the type of fish robot made by Jun do Liu in Essex University has the ability to navigate and travel in a pool [3]. Almost all of fish robots have the same aim, firstly to design robot that can swim in the water, and it has sensor to navigate. A fish robot is designed to have a great locomotion in the water using its tail spin and or pectoral spin. Robot made by EPA, called Boxybot [2], can swim and dive in the water using pectoral spin. Secondly, some of the fish robots have the ability to make social interaction to other robot, and stimulated by the environment such as light, color, obstacle or boundary. Many advanced idea was implemented in each type of robot. So the recent model is the result from developing step continuously. Issues about agility optimization in swimming forward or turn around have becoming the recent idea in some research. Agility can be achieved by analyzing the moving mechanism, body hydrodynamic shape, sequence coordination in all body to reduce the environmental resistance. To have a bigger speed in thrust swim there are some factors that must be observed. If the scope of observation just only to BCF mode (body and or caudal fin) then factors which should be observed, are the frequency of tail fin, amplitude of tail undulation, the angle body curve and the shape of body. The first two factors have been investigated by observed in Handoko *et al* [9 10 11]. However, the remaining factor that is the shape of body has not been investigated yet. Beside that, the basic factor such as stabilization of the fish, is also not considered in detail yet.

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2 Supporting Theory For The Fish Robot

2.1. Hydrodynamic Shape

To release from water friction the body of fish has usually fine-form like tuna. Sharp noise can break the water level resistance when the fish swims under water and also to deal with water pressure while diving. The coordination of moving mechanism, angle between body segment make fish can swing fast although it has to oppose the water stream. Although Boxybot [2] has no hydrodynamic shape it can have fast great speed by using its pectoral fin and tail fin working together to attain this fast speed.

Other than body shape, the thrust speed depends also on some parameters such as tail frequency, amplitude of frequency, angle of body. The remaining of parameters have been investigated in previous research. Some of issues which rise from previous research is that to gain optimum thrust speed the fish robot should combine undulation time with thrust time. Undulation time is the time while the tail keeps making oscillations and the thrust time is the time while after undulation time the tail keeps stop to let the body move forward without water to tail resistance. This thrust time hardly depends to water resistance on hydrodynamic body shape. The arrow shape can be easily released from this resistance however the cylindrical and cube shape have difficult way to deal with it. In fact, these are general theory of this investigation. At this investigation, the body shape and water resistance related to body shape will thoroughly be studied.

2.3. Locomotion of Fish

Fish swims mainly with fin and in general the swimming gait can be classified into two classes [5] : Body and/or Caudal Fin (BCF) and Median and/or Paired Fin (MPF). Fish in BCF class uses the body and tail (caudal) fin to accelerate and swim forward. The examples of this type are eel, tuna, and shark. Fish in this class moves its tail fin and/or the body simultaneously. However, in MPF class the fish only uses its pectoral fin to move or hover. Fin system of fish is shown in Figure 1.

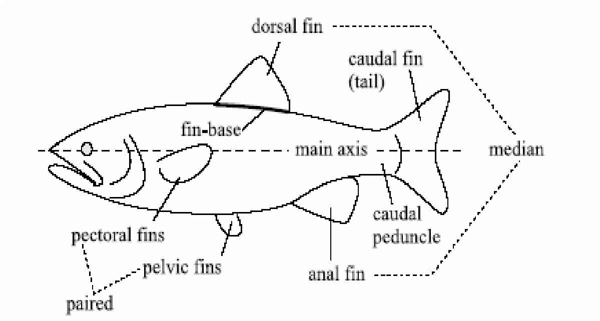


Figure 1: `Fin System of Fish [6]

In BCF, the tail fin undulates and make the momentum of water to push the body forward. The dexterity of fish is determined by the body angle and tail fin which moves simultaneously as it is done by shark and tuna.
Diving fish has some forces involved when it swims as it is shown in Figure 2

