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Sound source detection robot inspired by water striders

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Abstract: In this study, we investigate a position search algorithm inspired by the behavior of a water strider, and we develop a six-legged robot that moves toward a sound source autonomously by using this algorithm. First, we observe the behavior of water striders by using a high-speed camera, and we simplify the observed behavior to obtain some rules. Then, we evaluate the validity and effectiveness of the obtained rules by conducting simulations. Finally, we develop a six-legged robot that is controlled on the basis of the obtained rules. Experimental results show that the developed robot effectively moves toward the sound source.

Keywords: water strider, multi-legged robot, acoustic source localization.

1 Introduction

Recently, robots inspired by living beings such as animals and insects have attracted considerable attention. Living beings are able to adapt to complex real-world scenarios in spite of exhibiting simple behavior because they utilize the properties of their environment; in other words, they realize intelligent behavior by interacting with their environment. Thus, by extending the behavior of living beings to robots, we can control robots effectively using simple algorithms.

In this study, we investigate the behavior of a water strider. A water strider moves toward its prey by sensing ripples produced when its prey falls on the surface of a pond. We observe the behavior of a water strider by using a high-speed camera, and we simplify the observed behavior to obtain some rules for moving toward the prey. Then, we evaluate the validity and effectiveness of the obtained rules by conducting simulations. Finally, we develop a six-legged robot that moves toward a sound source on the basis of the obtained rules, and we demonstrate its effectiveness experimentally.

2 Water strider

We observed the behavior of a water strider by using a high-speed camera. Fig. 1 shows how a water strider moves toward its prey, and Table 1 summarizes the behavior of each leg. Fig. 2 shows the leg numbers.

We found that when a ripple is sensed by one of the water strider's legs, it turns in the direction of that leg, and after turning, it moves forward along a straight line. The turning angle is dependent on the leg by which the ripple is sensed first. The water strider repeats this action until it reaches its prey, as shown in Fig 3.

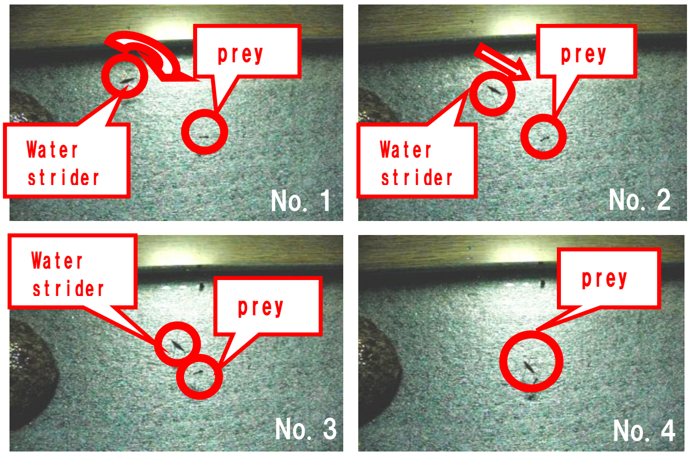


Fig. 1. Behavior of water strider

Table 1. Observed turning angle
(20 observations)

Leg 1		Leg 2		Leg 3	
No. of trial	angle[deg]	No. of trial	angle[deg]	No. of trial	angle[deg]
1	6.0	1	50.0	1	110.0
2	0.0	2	20.0	2	130.0
3	4.0	3	85.0	3	170.0
4	0.0	4	50.0	4	110.0
5	0.0	5	40.0	5	130.0
6	4.0	6	20.0	6	160.0
7	0.0	7	35.0	7	110.0
8	2.0	8	30.0	8	120.0
9	3.0	9	20.0	9	140.0
10	1.0	10	40.0	10	90.0
11	3.0	11	70.0	11	110.0
12	0.0	12	40.0	12	80.0
13	4.0	13	20.0	13	80.0
14	3.0	14	30.0	14	110.0
15	2.0	15	70.0	15	80.0
16	2.0	16	60.0	16	180.0
17	0.0	17	10.0	17	140.0
18	5.0	18	30.0	18	120.0
19	4.0	19	50.0	19	80.0
20	0.0	20	40.0	20	150.0
average	2.2	average	40.5	average	120.0

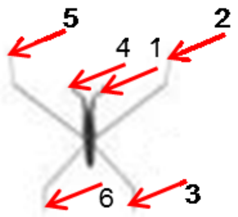


Fig. 2 Leg number

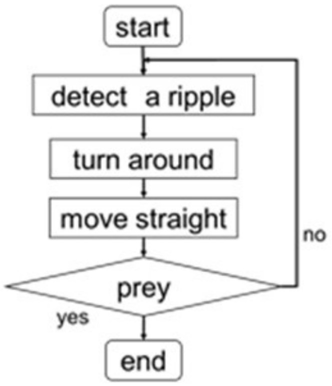


Fig 3. Strategy of water strider

3 Model of water strider

We modeled the water strider by using the following simple rules.

