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Development of Fish Robot with Prey Catching Behaviour Using Fuzzy Logic

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Abstract

In this paper, a designed and developed fish robot which has behaviors to catch prey will be presented. This behaviors were reflected by its capability in straight swimming gait and turning gait. Investigations were conducted to observe the behaviour of natural fish when following a prey. By doing this, the trajectory can be found and subsequently the specific behaviour can be derived which is reflected by the pattern of speed and undulation of tail. The pattern is then adopted to implement fuzzy logic algorithm which is realized in a microcontroller as artificial brain of the fish robot. The result shows that for some certain range, the fish robot could mimic natural fish when following a prey. The average speed and total time to catch a prey have been chosen as successful criteria.

Keywords: *fish robot, robotics, fuzzy logic, prey catching behaviour*

1. Introduction

In the area of robot technology, development of animal robots have been started since 1990. Several animal robots, such as spider robot, dog robot, cat and fish robot were developed by researchers. In this development, the ability to realize natural behavior into mechanical and electronic has become a passion of technology. Especially for fish robots, some preliminary investigations about the locomotion of fish robot have been done, e.g. by Hirata [1]. This dynamic motion of the fish has become one of interesting topics in the last few years. In reality, the fish robot employs its fin to move forward or turning.

Furthermore, on interesting behavior of a fish is the behavior to find its prey. In general, a prey is considered as a small fish or other sea animals which has the ability to escape when the fish intends to catch them. Handoko *et al* [2] studied the behavior of tail fish when pursuing a prey. The thrust speed as indicator to swim forward and C-turn speed as 180 degree turning speed indicate the agility to move a head of prey.

Based on fish swimming gait, a fish can be classified into two categories i.e. swimming with body and/or caudal fin (BCF), and Median body and/or Pectoral Fin (MPF). Because of the complexity of MPF, research on MPF swimming gait has seldom been conducted. Undulation and oscillator of pectoral fin are the most important and hardly to be made. In the BCF swimming gait, the fish uses its body and caudal fin to make fast straight motion and thrust with powerful force. In addition, the fish can also make turning action faster than the fish which uses only caudal (tail) fin. Naturally, in catching the prey, the fish uses its straight motion, where to escape from a predator then the fish uses the combination of its straight and turning motion. Fig. 1 shows the undulation of body and tail (caudal) fin of a fish [3].

In general, the are some natural behaviors according to appropriate agent which stimulates the behavior. For example the behavior of seeking food, mating, afraid. Almost all behaviors have special and same pattern for every species. The variety of behavior in the same species is very small. Sometime, a unique pattern can be used to determined the species at least to determine the gender for mating behavior.

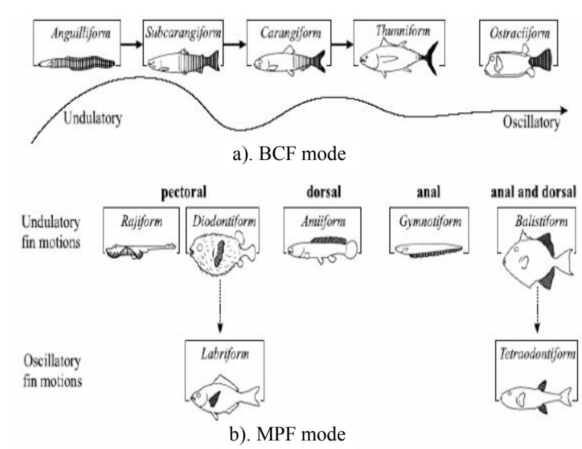

Fig. 1. Swimming gait type and moving mechanism of fish a). Body and/or caudal fin; b). Median body and /or pectoral fin

2. Fish Robot and its Behaviour

A. Body Design

Basically, a fish robot is designed by emulating the morphology of *Oreochromis niloticus*, which is locally called Nila fish *Oreochromis niloticus* normally swims in upper surface of water with no big current of wave come to its body. It usually has the form which is shown in Fig 2. A fish can make three motions, i.e. thrust (straight), yaw and turning. Rolling motion is not considered as normal motion although some fishes, i.e. dolphin, can do it easily. To move straight, a fish employs its tail fin and tail peduncle, and to turn a fish uses its body and tail fin. The undulation of its tail fin determines its speed. Other fin contributes in stabilizing the body and hovering.

