STUDY ON TURNING AND STRAIGHT MOTION OF A FISH ROBOT USING CATCHING PREY AND ESCAPE BEHAVIORS MODE

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Abstract- In robot technology, animal robot have been developed since 1990-an. Researcher has been made spider robot, dog robot, cat and fish robot. The ability to realize natural behavior into mechanical and electronic becomes a passion of technology. In this paper, a designed and developed a fish robot which has behavior to catch prey and escape from predator will be presented. This behavior was simulated in straight swimming gait and turning gait. Some tests to find the optimum parameter that show maximum thrust speed or turning speed was conducted. Parameters of observation were tail frequency and maximum undulation of tail. Three behavior modes relating to prey and predator were defined, where all modes represented the fish response naturally when there was a prey or predator surround. The results showed that there was optimum value to make maximum speed in each of modes.

Keywords- Fish Robot, Robotics, and Underwater Technology

I. INTRODUCTION

There are many research about locomotion of robot fish like was done by Hirata [1] in 1999. Dynamic motion of fish became the most interest topic for many years. Robot Fish actually used fin to propulsive or turning. In [1] the research uses only tail fin to swim and observe the turning performance.

Based on fish swimming gait, fish could be classified into two categories: swimming with body and/or caudal fin (BCF) and Median body and/or Pectoral Fin (MPF). Because the complexity of MPF, there was rarely research doing on MPF swimming gait. Undulation and oscillator of pectoral fin were the most important and hardly to be made. In the BCF swimming gait, fish used its body and caudal fin to make fast straight motion and thrust with powerful force. And also Fish can make turning action faster than fish which used only caudal (tail) fin. Naturally, in catching prey fish used straight motion and to escape from predator fish used straight combined with turning motion.

In this research, some modification of Hirata [1] idea has been developed like the locomotion mechanism not only by tail fin but also by body which used to in BCF swimming gait. The explanations of this paper systematically begin with body design, control system, behavior mode, experimental method, discussion and finally the conclusion of this research.

II. DESIGN OF FISH ROBOT

A. Body Design

Basically, fish robot was designed by mimic the morphology of *Oreochromis niloticus*, local called Nila fish

Oreochromis niloticus currently swimming in upper surface of water with no big current of wave come to its body. Its usually have form like shown in Fig 1. Fish can make three motion; thrust (straight), yaw and turning. Rolling motion was not considered as normal motion although some fish like dolphin can do it easily. To move straight fish used its tail fin and tail peduncle, and to turn fish uses its body and tail fin. The undulation of its tail fin determined its speed. Other fin contributed in stabilized the body and hovering.
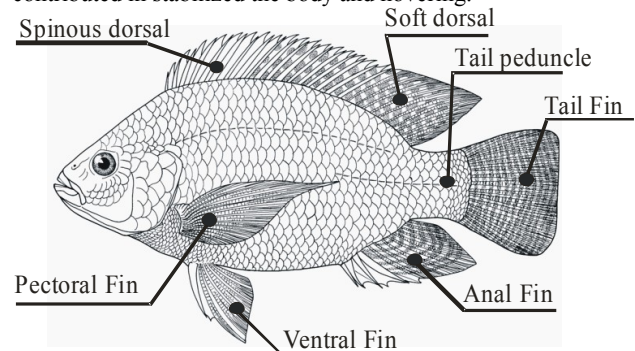

Fig. 1. Fin morphology of *Oreochromis niloticus*
(Drawing by S. Laurie-Bourque)

There were three segment of body fish: head, body and tail. The body of fish robot was made from two plastic jar, door joint and thick plastic for the tail and head.

Fig. 2. Photographic of fish robot

B. Control System and Moving Pattern

The standard servomotors are controlled by ATMEGA microcontroller. First servomotor was used to control the first joint (located between body and tail peduncle) the second servomotor was used to control the second joint (located between tail peduncle and tail fin). Both servomotors were

produced motion pattern according to signal control from microcontroller. Microcontroller contained some procedure of swimming gait and moving pattern programs based on straight and turning performance mode (Fig. 3)
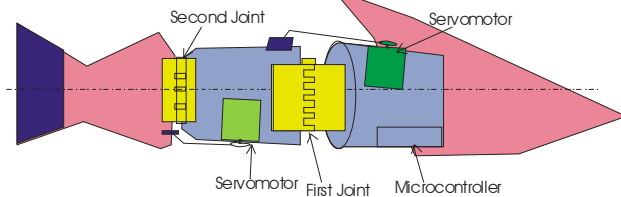

Fig 3. Schematic view of the fish robot

The robot was design to floating on upper surface, swimming by mean of tail fin and body. To make stabilize body from not rolling it was attached two static plastic fins as pectoral fin to maintain the balancing of the body. The head was design to make arrow shape to help increasing hydrodynamic speed at the water.