When a leg senses a ripple, the water strider turns in the direction of that leg (The turning angles are listed in Table 2).

Then, it moves forward along a straight line within a certain time period.

This cycle is repeated until the prey is reached.

Table 2. Turning angle

	Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	Leg 6
Turning angle [deg]	2	40	120	-2	-40	-120

Using these rules, the motion of a water strider in time t on a horizontal (xy) plane can be expressed as follows.

$$\theta(t+1) = \theta(t) + \Delta\theta(t) \qquad (1)$$

$$x(t+1) = x(t) + v\cos\theta(t) \qquad (2)$$

$$y(t+1) = y(t) + v\sin\theta(t) \qquad (3)$$

In the equations stated above, x and y denote the position of the water strider, θ denotes its orientation, v denotes its speed (assumed constant), and $\Delta\theta$ denotes its turning angle.

4 Simulation

To evaluate the validity of the simplified model, we conducted simulations. Table 3 lists the simulation parameters, and Fig. 4 shows the simulation results.

Table 3. Simulation parameters

length of water strider [cm]	6
width of water strider [cm]	4.8
speed of water strider [cm/s]	2
interval between ripples [s]	1
speed of ripple [cm/s]	2.5

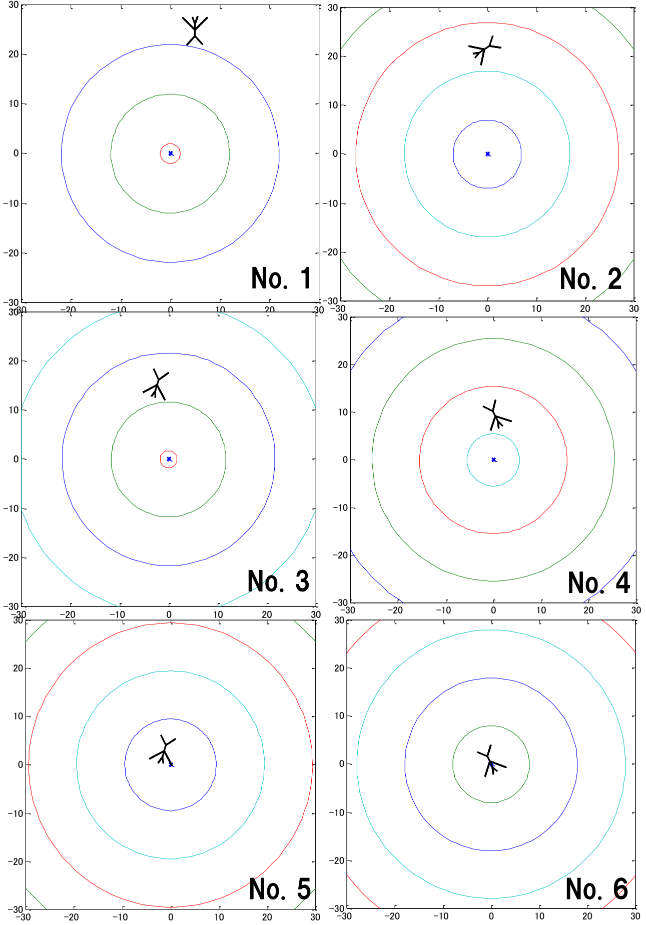


Fig. 4. Simulation results

The results show that the water strider can move toward the ripple source by following the simplified rules.

5 Application to six-legged robot

We developed a six-legged robot, and we adopted the simplified rules to control it.

5.1 Task

Fig. 5 shows the outline of the task. The objective of the task is to move toward the sound source. The position of the sound source is unknown, and the robot moves toward the sound source by using the rules of the water strider.