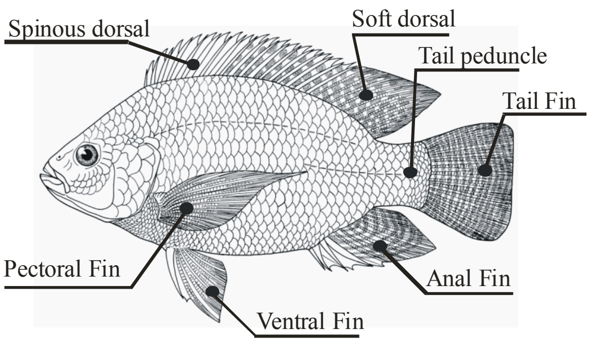

Fig. 2. Fin morphology of *Oreochromis niloticus* (*Drawing* by S. Laurie-Bourque)

In general, the fish body consists of three segments, namely head, body and tail. The body part of the designed fish robot was made from two plastic jars, door joint and thick plastic for the tail and head. Fig. 3 shows the basic design of the fish robot and its three segments

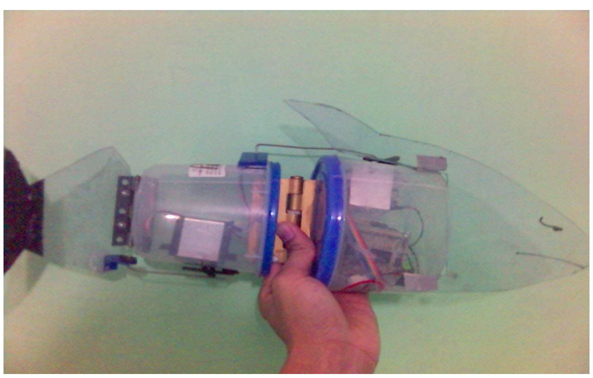

Fig. 3. Basic design of the fish robot

B. Control System and Moving Pattern

The standard servomotors are controlled by ATMEGA microcontroller. First servomotor is used to control the first joint (located between body and tail peduncle), whereas the second servomotor is used to control the second joint (located between tail peduncle and tail fin). Both servomotors produce motion pattern according to signal control from the microcontroller. The microcontroller contains some programs which are the procedures of swimming gait and moving pattern based on straight and turning performance mode (Fig. 4)

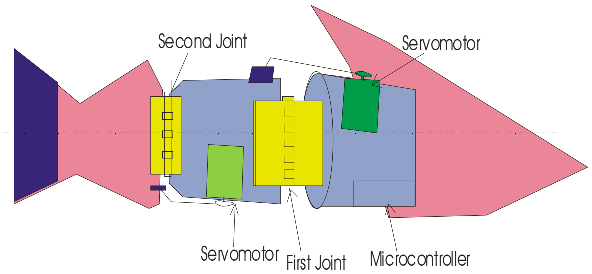

Fig 4. Schematic view of the fish robot

C. Design of Behavior Mode

Observations were referred to Nila fish (*Oreochromis niloticus)* which has habitat in some lakes in Indonesia. The behavior of the fish can be classified into three simple behaviors, namely finding the food, catching a prey, and escape. Quite often, these primary behaviors are called as basic animal instinct. To catch a prey and to escape, usually a fish accomplishes this action by fast thrust and fast turning. However, fast turning to catch prey is rarely done in some fishes. Only the big predator such as shark and whale performs that style. Some fishes lurk and when a prey passes in front of them, they caught it with fast action. The other catching style is by chasing the prey for a while and this action needs high acceleration. So, the prey catching behavior can be divided into two styles. Firstly, catching with high initial speed, and secondly catching with high acceleration. All styles use fast swimming which is supported by the body and tail. In this experiment, the supporting agent which contributes to the fast swimming is done by body and tail fin. The orientation of body and tail fin will determine the speed and direction of its swimming. From experiment and observation done by Hirata [1] and Handoko *et al* [2,4], it is shown that the speed of thrust and turning mostly done by its tail fin. The frequency of tail fin and the orientation of its tail can be chosen as important parameter. In all conducted experiments, three mode of tail fin were used.

