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Knowledge presentation by the MNSM-based controller for swimming motion of a snake-like robot[①]

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Abstract

A MNSM (mirror neuron system mechanism)-based controller is developed to present the swimming rhythm of a snake-like robot in Cartesian space. From engineering viewpoint, the proposed controller is composed of a neuron for rhythm angle and two neurons for motion knowledge in *XY* plane. The given knowledge is a rhythm curve for swimming motion of a snake-like robot. Experimental results show that the proposed controller can present the knowledge of swimming rhythm, which represents the corresponding control law to drive the snake-like robot to swim with different speeds and turning motion. This work provides a novel method to present the knowledge for swimming motion of snake-like robots.

Key words: mirror neuron system mechanism (MNSM), swimming motion, snake-like robot, knowledge presentation

0 Introduction

How to perceive the knowledge and control a snake-like robot to imitate the motion of snakes is a hot topic for researchers. The MNSM-based controller for a snake-like robot is developed to understand the rhythm of swimming motion, and uses its knowledge to represent the swimming strategies.

The remainder of this study is organized as follows: In Section 1, the related work is specified. Section 2 presents a MNSM-based controller for swimming motion of snake-like robots. A dynamic model of a snake-like robot is addressed in Section 3. In Section 4, the knowledge definition for swimming motion of snake-like robots is specified. In section 5, the swimming motion by MNSM-based controller is developed. The swimming motion speed regulated by MNSM-based controller is studied in Section 6. In Section 7, the phase modulation knowledge presentation is defined. Finally, the conclusion is discussed in Section 8.

1 Related work

The lack of legs does not impede the locomotion of snakes. They use several different gaits to deal with particular environments. Unlike the gaits of legged animals, snakes use at least five unique modes of terrestrial locomotion. The typical gaits are serpentine locomotion, side-winding locomotion, concertina locomotion, and rectilinear locomotion[1].

In serpentine gait, waves of lateral bending are propagated along the body from head to tail. When the body contacts an object, it exerts force against it and deforms locally around it. When a snake pushes against multiple objects, the lateral force vectors counteract each other, generating a resultant vector that propels the snake forward[2].

When swimming in water, the waves become larger as they move down the snake's body, and the thrust can be generated by pushing their body against the water, resulting in the observed slip[3].

Different snake-like robots are developed to imitate the swimming motion in water[4-7].

Most swimming motions of snake-like robots could be controlled by kinematic planning, artificial neuron networks, etc[8-12]. In order to understand the mechanism and realize similar motion of snake-like robot, knowledge presentation should be adopted to present

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the motion, and generate corresponding control strategies. Typically, knowledge presentation is a high level neuron system activity. Neuroscientists have previously identified that the MNSM (mirror neuron system mechanism) appears to play a fundamental role in both action understanding and imitation[13-15].

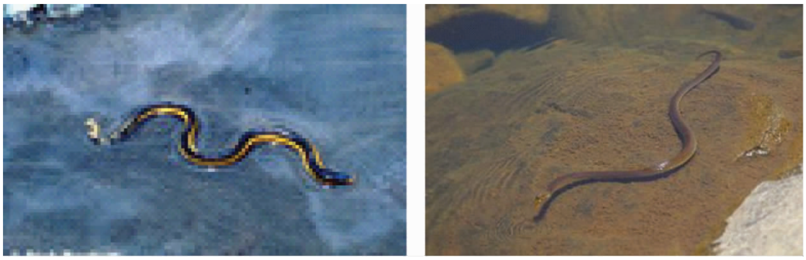


Fig. 1 Swimming snake

In humans, mirror neuron systems have been found in Broca's area and the inferior parietal cortex of the brain[13]. Diagram of the brain, as shown in Fig. 2, shows the locations of the frontal and parietal lobes of the cerebrum, viewed from the left. It contains the inferior frontal lobe, and the superior parietal lobe.

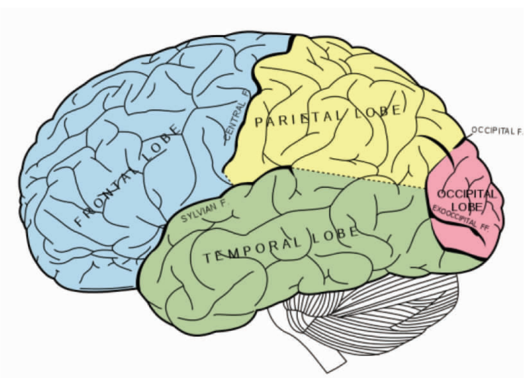


Fig. 2 Diagram of the brain

Based on the mechanism of mirror neuron system, different controllers are developed for the motion control or knowledge presentation for humanoid robots or robotic arms[16-18]. Lu presented typical applications of MNSM based method for motion control of dual robotic arms[18], as shown in Fig. 3.

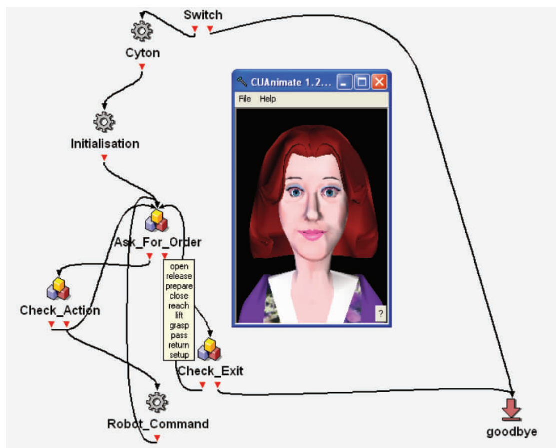


Fig. 3 MNSM motion control for dual arm robots

The MNSM-based controller has been developed by Lu to perceive the rhythmic output of the UCI-CPG (unidirectional cyclic inhibition-central pattern generator) network-based swimming motion of the snake-like robot[19], as shown in Fig. 4.

