Modeling of fish predatory behavior using autonomous underwater vehicle

−Modeling of fish predatory behavior for two-dimensional moving target−

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Abstract—In this paper, we try to elucidate a model of the predatory behavior of the Beryx splendens. We constructed a system to judge the opening and closing of a grasping mechanism and a visual tracking system to achieve automatic capture to model predatory behavior. We constructed a laboratory environment in which three types of planar motions can be performed in the water by an autonomous predation robot. By doing this, we can evaluate the autonomous predation system and contribute to the predation of a three-dimensional swimming target, which will be required to model the predatory behavior in the future.

Index Terms— underwater vehicle, predatory behavior, visual tracking, autonomous capturing, modeling.

I. INTRODUCTION

Creatures acquired species-specific functions and ecosystems during evolution. The acquisition of motor and sensory functions adapted to the habitat specifically plays an extremely important role in the habitation, survival, maintenance, and preservation of the species and may also be a factor in clarifying biodiversity.

We focus on understanding the functions of marine biodiversity and the ecosystem. When clarifying the behavior of creatures, we generally observe the movement of the object.[1,2] However, since predation behavior is a high-speed motion performed underwater or in the sea, it is extremely difficult to elucidate the motion control system by observation. In this research, we try to elucidate a model of the predatory behavior of Beryx splendens. It is speculated that the direction fish move changes from time to time in accordance with the movement of the target when Beryx splendens behaves in a predatory manner.[3] We constructed a system for judging the opening and closing of a grasping mechanism and visually tracking to automatically capture the predatory behavior modeled.[4] In this paper, we constructed a laboratory environment in which several types of planar motion can be performed in the water by an autonomous predation robot. By doing this, we can evaluate the autonomous predation system and contribute to the predation of three-dimensional swimming target, which will be required to model the predatory behavior in the future.

II. REQUIRED FUNCTIONS

At first, we summarized the flow of predatory behavior: (i) freely swim; (ii) estimate the target by sight, sound, and smell; (iii) point the body's axis at the target; (iv) be convinced that it is a target; (v) rush while predicting; and (vi) close the mouth. From this series, the required functions for modeling predation behavior are as follows:

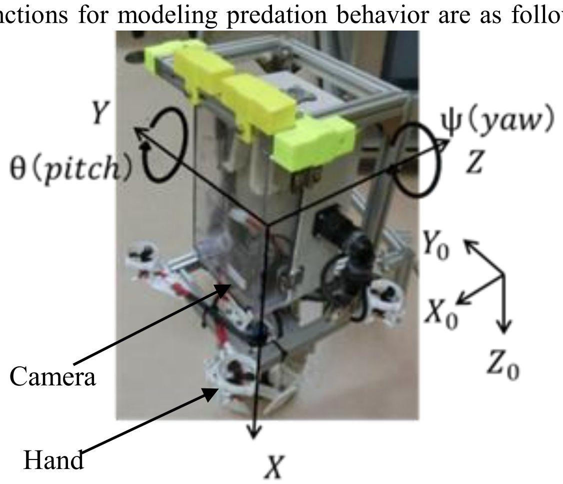

Fig. 1 The Predator's appearance.

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(i) track the target using a visual servo with a camera and propulsion mechanism with degrees of freedom of surge, pitch, and yaw; (ii) predict the movement of the target; (iii) rush to the target; (iv) determine whether the target has entered the robot's hand, and reproduce predation by closing the hand.

In order to accomplish i, iii, and iv of the above, the control system of the Predator was designed to be composed of a color camera, microcomputers for generating an actuator driving pulse, and the propeller propulsion mechanism, which has degrees of freedom of surge, pitch, and yaw and has a hand in the surge direction. Its appearance is shown in Fig. 1. We evaluated the tracking performance without function ii. The evaluation would contribute to a comparison with a later performance when function ii is implemented.