Table 1. Principle Particulars of fish robot

Body length	43 cm
Weight	1.2 Kg
Number of joints	2
Servomotor	Parallax standard servo
Number	2
Max. torque	4 N.m
Max. speed	120 deg/sec
Battery	9 Volt

It is necessary that the tail peduncle should be molded using very soft material to move the tail flexibly. In this experiment plastic rule can be shape into many form. Subsequently, it was then cutting into artificial tail-shaped.

C. Design of Behavior Mode

Observations were refer to Nila fish (*Oreochromis niloticus)* which has habitat in some lake at Indonesia, the behavior of fish could be classified into three simply behavior. There were a) finding food b) catching a prey and c) escape. These primary behaviors sometimes called as basic animal instinct. To solve catching and escape behavior, usually fish accomplished it by fast thrust and fast turning. Turning and thrust mode in BCF swimming gait are done by coordination of body orientation and swinging of the tail fin. Although the swinging tail is the most dominant agent in turning mode the body orientation also have big contribution in the speed of suddenly turning. In this paper we tried to find out these two behaviors by make some three mode of swimming pattern. These swimming patterns were developed from Hirata research [1].

Mode A

Fig 4. (a) Shows the case of Mode A. The fish robot made some undulation swing on its tail around the center line of body. Mode A was dedicated to thrust mode for straight swimming and escape behavior. There was some range of high frequency of tail swing which can achieve fast thrust that represented escape behavior. In this mode, the body made some little turning angle with different direction to the turning angle of the tail.

Head of fish robot are equivalent to a rudder; the body and the tail fin are equivalent to a screw propeller of the ship.

Mode B

Fig. 4 (b) shows the case of Mode B. Firstly the fish robot attempted doing the Mode A than followed by the angle of body turned for some little turning angle. The tail fin accelerated the turning mode by make undulation with one side orientation. One side orientation was 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 turning into 180 degrees. This mode simulated the catching action when fish pursue the prey and the prey escape by turning action. It is also simulated the escape behavior when fish try to loss from predator coming from in front direction.

Mode C

In this mode like shown in Fig. 4 (c), the tail make Mode A first for a while then the tail stop at some angle. The body makes some angle at the time of tail being stop. This mode simulated condition when fish has captured the prey and fish let its tail at some angle. By kinetic energy the fish could turning without move its body or tail fin.
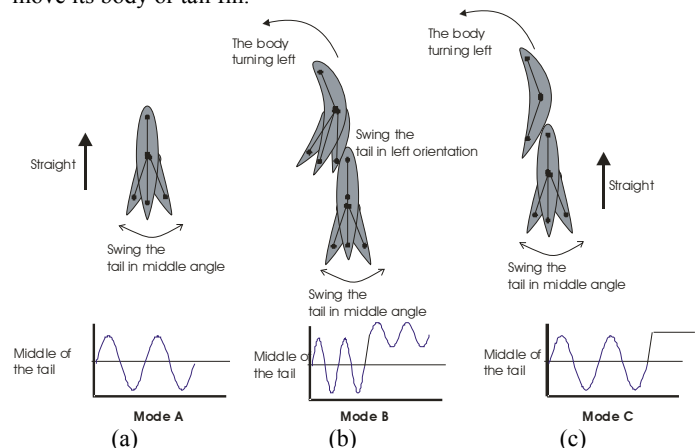