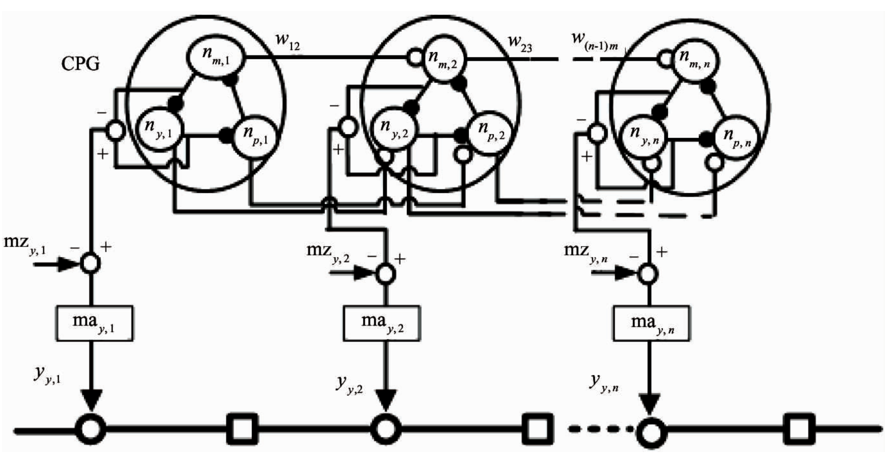


Fig. 4 UCI-CPG control system of the snake-like robot

A MNSM-based controller for a snake-like robot is developed to understand the rhythm of swimming motion, and uses its knowledge to represent the swimming strategies.

2 MNSM-based controller for swimming motion of snake-like robots

A MNSM-based controller is developed, as shown in Fig. 5, to present the knowledge in Cartesian space.

The dynamics of the MNSM-based controller is shown as follows.

$$\begin{bmatrix} \dot{M}_{x,i}(r) \\ \dot{M}_{y,i}(r) \\ \dot{M}_{r,i}(r) \end{bmatrix} = \begin{bmatrix} Fx((M_{r,i}(r))) \\ Fy((M_{r,i}(r))) \\ Fr((R_i(r))) \end{bmatrix} \mathrm{d}r \quad (1)$$

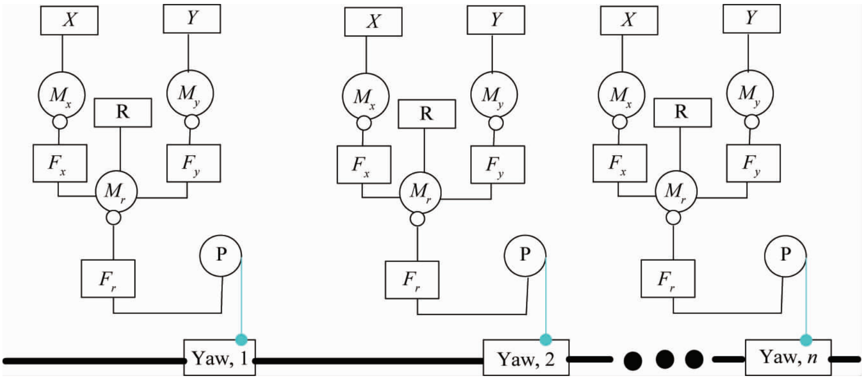


Fig. 5 MNSM-based controller of the snake-like robot

Here, $M_{x,i}(r)$, $M_{y,i}(r)$, $M_{r,i}(r)$ are the neurons to generate a mirror network for a snake-like robot; $F_{r,i}(r)$ is the knowledge function to present the dynamic of the swimming motion; $F_{x,i}(r)$, $F_{y,i}(r)$, are the high level knowledge function to perceive the rhythm and generate the corresponding information in XY plane.

3 Dynamic model of a snake-like robot

The dynamic model of a snake-like robot[20] is developed with V-REP for the study of swimming motion, as shown in Fig. 6.

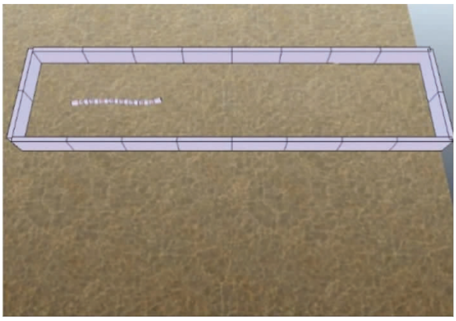


Fig. 6 Snake-like robot model

Table 1 Robot parameter

Links' number (N)	9
Links' length l(mm)	200
Links' mass m(kg)	1.833
Max. joint torque T(N · m)	10
Total lengthl_r(mm)	1800

The snake-like robot model is composed of 9 links connected with 8 vertical joints. Each joint has one DOF (degree of freedom) which makes the robot realize swimming motion in horizontal plane. The parameters of the experiment system are shown in Table 1.