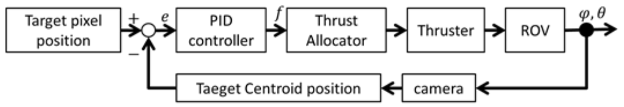


Fig. 2 The flow of the visual tracking system.

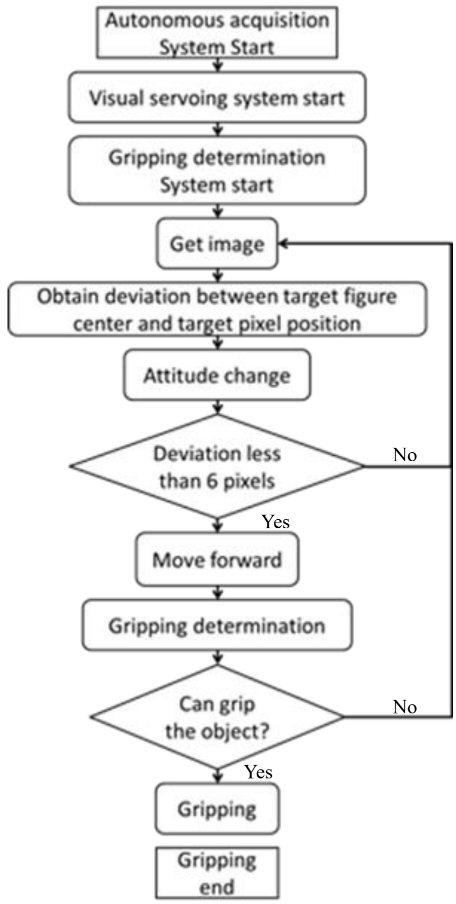


Fig. 3 The flow of the autonomous capturing system.

III. AUTONOMOUS CAPTURING SYSTEM

Regarding the approach to accomplish the predation of the target, the Predator recognizes the target and points the Predator's x-axis toward the target before generating thrust in the x-axis direction to move forward. Finally, the target will be captured by the hand when the Predator judges that the target has entered the hand. In order to point the x-axis of the Predator toward the target, we used a visual tracking system based on the camera image. The block diagram of this system is shown in Fig. 2. The system is executed as follows: (i) the target pixel position is given; (ii) the deviation from the centroid position of the target obtained from the camera is calculated; (iii) the deviation for posture change is input to the PID controller; (iv) the thrust corresponding to the output is distributed to each thruster; (v) the posture of the Predator is changed and the camera is pointed toward the target. Next, if the deviation is less than the threshold, set to be 6 pixels, the robot moves forward, judges the fitting of the hand, and captures the target. The operation is shown in Fig. 3.

IV. AUTONOMOUS CAPTURING EXPERIMENT

A. Experimental environment

We executed an autonomous capturing operation on the moving target under water using the system described in Chapter 3. An overview of the experimental environment is shown in Fig. 4. We put the *Predator* and the target (red ball) in a tank whose size was 1600×1200×1200 [mm] and connected the actuator prepared outside the tank to an aluminum frame with the red ball. We used two linear sliders (MY2C25G-700L) as the red ball's planar movement mechanism of the X, Y direction. We will

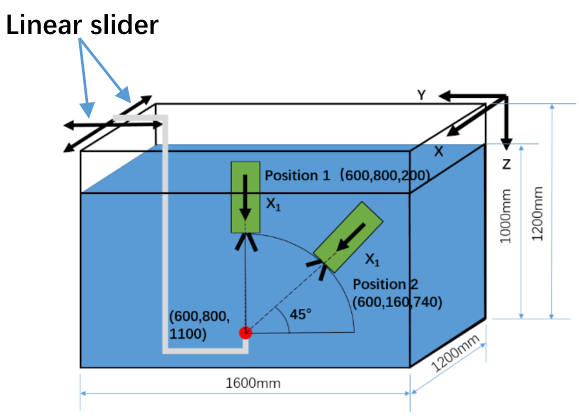
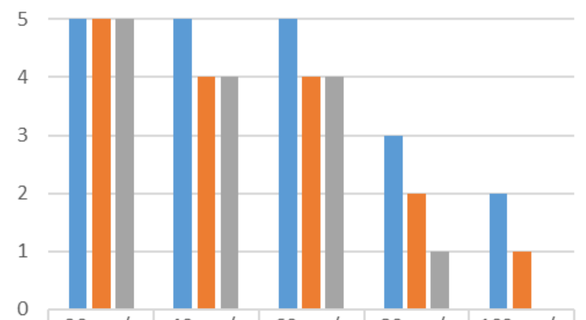


Fig. 4 An overview of the experimental environment.