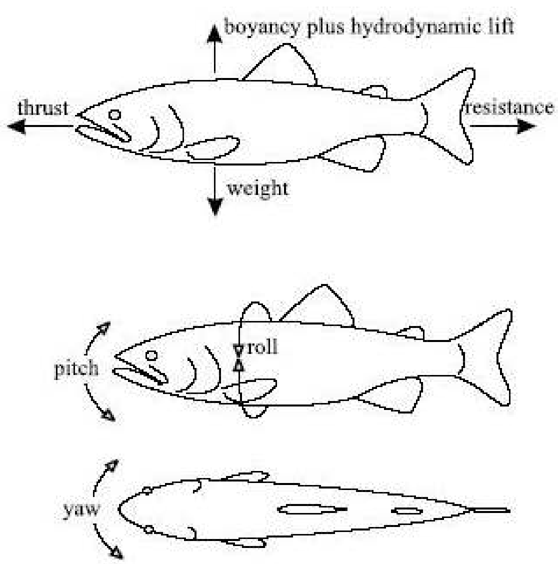


Figure 2: Force acting on fish body [6]

The force involved in diving and swimming are thrust, air resistance, buoyancy and hydrodynamic lift, weight [6]. The action of fish can be yaw, pitch, and rolling. The normal fish rarely uses rolling action when its body stabilized. The deeper it dives the more pressure it can get. When a fish floats or does not dive so deep, the significant forces are only resistance and drag force from water. Drag force is produced from water attached to its skin or from the water resonance at the back of the tail. However, in floating fish and fish-like swimming boat the problem to be dealt with is only the rolling as stabilized factors. The thrust speed become parameter to be maximized and it is influenced by dexterity behavior of fish itself

3 Designing the Body of Fish Robot Description

3.1. Designing the head and body

The body is made from plastic, the material is obtained from plastic bowl and kid toys bounded together with super glue. The three fish robot was named Roby [9], Acep [10] and Geri [11] respectively. The design of each robot can be shown in Figure 3. The Roby fish robot head is formed by mounting this plastic in its triangular for onto cylindrical plastic jar. This is very good shape like shark. Cylindrical plastic has 12 cm diameters. The Geri fish robot has a thin shape with oval form in the front side, the depth is 3 cm. The last designed, Acep fish robot, has a swimming-boat form.

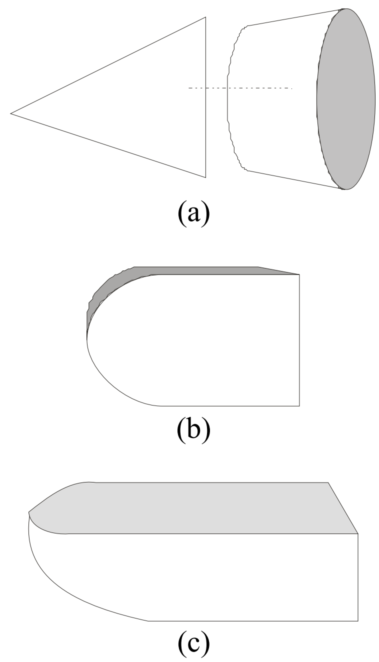


Figure 3: Head of Fish robot
(a) Roby (b) Geri (c) Acep

Principally, all shapes are designed to deal with water resistance by making water stream flowing without resistance. The face area strongly determines the hydrodynamic property. As a simple idea the path of stream will follow the edge of body, if there is no smooth edge then it will be tendentiously resistance area for the stream. Roby and Geri has made a fish robot with half sink body which is is about ¾ body under the water, however Acep's fish robot is almost a floating fish robot, it is like swimming boat. The water resistance being suffered by Acep's robot is more less than two other fish robots. Roby fish robot is the hardest suffering from water resistance, its head has perfectly resistance to water stream causing by large face area. However, by mounting triangle plastic, the body can cut through the water and enlighten the water resistance onto the body. The sketch of water resistance can be illustrated in Figure 4.