The body contacting force is set as $\{0,0, m\{i\}.g\}$, $m\{i\}$ is the mass of i-th link, $i = 1,\cdots,9$. And the reaction force between robot and water is decomposed into x, y and z directions which will propel the robot swimming in the water.

4 Knowledge definition for swimming motion of snake-like robots

Firstly, the snake-like robot realizes kinematical motion along the given curve formulated as

$$y(r) = a \times \cos(b \times (r + r_0)) \quad (2)$$

Here, $y(r)$ is the output of the rhythm (Knowledge); a and b are the constant parameters to regulate the rhythm; r is a variable, here $r \geq 0$; r_0 is a constant value for the beginning stage, here $r_0 = 20000$. In order to show that the knowledge is suitable for snake-like robot motion control, the parameters are $b = 2 \times kn \times \pi / l\_r$, and $a = \lambda \times \sin(kn \times \pi/N) \times l\_r/(kn \times \pi)$. An example is shown in Fig. 7, where $kn = 1$, $\pi = 3.1415926$, $N = 9$, $l\_r = 1800$, $\lambda = 0.4$.

In order to control the whole shape of the snake-like robot to imitate the given curve, the rhythm pattern in joint angle space can be given as

$$\beta_i(r) = \mathrm{sign}(*) \times a \times b \times \sin(b \times (r + r_0) + i \times P) \quad (3)$$

where, $\beta_i(r)$ is the joint angle of i-th joint; sign(*) is 1 or -1 to regulate the rotation direction of the joint; P is defined as $2 \times kn \times \pi / N$; $i = 1, \cdots, N$. The outputs of the joint patterns are shown in Fig. 8.

Under a speed $v_r = 60$mm, the variable r changes from 0mm to 120000mm. With given parameters, the snake-like robot can realize swimming motion, as shown in Fig. 9. The size of swimming pool is 8m × 2m × 2m.

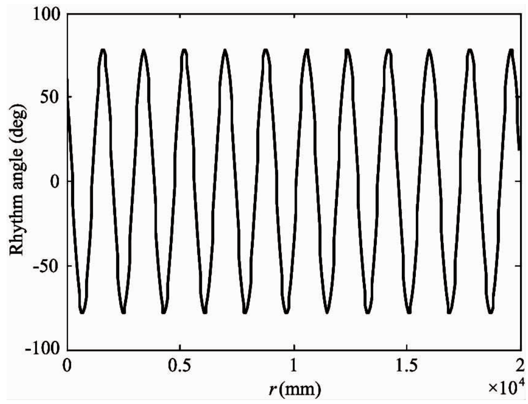
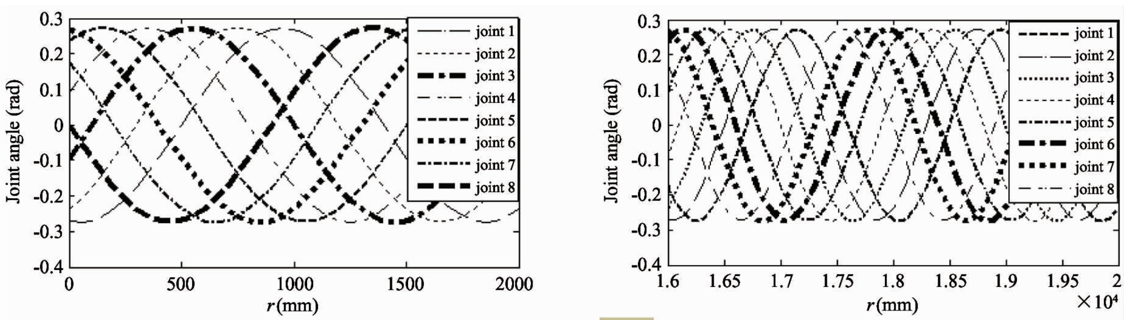
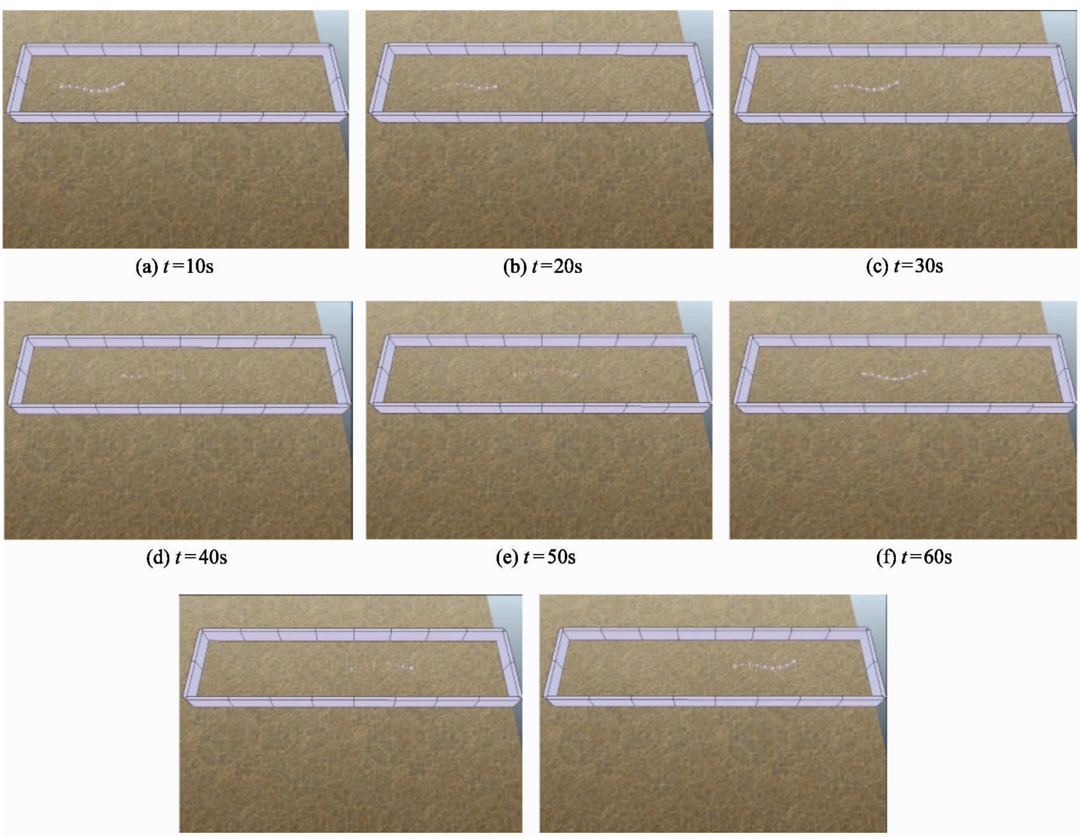