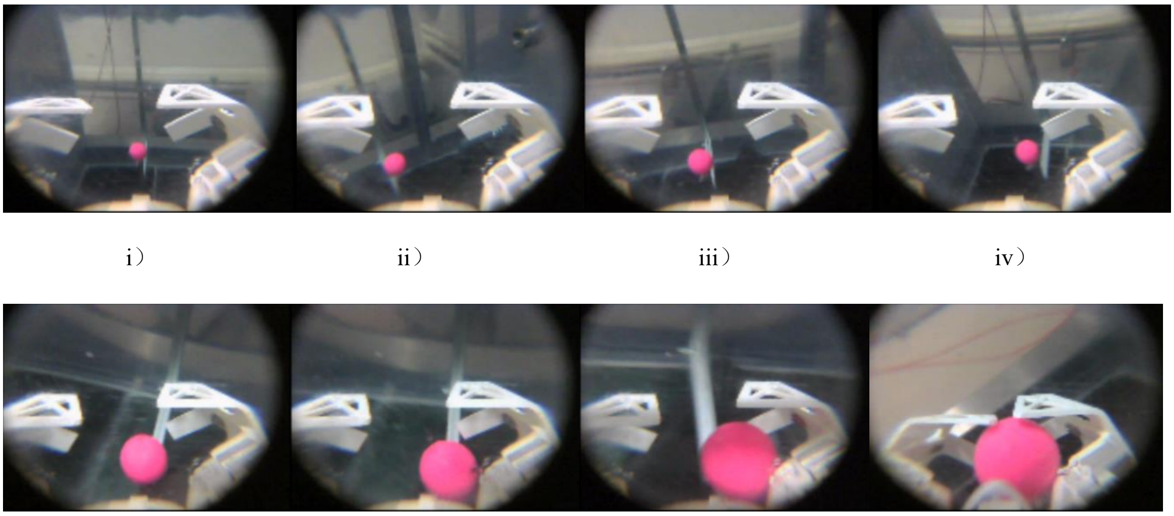
describe the locus later. The diameter of the red ball was 80 mm, and the water depth was set at 900 mm. In the previous experiments, we found cases where the robot lost the object when it turned back in a linear reciprocating motion when the robot approached it. In order to figure out the features of the predatory behavior based on a visual tracking system when the target changed direction in a planar motion, we prepared several conditions with different changes in direction by the target, including a linear reciprocating motion, a circular motion, and a rectangular motion. In addition, in order to make the predatory behavior more realistic and contribute to the predation of a three-dimensional swimming target, we want the target to move closer and farther away in the X_1 direction of the predator as an escaping motion, rather than only keeping predators close to the target during the predatory behavior. In the coordinates of the tank shown in Fig.4, we set the center position of the planar motion of the target to be (600,800,1100) [mm]; we made the circular motion and rectangular motion run in the X,Y plane and the linear reciprocating motion run in the X direction. At this time, we have two strategies for the position of the *Predator's* starting motion. Position 1 is set to be (600,800,200) [mm], water surface and slightly sink, and point the X_1 of predator directly to the center of planar motion of target. Position 2 is set to be (600,160,740) [mm], while pointing the X_1 of the *Predator* directly toward the center of the target's planar motion of 45 degrees with respect to the X,Y plane. By doing this, while observing the predatory behavior when the target changes directions in a planar motion, we can observe



	20mm/s	40mm/s	60mm/s	80mm/s	100mm/s
Circular motion	5	5	5	3	2
Rectangular motion	5	4	4	2	1
Linear reciprocating motion	5	4	4	1	0

Circular motion Rectangular motion Linear reciprocating motion

Fig. 5 The number of successful captures in position 1.



i） ii） iii） iv）

v） vi） vii） viii）

Fig. 6 An image of the successful capture of reciprocating target motions.

the features of both 2-directional and 3-directional changes (increasing the X_1 axis) with respect to the robot's coordinate system.