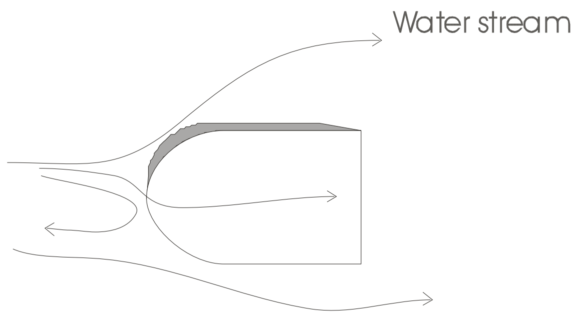


Figure 4: The sketch of water stream follows through the edge of body

3.2. Tail Fin Mechanism

To push the fish robot's body forward, the moving mechanism used in this design is divided into two types :

a. Joint driven motor
b. Yoke driven motor

In the first type, joint driven motor, the tail fin is attached to the body using joint, and by pull-push mechanism applies to tail fin, the moving mechanism being created. Servomotor as activator, roll over vise versa in some range of angle to produce undulation motion in tail fin. Sometimes it needs some huge energy when water streams against the tail fin direction. The motor and tail fin make some discontinues moment when servomotor makes changes to the direction of its rolling. In this moment the extra work, which can be optimized later, is generated. Nevertheless, the joint driven motor is effective for the fish robot when it makes turning motion. There is a lot of angle-turning variability can be achieved. However, this will not be easy to be done by the second type of the motor.

In the second type, it uses yoke mechanism to change the direction of tail fin undulation. DC motor runs continuously in one direction without changing direction and rest. A coin with unconcentric position is attached to the center of the motor. This makes a yoke device (see Figure 5) So the transfer energy between motor and tail fin mechanism is more effective than first time.

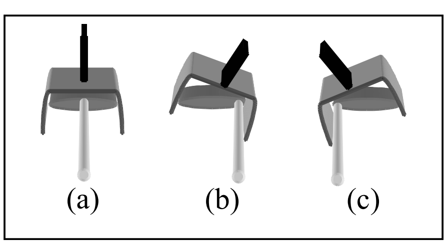


Figure 5: Yoke driven motor (a) zero orientation (b) right orientation (c) left orientation

However, there is some risks while using this mechanism. The yoke driven motor can have turning control. To turn in some specified angle does not happened in this type. Of course, the second type can make the fish robot turning however the turning mechanism is not done by intention. Nevertheless, the turning of fish robot in this time is caused merely by the final rest direction of tail fin. So when undulation of tail fin is stopped and the orientation of tail is not zero as shown in Figure 5 then the fish robot begins to turn according to its tail orientation.

The wake left behind the tail of undulatory BCF swimmers is a staggered array of trailing discrete vortices of alternating sign, generated as the tail fin moves back and forth. A jet flow with alternating direction between the vortices is also visible (see Fig. 6(c)). The structure of the wake is of a thrust-type, i.e. it has a reverse rotational direction compared to the well documented drag-producing Karman vortex street. The latter is typically observed in the wake of bluff (non streamlined) objects (see Fig. 6(a)) for a specific range of Reynolds numbers (roughly), but also in the wake of stationary (see Fig.6(b)) or low-frequency-heaving aerofoil (see [8])

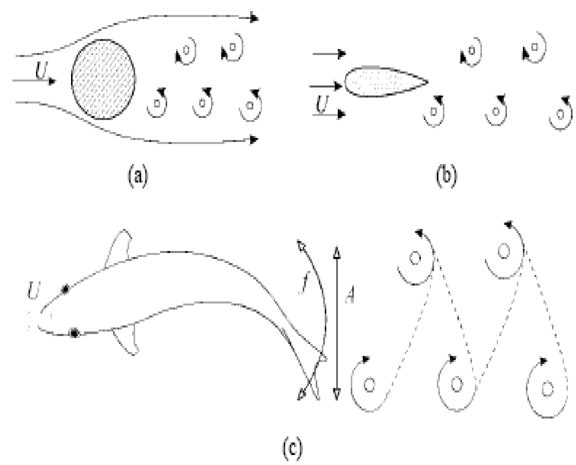
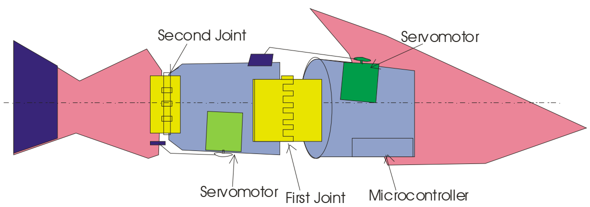