Fig. 7 Rhythm curve



(a) Beginning stage (b) Stable stage

Fig. 8 Joint angle patterns



(a) t=10s (b) t=20s (c) t=30s

(d) t=40s (e) t=50s (f) t=60s

(g) t=70s (h) t=80s

Fig. 9 Experimental results

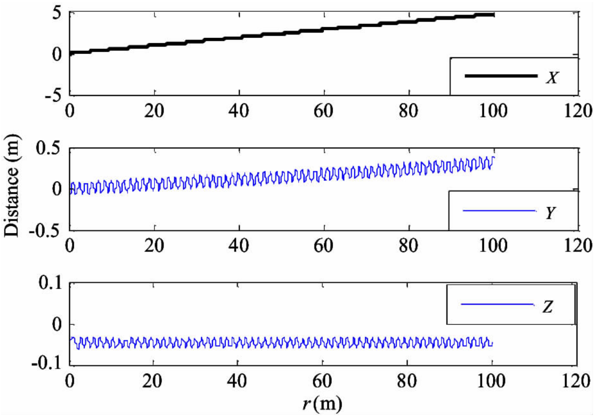


Fig. 10 Motion trajectories in Cartesian space

The trajectories of robot head in *XYZ* plane are shown in Fig. 10, and it moves towards a fixed direction.

5 Swimming motion by MNSM-based controller

A MNSM-based controller is developed, as shown in Fig. 11, to represent the knowledge for swimming motion control of the snake-like robot.

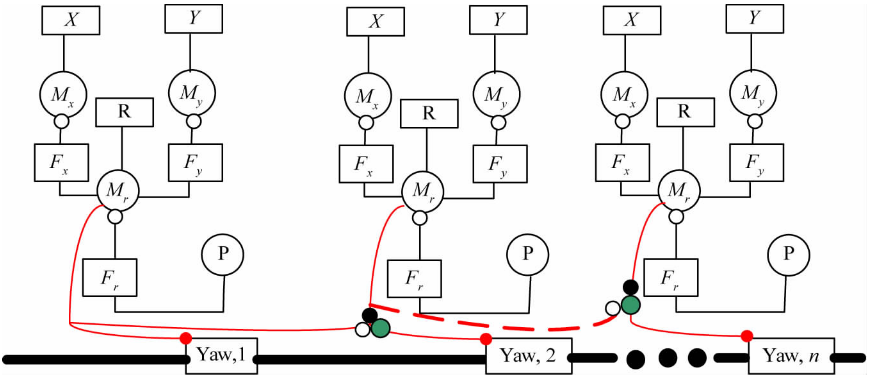


Fig. 11 MNSM-based control system for swimming motion

The dynamics of the MNSM-based controller is shown as

$$\begin{bmatrix} \dot{M}_{x,i}(r) \\ \dot{M}_{y,i}(r) \\ \dot{M}_{r,i}(r) \end{bmatrix} = \begin{bmatrix} \cos\ (M_{r,i}(r) \times C\_d\_to\_r) \\ \sin(M_{r,i}(r) \times C\_d\_to\_r) \\ \text{sign}(\ *\ ) \times (\beta_i(r)) \end{bmatrix} \mathrm{d}r \tag{4}$$

where $C\_d\_to\_r = \pi/180$. The knowledge shown in Fig. 12 is the rhythm in ***XY*** plane, the phase angle of the rhythm for i-th joint is the output of $M_{r,i}(r)$.