Fig. 4 The three behavior of catching and escape mode

III. PERFORMANCE OF THE PROTOTYPE FISH ROBOT

A. Parameter of Performance

For observation purposes, it was determined four observation parameters: the speed (thrust and turning), time segment between two gaits (mode B and C), tail frequency and maximum undulation amplitude of tail. Hirata [1] has proved there was connection among frequency of the tail, maximum undulation amplitude of tail and the speed. The undulation wave of tail can be modeled by this following equation

$$A = K_a sin(2\pi ft - \beta) \qquad (1)$$

With A = amplitude of tail
Ka = maximum amplitude of tail fin
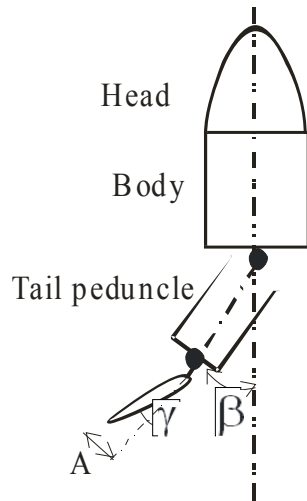f = tail frequency
β = angle between body and tail peduncle

Fig. 5 Body model of fish robot

B. Method to Measurement

Turning performance is measured at a small water balloon-tank, which is 0.9 m length, 1.6 m width and 0.4 m depth. A Digital Camera which has ability to record motion picture was located on upper side of the water tank and some angle of interest.

IV. EXPERIMENTAL RESEARCH

By digital camera, every motion of each mode were recorded, subsequently four observation parameters were analyzed and measured.

The speed of thrust obtained by divided the mark area with time and the speed of turning obtained by divided the point aim when turning with time.

MODE A

Experimentally, in this mode fish robot could travel 60 mm from the center of tank to the marked point for certain time according to its tail frequency. The experimental photographic could be shown in Fig. 6. The table 2 shown the experimental data of thrust speed (V_{thrust}) according to some tail frequency (f) and maximum undulation amplitude of tail (Ka)

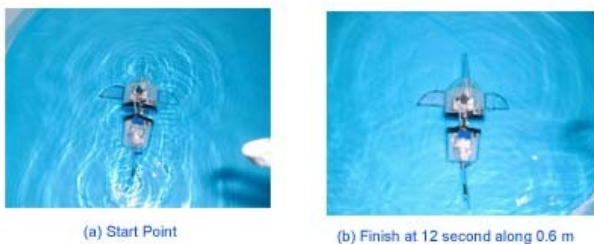(a) Start Point   (b) Finish at 12 second along 0.6 m

Figure 6. Experimental of mode A with low frequency

It was shown at Table 2 that there was optimum condition of tail frequency which can provide maximum thrust speed. Almost for all maximum undulation amplitude the optimum condition for thrust speed was achieved at 7.8 Hz of tail frequency. Except at the Ka = 2 the optimum condition was occurred at 5.2 Hz.

Table 2. The relation among tail frequency (f) , maximum undulation amplitude of tail (Ka) and thrust speed (V_{thrust})

f (Hz)	Thrust Speed (cm/s)			
	Ka = 2	Ka = 4	Ka = 6	Ka = 8
1.7	2.85	3	2.2	2.5
2	4	3.14	2.36	2.55
2.2	4.2	3.28	3.28	4
2.6	6.67	4.2	4	4.17
3.1	7	5	6.67	4.44
3.9	7.3	6.67	10	5.6
5.2	8.4	7	10,5	12.5
7.8	6.67	21	22	12.5
15.6	5	10	10	20
31.3	2	5	5	7

After the optimum point the speed tendentiously become more less. The more Ka it mean the more power to supply motor. For efficiently reason, it can be concluded Ka = 4 and Ka = 6 are the best condition which provide optimum speed and powerless for escape behavior of fish robot.

The curvature of thrust speed was shown at Fig. 7. There was one maximum condition for every condition. And the tendentiously of curvature were nearly same shape
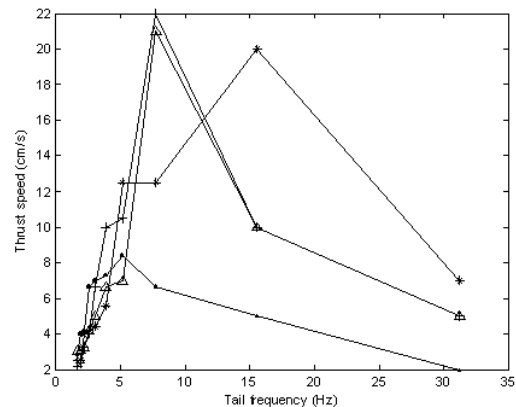

Fig. 7 Curvature of thrust speed to tail frequency with different Ka

MODE B

As written before, this mode simulated turning action to pursue prey or loss form predator. So to have some optimum condition, comparing was done on any condition of turning that relating to tail frequency, like turning diameter and time turning. Fig. 8 show the photographic condition of mode B