Mode A

Fig 5.a shows the case of Mode A. The fish robot makes some undulation swing on its tail around the center line of the body. Mode A is dedicated to thrust mode for straight swimming and escape behavior. There are some range of high frequency of tail swing which can achieve fast thrust representing escape behavior. In this mode, the body make some little turning angle with different direction to the turning angle of the tail. The head of fish robot can be considered as similar to a rudder, whereas the body and the tail fin are similar to a screw propeller of the ship.

Mode B

Fig. 5.b shows the case of Mode B. Firstly, the fish robot attempts to perform the Mode A than followed by the angle of body turned for a small turning angle. The tail fin accelerates the turning mode by making undulation with one side orientation. One side orientation is the undulation

in half side on the left or right from center line of tail with angle tendency not in middle angle. The last swimming gait is done until the fish turns into 180 degrees. This mode simulates the catching action when the fish follows the prey and the prey escapes by turning action. The escape behavior is also simulated when the fish tries to get loss from predator coming from front direction.

Mode C
In this mode as shown in Fig. 5.c, first the tail makes Mode A for a while then the tail stops at some angle. The body makes some angle at the time of tail being stop. This mode simulates a condition when the fish has captured the prey and the fish lets its tail at some angle. By kinetic energy the fish could make a turning without moving its body or tail fin.

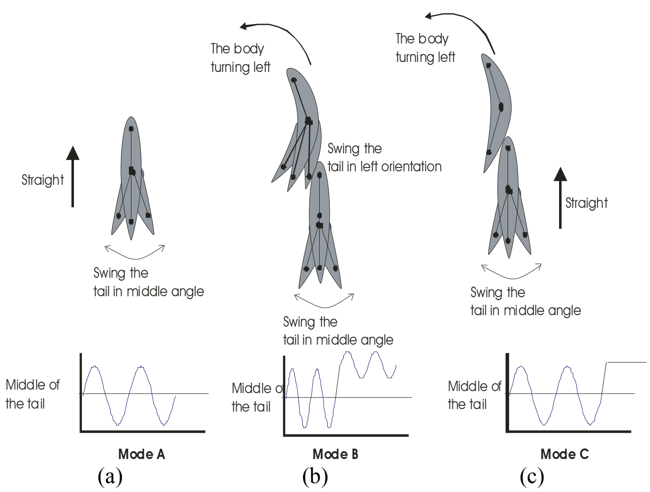

Fig. 5. The three behaviors of catching and escape mode

Based only on mode A, the prey catching behavior was established. For High Initial Speed (HIS) style, the tail fin is made to perform some series of mode A, firstly with high amplitude and followed by long delay as shown in Fig. 5.a. High Acceleration (HA) style is performed by a series of mode A with constant amplitude and separated with gradually decreasing time delay.

As mentioned above, the designed fish robot has one DC motor, one controller with two joint. The HIS style is easy to implement because normally the DC motor will gradually lose its energy when attached with hydrodynamic pressure. HA-style is established by implementing different time delay for every segment of mode A. This sequence can be realized by fuzzy logic. A proximity sensor attached to the fish body will be the single transducer used in this experiment. The orientation of tail fin is forced to remain in the center using rubber rope.

In the experiment, the prey was made by small wood-object controlled manually by hand and to be located at a desired location. This made-man prey was not designed to fully sink in the water.

3. Fuzzy Logic Algorithm as Behavior Imitator

In the microcontroller AT89C52 with 4 Kbyte Flash PEROM, the complexity of fuzzy logic algorithm should be reduced to adequate size with minimal error. Two parameters were chosen to be inserted into fuzzy logic system, namely distance and gradient of distance to time. The output of the system is the value of time delay which is calculated using Tsukamoto-defuzzification algorithm.

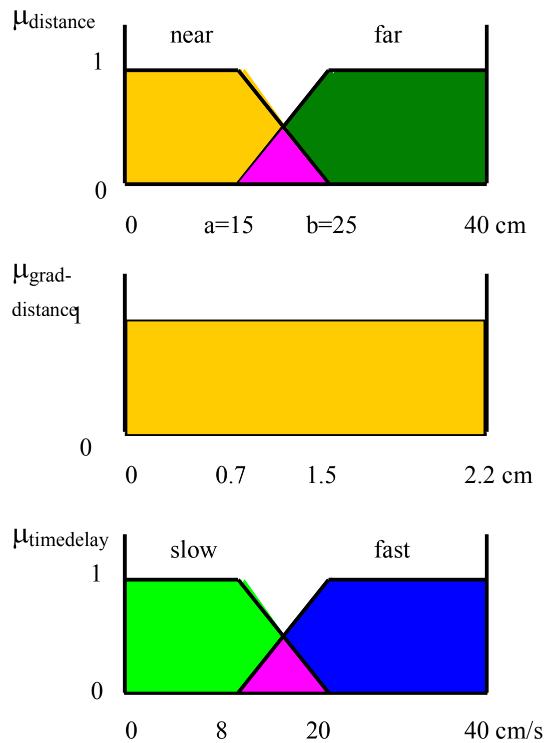

Fig. 6. Fuzzy Membership Function for distance, gradient of distance and time delay