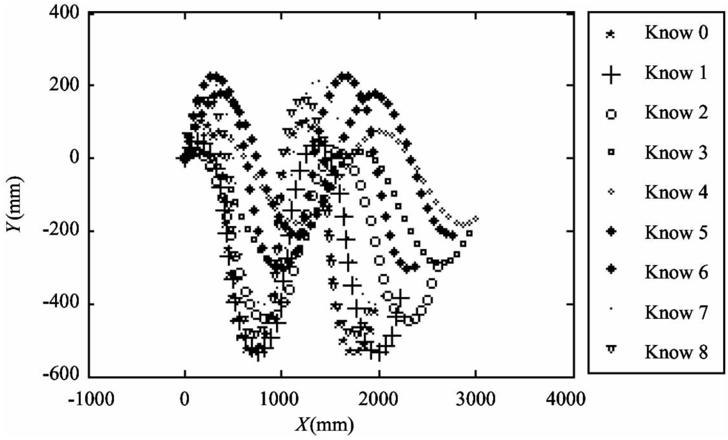


Fig. 12 Rhythm in Cartesian space

With an inhibitory connection from head to tail, a MNSM-based controller is developed to generate corresponding joint pattern. The dynamics of the joint patterns are shown as

$$\beta_i(r) = \begin{cases} M_{r,i}(r+r)\cdot C\_d\_to\_r, & \text{if } i=0 \\ (M_{r,i+1}(r+r_0) - M_{r,i}(r+r_0))\cdot C\_d\_to\_r, & \text{if } i>0 \end{cases} \quad (5)$$

The outputs of the joint patterns by MNSM-based controller are shown in Fig. 13. Here 1, 2, ⋯, 8-th output of the networks controls the corresponding joints of the snake-like robot.

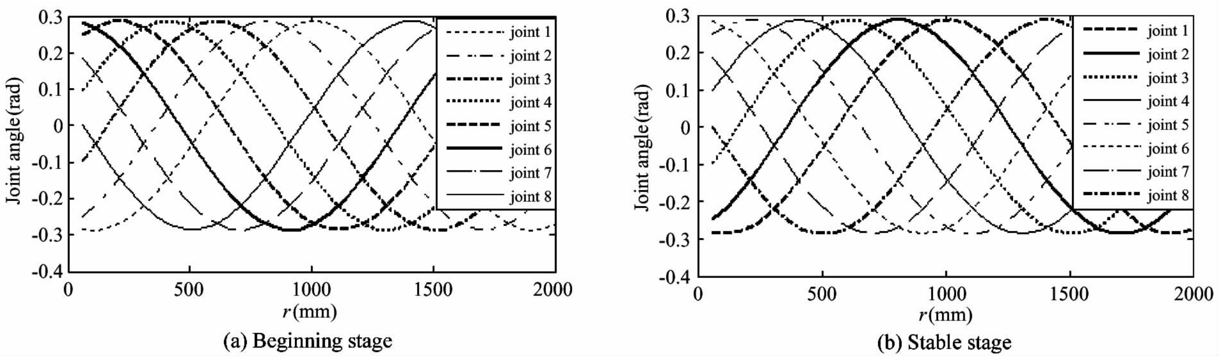


Fig. 13 Joint angle patterns

The errors between the outputs of Fig. 8 and Fig. 13 are shown in Fig. 14.