The diameter of the circular motion is set to be 500 mm while making a rectangular motion and a linear reciprocating motion at the same time in the cycle as the circular motion at the same speed. Autonomous capturing trials were repeatedly executed 5 separate times for each starting condition—positions 1 and 2 of the robot—while the value of the target's speed was 20, 40, 60, 80, or 100 mm/s and whose corresponding cycle time was, respectively, 78, 39, 26, 20, or 16 s. We checked the operating state under each condition.

B. Experimental results and discussion

Experimental results of the *Predator* starting in position 1 are shown in Fig. 5. In each trajectory where the *Predator* started at position 1, we can see that autonomous capturing remains efficient at speeds no higher than the target's speed of 60 mm/s. The speed limits for circular motions, rectangular motions, and linear reciprocating motions are, respectively, 100 mm/s, 80 mm/s, and 60 mm/s.

The camera image obtained during the experiment regarding the successful capturing of the reciprocating target is shown in Fig. 6. The autonomous operation was executed as follows: (i) The *Predator* changed its posture slightly to point the camera at the target. At this time the target was away. (ii) The target performed a turning motion, and the tracking was delayed. (iii) The target converged again with the target's pixel position. (iv) The Predator advanced when the target converged on the target's pixel position. (v) The *Predator* approached the target. (vi) The *Predator* approached the target while coping with a sudden change in the target's direction of movement. (vii) The target was within the hand, and the *Predator* must

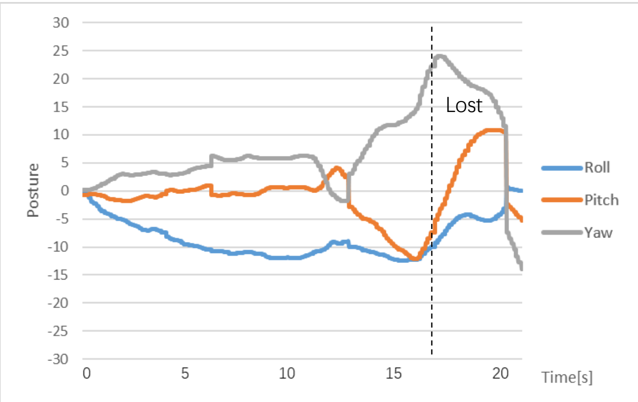


Fig. 7 The posture of the Predator while capturing the target with a circular motion.

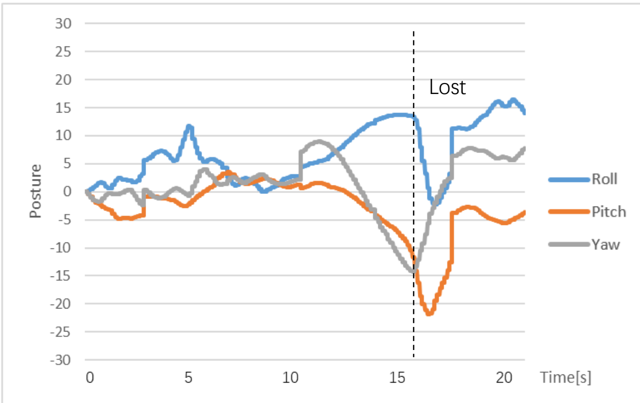


Fig. 8 The posture of the Predator while capturing the target while moving in a rectangular motion.