Using Fuzzy Associative Memory :

	Distance: Near	Distance: Far
Gradient of Distance	Slow	fast

This could be represented as Fuzzy rule as follows:

[R1] *if distance is near and gradient-of-distance at range then time delay is slow*
[R2] *if distance is far and gradient-of-distance at range then time delay is fast*

4. Experimental Results

From every successful capture, which means that in every experiments, the fish robot could strike the made-man prey, the speed was calculated by dividing the total distance with the time needed. For simplicity reason, the Fuzzy Membership Function (FMF) of second input (gradient distance) was set equal to one. Therefore, the effort is done only on the first input, by maintaining the shape of FMF and vary the parameters a and b. Observations in several experiments revealed that it has produced some successful criteria, stroke (mean caught) of prey and good trajectory follower for some little-moving-distance prey. Although good trajectory follower was not directly measured however it could be represented by the time and successfully stroke. Table 1, 2 and 3 show the results of experiment for different styles with different distance of prey.

Table 1. Experiment for HIS-Style with fix distance of prey (15 cm)

Parameter of experiment		**Total time to catch (second)**	**Average speed (cm/s)**
a	**b**		
10	15	3.11	4.82
10	20	2.58	5.81
10	25	2.38	6.30
10	35	2.76	5.43
15	25	2.93	5.12

Table 2. Experiment for HA-Style with fix distance of prey (35 cm)

Parameter of experiment		**Total time to catch (second)**	**Average speed (cm/s)**
a	**b**		
10	15	12.11	2.89
10	20	14.58	2.40
10	25	15.38	2.28
10	35	12.76	2.74
15	25	12.93	2.71

Table 3. Experiment for HA-Style with variable distance of prey (35 cm)

Distance (cm)	**Total time to catch (second)**	**Average speed (cm/s)**
15	4.82	3.11
20	8.74	2.29
30	12.63	2.38
40	15.46	2.59

There was some possibilities of occurence of error in the experiments which affected also to the results. Sometimes, the error could be caused by nonlinearity measurement of the transducer. Therefore, initially some tests to observe the linearity characteristics of the sensor have been conducted. From the experiment, it was found that the characteristics of the transducer to distance were not actually linear (see Fig. 7), although it can still be used for a certain linear range. Another possibility of error is due to quantization process in Analog to Digital Converter.

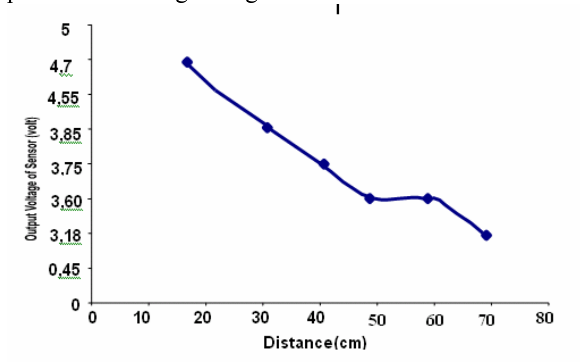

Fig. 7. Linearity characteristics of sensor

5. Conclusions

A prototype of a fish robot have been designed and developed in this investigation and its fundamental performances in prey catching behaviour have been observed and the results are presented in this paper. If it was assumed that a real fish will catch prey with minimal time, then based on the experimental investigation it was found that the fish robot would catch prey with minimal average speed to HIS style and HA style, which was equal 4.82 and 2.28 cm/s. respectively. The variation of time delay at HA-style could be reduced if the water resistant was reduced and it could make the fish robot to accelerate its motion to catch prey. Further research will be concentrated to compare the best possible profiles of the fish robot to natural fish trajectory. Also the trajectory to catch prey could be used to identify the prey

6. References

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