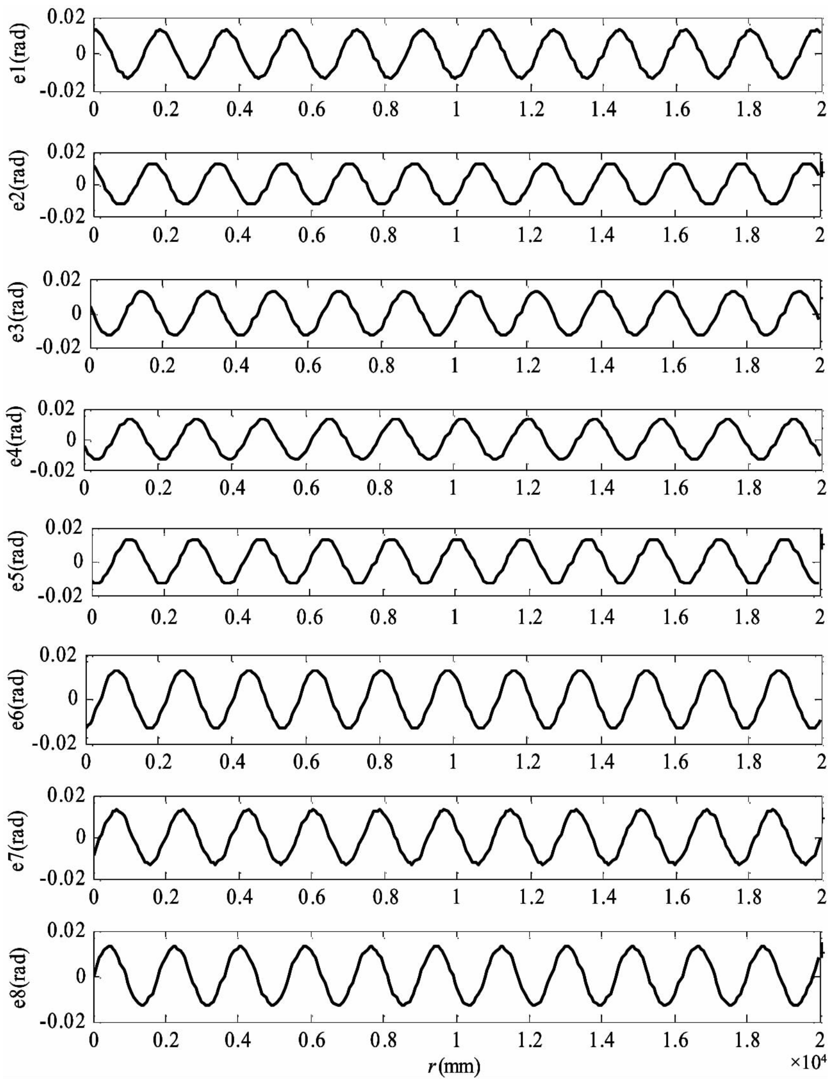


Fig. 14 Errors between two outputs

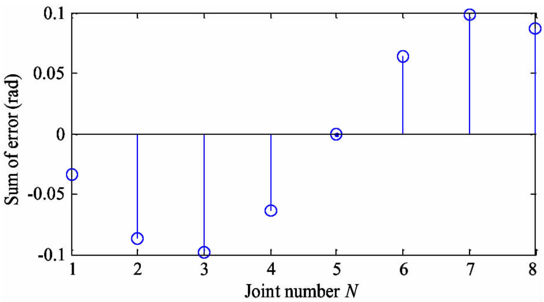


Fig. 15 Absolute errors

The errors are rhythmic, it shows that the joint pattern by the MNSM-based controller is the same knowledge of the curve-based controller. The sums of the errors are shown in Fig. 15. With the output of MNSM-based controller, the snake-like robot can reproduce swimming motion of given knowledge. The experimental results are shown in Fig. 16.

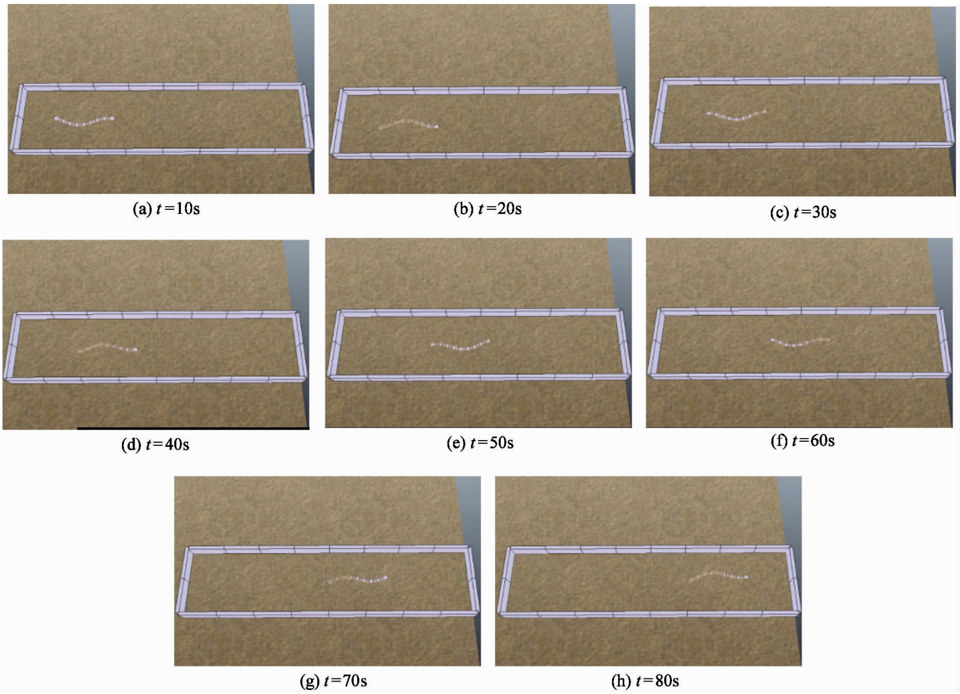


Fig. 16 Experimental results

The snake-like robot swims in water towards a fixed direction. The trajectories in *XYZ* plane are shown in Fig. 17.

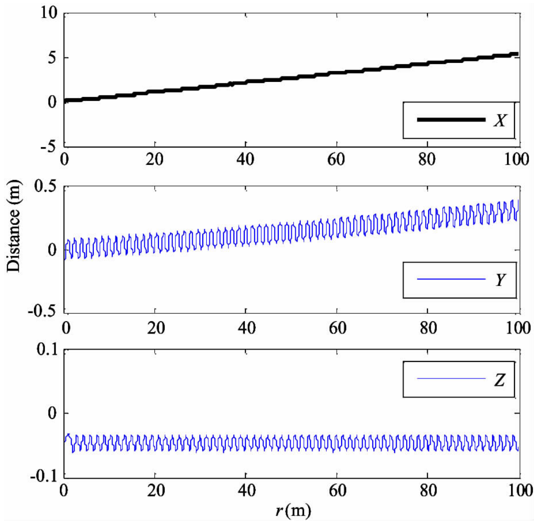


Fig. 17 Motion trajectories in Cartesian space

6 Swimming motion speed regulated by MNSM-based controller

The swimming speed of the snake-like robot can be regulated by the variation speed v_r. The average speeds for different values of v_r (0, 0.2, 0.4, 0.6, 0.8, 1.2) are shown in Fig. 18 . The motion trajectories are shown in Fig. 19.

7 Phase modulation knowledge presentation

The proposed MNSM-based controller presented the knowledge of serpenoid curve for each joint, and the new knowledge by phase modulation of Eq. (3) will also generate the corresponding knowledge through Eq. (5).