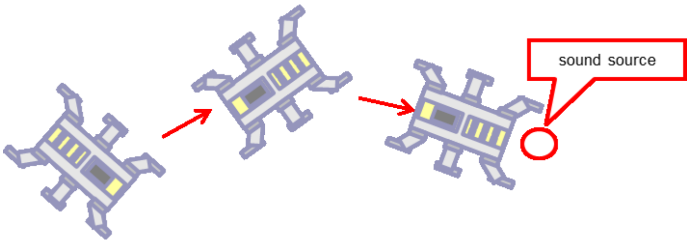


Fig. 5 Task

5.2 Six-legged robot

Fig. 6 shows the developed six-legged robot, and Table 4 lists its specifications. Each leg has two servo motors (Fig. 6 (a)), and it can move from right to left or up and down, as shown in Fig. 7. A microcomputer for controlling the legs is mounted at the center of the body (Fig. 6 (b)). Six microphones are employed to detect sounds; one microphone is attached to each leg (Fig. 6 (c)).

Sound waves from the sound source are detected by the 6 microphones, and the time lag is determined by an electrical circuit (Fig. 6 (d)).

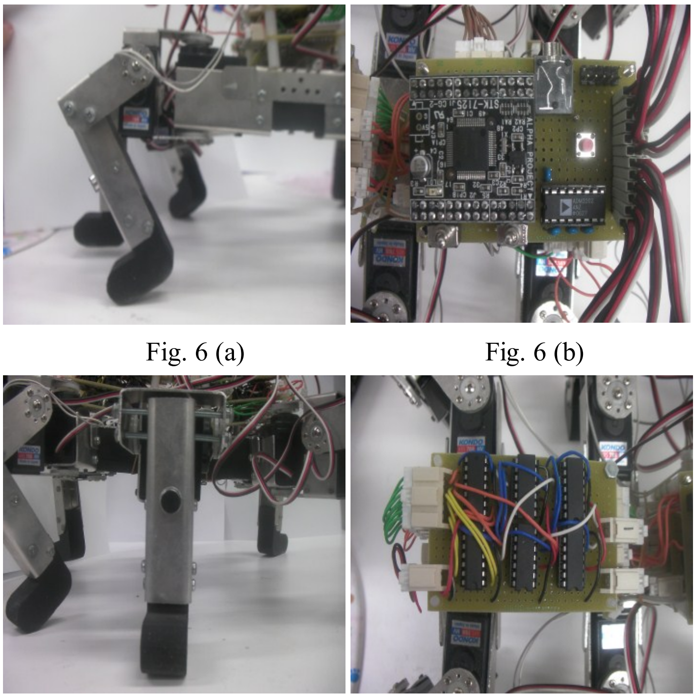


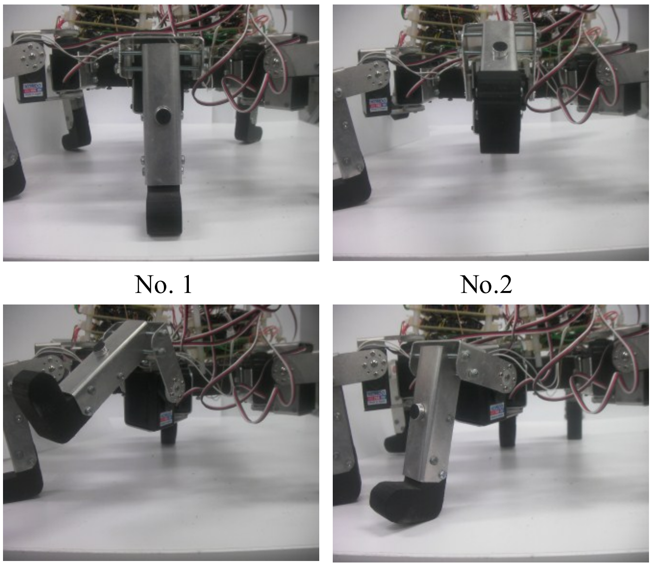
Fig. 6 (a) Fig. 6 (b)

Fig. 6 (c) Fig. 6 (d)

Fig. 6. Six-legged robot

Table 4. Specifications of the robot

Length [mm]	295
Width [mm]	275
Height [mm]	165
Weight [kg]	1.9



No. 1 No.2

No. 3 No.4

Fig. 7. Motion of leg

Fig. 8 shows the flow of the control signal. The electrical circuit for determining the time lag provides information for identifying the leg that sensed the sound wave first, and this information is passed to the microcomputer. The locomotion pattern for turning and moving along a straight line is pre-programmed in the microcomputer, and the robot moves on the basis of the rules stated in section 3.