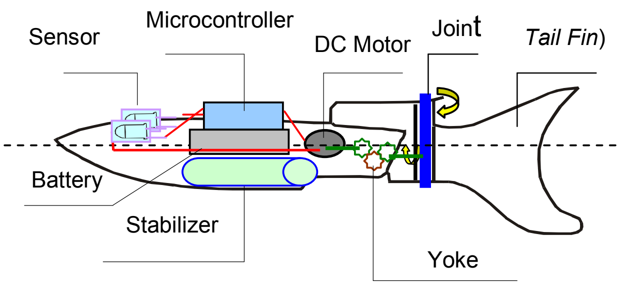
Figure 6: The Karman street generates a drag force for either (a) bluff or (b) streamlined bodies, placed in a free stream. (c) The wake of a swimming fish has reverse rotational direction, associated with thrust generation.

3.3. Overall Design

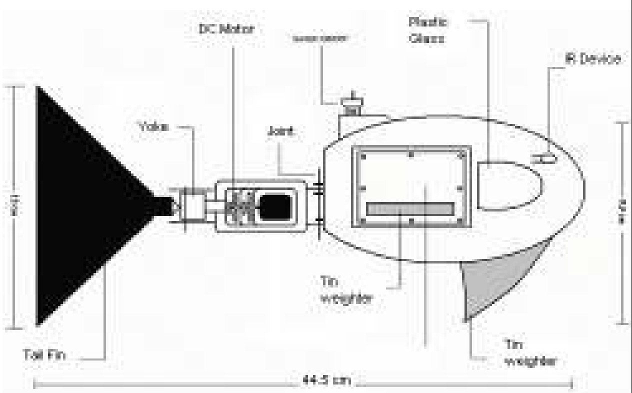
Other important parameter that should be concerned is the stability while moving forward and thrust. The construction of fish robot should maintain the body not or can recover as soon as possible when the body tries to yaw of rolling (see Figure 2). The balancing mechanism must be attached to the body or into the microcontroller. In this research, the mechanism of balancing is overcome by attaching the pectoral fin and additional tin weight. In Acep design (see Figure 7(b)) the stability is less concern. It just applies an empty water resistance tube at right and left side of the body to preserve the stability. However the Geri's fish robot is more dynamic than all designed fish robot. The stability must be thoroughly given. The rolling and yaw protection are preserved by adding tin weight. It earns a great effort to make the Geri's fish robot to stabilize, without wing (or pectoral fin). Extra load causing by tin weight influences the thrust speed, however the stabilize performance still can be attained. The Roby's fish robot uses a static wing, more to say a wing than pectoral fin, to maintain stability when trust and turning. The wing is made by plastic sheet attached with super glue to the body. Although the wing can keep the body stabilized however the slope of the wing can be considered as a valuable factor to increase the water resistance and lower the thrust speed and so the turning speed. So to deal with this design, the other joint is placed between head and tail. So it becomes two-joint fish robot. The angle of body can decrease the water resistance. The overall design of all type can be shown in Figure 7.