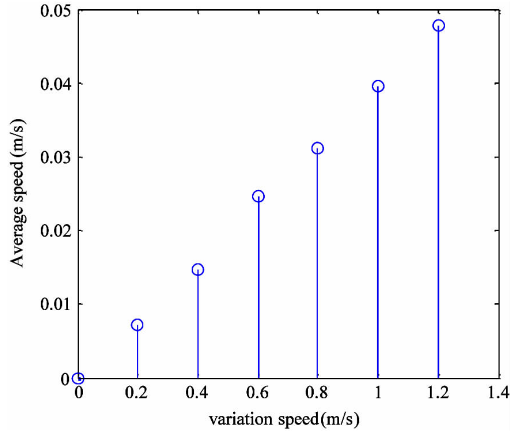


Fig. 18 Average speeds of swimming motion

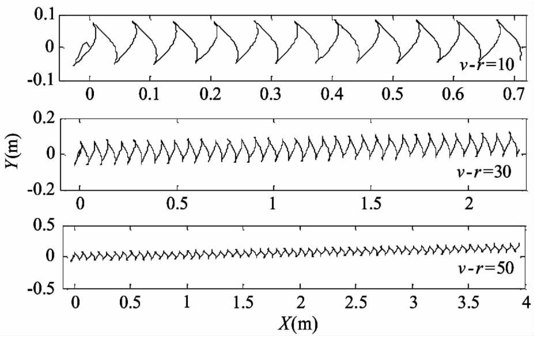


Fig. 19 Motion trajectories in Cartesian space

Through adding a bias to Eq. (3), a new knowledge to control the movement of the snake-like robot could be got as shown in

$$\beta_i(r) = \text{sign}(*) \times a \times b \times \sin(b \times (r + r_0) + i \times P) + Bias_i \quad (6)$$

where, $Bias_i$ is the bias value of i-th joint, and here all bias value is set as

$$Bias_i = \begin{cases} 0 \\ 0.0015 \text{ rad} \end{cases} \quad (7)$$

where, $t < t_0$ is one stage of swimming knowledge, and $t \geq t_0$ is another stage of swimming knowledge. When the knowledge Eq. (6) changes from the state of $t < t_0$ to the state of $t \geq t_0$, it will control the snake-like robot to generate a turn motion during swimming, here t_0 = 20s. The knowledge of joint angle is shown in Fig. 20. The trajectory of the robot is shown in Fig. 21. The experimental result captured from the video is shown in Fig. 22.