Fig. 8 Experimental of mode B
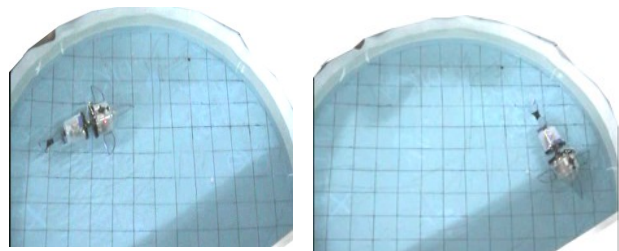
If concerning only about how fast fish robot turn 180 degree and ignored the accuracy position (turning diameter) of fish robot after turning action. Calculation of turning speed related to tail frequency, can be derived and shown at Table 3

Table 3. Turning speed at Mode B

f (Hz)	Turning speed (cm/s)			
	Ka = 2	Ka = 4	Ka = 6	Ka = 8
1.7	2.53	1.69	1.85	0.49
2	3.33	1.83	1.54	0.87
2.2	2.22	1.82	1.62	1.54
2.6	2.03	1.82	2.33	2.00
3.1	2.01	3.90	2.14	1.76
3.9	1.96	3.96	3.32	3.05
5.2	0.26	2.21	3.89	4.06
7.8	0.24	1.83	2.83	5.19

The most turning speed occurred at Ka = 8 and 7.8 Hz of tail frequency. As mention about to have efficient power the optimum condition are taken from low maximum amplitude and low tail frequency. So this value could no be an optimum value so it was chosen that the optimum turning speed of Mode B obtained at Ka=4 with tail frequency 3.9. And conclusion can be made from this result that maximum turning speed of fish robot 3.96 cm/s.

MODE C

In mode C, firstly thrust speeds were setting in maximum level, 22 cm/s. Applied for about 1 second. And every ability to made 180 degree turning (C-curve motion) was recorded

Table 4. Time to turn 180 degree relating to peduncle angle and tail angle

Peduncle angle (β)	Tail-fin angle (γ)	Time (second)
-10	-20	0.5
8	12	1
-15	0	1.5
-20	0	2
-20	0	2.5
-18	0	3

From table 4, when orientation of peduncle angle were the same as tail angle it promote less time to turn even there was not any power to motor. When angle between tail peduncle and body = 10 degree and tail-fin angle = 20 degree, time to make C-curve only about 0.5 second.

IV. DISCUSSION

There were some parameters that contributed in slower the fish robot when traveling on the water; the drag force from water itself, asynchronous of angle change between tail peduncle and tail fin and the hydrodynamic shape of robot itself.

The higher speed of robot the Drag force from water became higher. This drag force from water could be eliminate by made some combination swimming between swimming with tail fin and swimming without tail fin (gladding thrust) only used kinetic energy from thrust. Mode C combined this profile speed, after accelerating its speed fish robot turned only with force from kinetic energy of itself without moving its tail fin.

The asynchronous of angle change between tail peduncle and tail fin could promote internal force resistance in each of joint. This internal force resistance occurred on straight and turning, but the effect less at turning. When direction change still steady, the speed not affected by this force as shown in Table 4. The maximum value obtained when the peduncle tail angle and tail fin angle were in the same orientation.

To make turning action, fish need some minimal of thrust speed to push itself before making turning action. Turning speed can be accelerated by making tail undulation during turning like was done in mode B.

Other thing could be discussed that the rolling motion could eliminate by pectoral fin, which conducted as balance tool. The tail should be flexible enough to support the speed of swim and making undulation pattern. Also it was necessary to develop a high quality control system for motion of the servomotors and making profile speed more tide.

VI. CONCLUSION

In this study, the prototype fish robot was developed, and its fundamental performance was clarified. Some conclusions are

(1) The maximum speed to catch predator ant escape from prey by mean of thrust action was done with optimum condition at 22 cm/s where Ka = 6 cm. In this point, power supply has to give more power to make the tail moving. (Mode A)

(2) The maximum turning speed are obtained to turn escape form predator was 3.96 cm/s (Mode B)

(3) In Mode C, The scenario was after fish robot caught prey, its can made 180 turning degree in 0.5 second. And it was done when tail peduncle angle and tail-fin angle were the same orientation.

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