(a)



(b)



(c)

Figure 7: The final design of fish robot namely (a) Roby (b) Acep (c) Geri

The microcontroller is placed in the body. The three designs have a different algorithm to have hydrodynamic design by which against the water resistance and have good curvature body to allow water stream increasing the speed. The Roby's fish robot uses timing algorithm to switch between two different rolling orientations of motor which causes tail fin undulation. The delay time between changing the orientation becomes the optimum variable to be observed. The Acep's fish robot uses expert system to combine the three state of speeds : zero speed, fast speed, normal speed. Variation among the three states becomes the parameter to be observed. For the last design, the Geri's fish robot uses Fuzzy algorithm to find pause time between undulations. The pause time which means stopping the motor and let thrust swim occurred can be used to loose the water resistance caused by tail undulation and promote more fast thrust speed.

4 The Results and Evaluations

For all experiment, comparation has been done to examine the all design and observe for the best performance of body construction.

Table 1. Performance Comparison of all fish robot

Variable observed	Type of fish robot		
	Roby	Acep	Geri
Max. Thrust speed (cm/s)	22	23.	25
Tail undulation frequency	7.8	1.4	3
Turning	Controlled	Non controlled	Not controlled
Forward swim	Not always Range of tolerance 1 m	Not always Range of tolerance 0,75 m	Always Range of tolerance 20 cm
Mechanism to reduce tail resistance	Not added	Not added	Added
Part float	¾	4/5	1/6
Effect of Water level	Great	Great	Less
Ripple wave cause by tail	Great	Less	Less
Obstacle avoidance Mechanism	IR	IR	IR
Action to avoid obstacle	Turning	Stop	Stop or turning
Weight (kg)	1.2	0.8	1.7
Split the water mechanism	Great	No	best
Distributed of Mass	1/2 from head	Center of body	Focused on the 2/3 from head center of body
Speed	On off	Three state : zero, normal, fast	Variability cause by fuzzy logic controller
Agility	Good	Not good	Good
Tail shape	Stiff Triangle made by plastic	Stiff Triangle made by plastic	Flexible rubber triangle

Table 1. gives the qualitative and quantitative values from the results of observation. From the shape of hull, it can be concluded that because Geri's fish robot lets the water passes through without contact or resist by its body, it gives more thrust speed than other robots. Adding a plastic sheet to split the water on Roby's fish robot does not give enough result if it is not followed by joint angle control.

The algorithm for thrust has been modified in Geri's fish robot by optimizing the time of thrust using Fuzzy logic controller and it adds some benefits in increasing speed and obstacle avoidance mechanism. All designs used the same proximity sensor as obstacle avoidance.

The Geri's fish robot has the smallest range of tolerance which means this fish robot can maintain its swim to always straight forward without turning and out of track. The out of track action occurs in Roby's and Acep's fish robot is caused by the angle of joint between body and tail fin orientation respectively for each fish robot.

Although diving procedure is not discussed in this paper, but by showing the action of all fish robots, the pitch action is founded in Acep's fish robot. This action does not interfere the thrust speed but sometimes it can turn the orientation of the body and adds more variable to be controlled.

The flexibility can give extra force to push. Using rubber tail fin makes the thrust speed more flexible and more speed can be gained. The strong but not flexible tail fin just gives one swept force and the mass transfer from this swept just happened instantly. However with strong and flexible tail fin, the mass transfer of water becomes continue and the momentum in increasing which causes the push force increases.

5 Conclusions

Some observations have been done to the designed three types of fish robot. The hydrodynamic parameter like water resistance has been overcome with some different methods such as design of head, attached wing (or pectoral fin), increasing-thrust speed mechanism (pause time, different state of speed) and tail fin undulation generated method. The assumption that the water resistance is caused by shape and undulation tail can be proved and the hypothesis that the thrust speed can be increased by reducing the tail water resistance is achieved in Geri's fish robot. In addition, the pause time is the important variable to be observed intensively in further research. The tail shape and its flexibility give extra force to push force of fish robot. It can be observed further especially the shape which is not yet being considered in this investigation. Also, the water stream was considered in still condition or there was now significant wave. These could be contributing factors for stabilization and thrust speed of the fish robot.

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