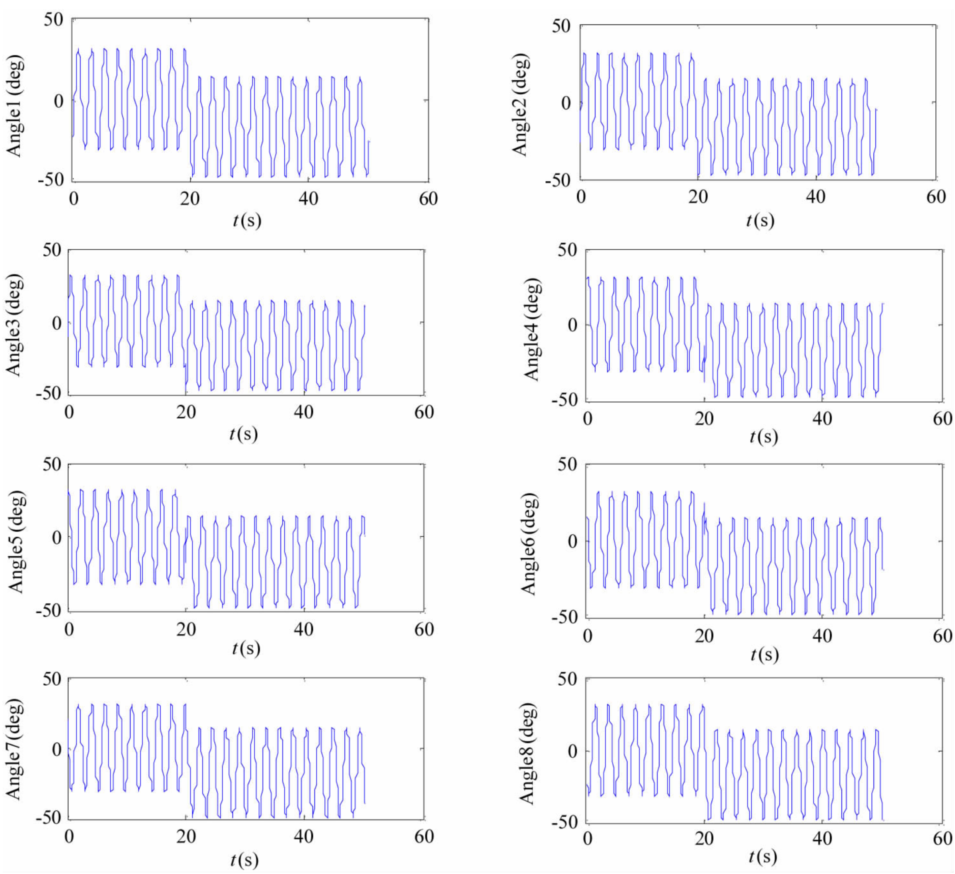


Fig. 20 Joint angle rhythm of snake-like robot

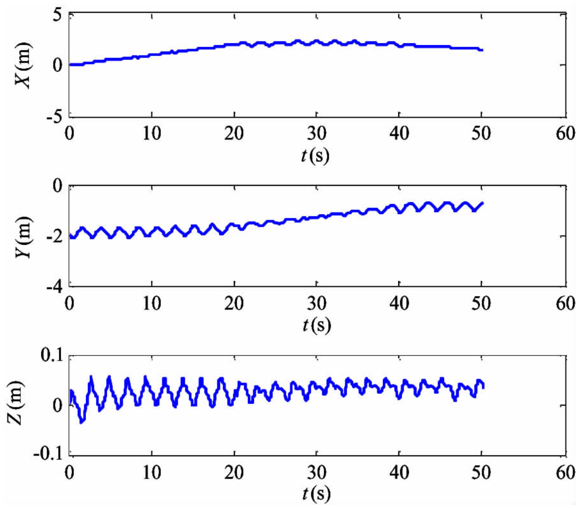


Fig. 21 Swimming trajectory

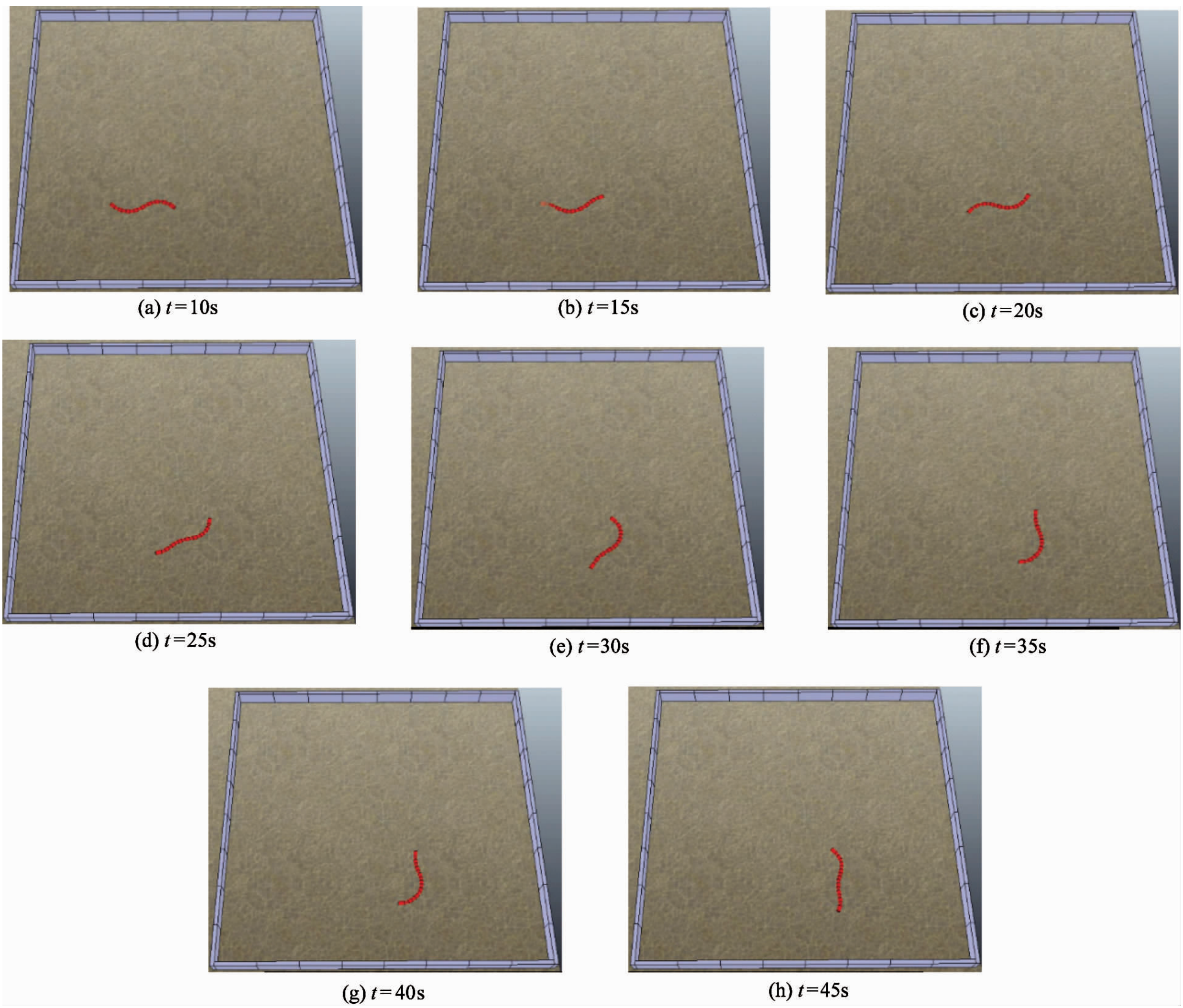


Fig. 22 Experimental results

8 Conclusions

A MNSM-based controller has been proposed to realize knowledge presentation for swimming motion of a snake-like robot. The curve based motion knowledge can be decomposed as rhythm angle, rhythm coordinates in *XY* plane. By an inhibitory connection of the

MNSM-based controller from head to tail, it can represent the curve-based knowledge for swimming motion of the snake-like robot. The experimental results have validated that the proposed MNSM-based controller can realize not only knowledge presentation of curve-based swimming motion of the snake-like robot, but also realize knowledge representation for swimming motion in different speeds and turn motion during swimming.

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