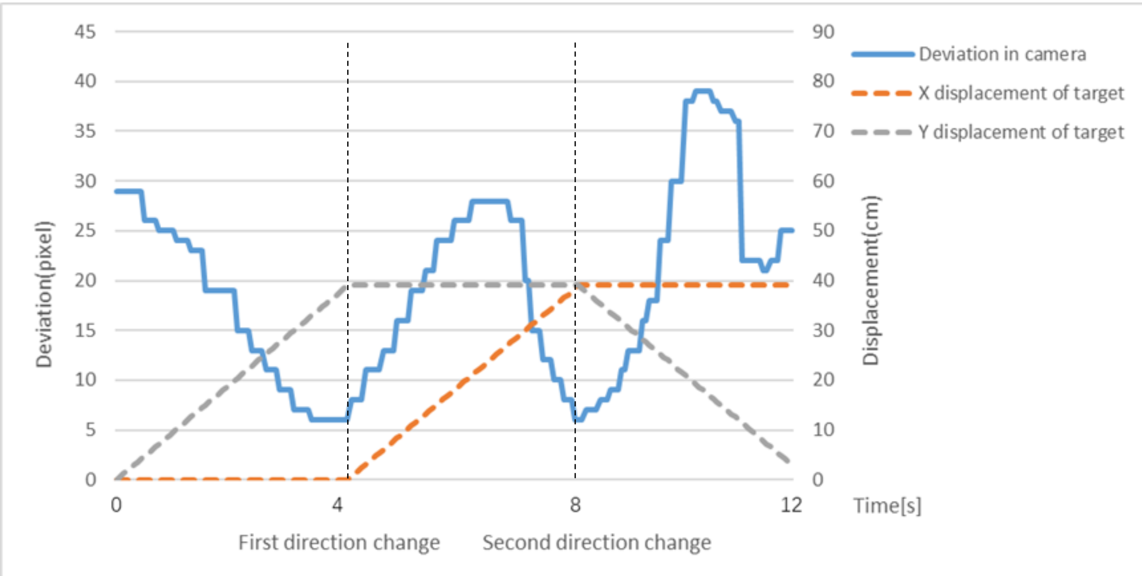


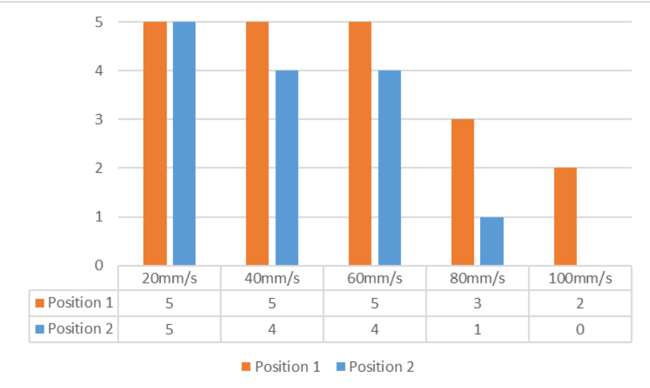
Fig. 9 The displacement and deviation of the target in camera while capturing the target while moving in a rectangular motion.

determine whether to open or close the hand. (viii) The *Predator* grasped the target.

In the same condition with the robot starting in position 1, we can apparently see that it is easier to capture a target moving in a circular motion than it is one moving in a rectangular motion, while it is also easier than capturing a target moving in a linear reciprocating motion. The posture of the *Predator's* surge, pitch, and yaw during the 100 mm/s of the circular motion and the rectangular motion during failed capturing are shown in Figs. 7 and 8. In each condition, before losing the target, the amount of posture change of pitch and yaw increased as the distance from the target decreased. This is because the *Predator* must keep the object within the line of sight to track the target; however, small movements by the target can create a large output thrust as the distance decreases. Respectively, the posture change of the pitch and yaw during a rectangular motion is more drastic than one during a circular motion, especially when the target changes direction. When performing a circular motion, the target slowly changes direction; in contrast, the target performing a rectangular motion suddenly and drastically changes its direction during the movement. We can speculate that the contrast of features shown is related to the intensity of the change in direction. In Fig. 9, we specifically show the displacement of the target and the deviation of the target in the camera while capturing the target moving in a rectangular motion. We can see that before the target first changes direction, the robot adjusted its posture to keep the target close to the center of camera, thus, decreasing the target's deviation in the camera. When the target suddenly changed direction the first time, the target's deviation in the camera increased drastically, and the robot managed to adjust itself. However, when the target suddenly changed direction the second time, the target's deviation in camera increased much more drastically than the first time, and the robot failed to adjust itself, thus losing the target. We found that the *Predator* always lost the target at the stage of changing direction leading to the drastic change of posture; as the target changed directions one after another, it became more and more difficult for the *Predator* to adjust its posture to track the target.