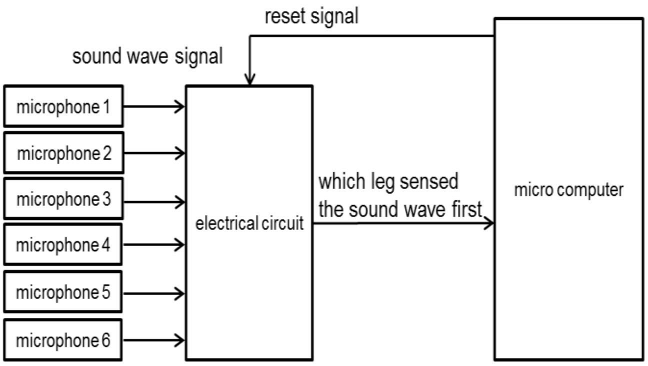


Fig. 8 Flow of control signal

6 Experiment

Experiments were conducted to demonstrate the effectiveness of the proposed framework.

Fig. 9 shows the experimental environment. A participant claps his hands repeatedly, and the robot moves towards him. Fig. 10 shows the realized behavior.

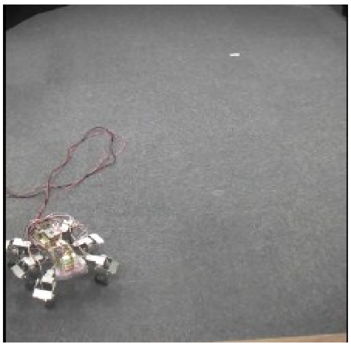
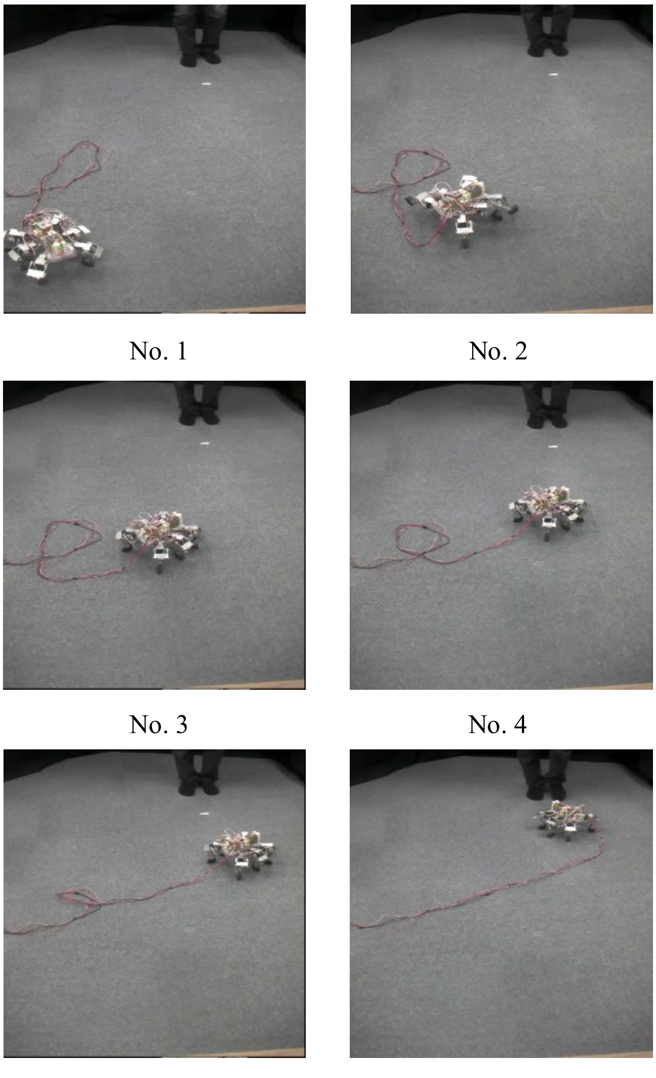


Fig. 9. Experimental environment



No. 1

No. 2

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No. 4

No. 5

No. 6

Fig. 10. Realized behavior

7 CONCLUSION

In this paper, we investigated the behavior of water striders; we observed their behavior by using a high-speed camera in order to obtain simple rules for determining the prey's position. We evaluated the validity and effectiveness of the obtained rules by conducting simulations, and we adopted the rules to control a six-legged robot. Experiments were conducted using the developed robot, and we confirmed that the robot could move toward the sound source. We can conclude that the rules inspired by the water strider are effective in determining the position of the sound source, even though they are very simple.

In the future, we plan to apply these simple rules to useful practical applications such as search and rescue missions for locating survivors in the event of extensive disasters.

8 Acknowledgment

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