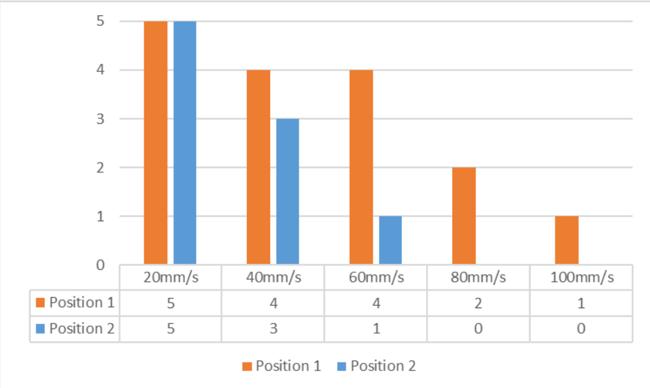
As we said earlier, during the behavior of the target's changing direction in a planar motion, we can observe the features in 2-directional changes with respect to the robot's coordinate system when the robot starts at position 1 and observe the features in 3-directional changes (increasing the X_1 axis) with respect to the coordinate system of the robot when the robot starts at position 2. Experimental results of capturing a target moving in a circular motion while starting at positions 1 and 2 are shown in Fig. 10, and experimental results of capturing the target moving in a rectangular motion starting at positions 1 and 2 are shown in Fig. 11. It is apparent that, in capturing both the circular moving target and the rectangular moving target, it is much easier to capture the target starting at position 1 than starting at position 2. We find that changing direction in the X_1 axis with respect to the coordinates of the *Predator*, the axis that is perpendicular to the camera plane has a big influence on the behavior of predators.

In real-life behavior of predators, *Beryx splendens* always approaches the target while predicting its movement.[3] However, in this paper, The *Predator* is not equipped with a predicting function. We will try to



	20mm/s	40mm/s	60mm/s	80mm/s	100mm/s
Position 1	5	5	5	3	2
Position 2	5	4	4	1	0

Fig. 10 The number of successful captures while the target moved in a circular motion in positions 1 and 2.



	20mm/s	40mm/s	60mm/s	80mm/s	100mm/s
Position 1	5	4	4	2	1
Position 2	5	3	1	0	0

Fig. 11 The number of successful captures of the target moving with a rectangular motion in positions 1 and 2.

construct a system with a predicting function by which the robot can first observe and learn the motion of a target before approaching it and then predict the motion of the target and rush to capture it. In constructing a predicting system, we are reminded to focus on the fact that the output thrust for rushing must be adjustable to the distance between the target and the robot and the intensity of the target's changing direction. In the future, the specific influence of the change of direction in the axis, which is perpendicular to the camera plane during predatory behavior, needs to be figured out. Finally, we will attempt to capture three-dimensional swimming targets and analyze their behavior to further elucidate the predation behavior of fish.

V. CONCLUSION

In this paper, we constructed a laboratory environment in which several types of planar motion can be performed in the water and programmed a robot for autonomous predation. As a result, we achieve autonomous capturing at speeds of less than of 60 mm/s and made observations during failed capturing. During the process of capturing the target, we found that the amount of posture change increased as the distance decreased.

ACKNOWLEDGMENT

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