Development of a Snake-Like Robot Adapting to the Ground

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Abstract

Biological snakes' diverse locomotion modes and physiology make them supremely adapted for the ground. This paper discusses the biological snakes' locomotion mode on the diverse ground, and describes the development of a snake-like robot with the adaptability for the ground. The method to realize some locomotion modes is given. The method for detecting the characteristic of ground is proposed and identified in test.

1 Introduction

In the earth, there are many kinds of snake. The movement of a real snake is very flexible as it can be adapted to various environments. Snakes are able to move on rough surfaces, they cross obstacles, and they can creep into areas that are very difficult to reach with any other kind of movement. This means, a snake-like robot with the same properties would be an ideal inspection system. It is interesting for scholars to make snake-like robot moving and acting as biological snake.

Snake as a biological machine, in spite of its simplicity, performs well in terms of changing its highly redundant body to adapt to the environment. Several snake-like robots that emulate snakes' motion were developed [9]. The first serpentine robot was built by Hirose [1], who recently carried out the gliding experiments on ice to show that the creeping motion is the same as the principle of skating [2]. How such mechanisms can locomote in a plane was studied in [1] [3][4]. The snake robot locomotion theory based on Geometric Mechanics was also discussed for the serpentine robot [5]. NEC developed a 3-dimensional motion robot for the purpose of search and rescue for survivors in collapsed buildings [6]. GMD built another 3-dimensional motion robot by tend on driven mechanism [7], SIA built a 3-dimensional motion robot to study the mechanism of locomotion [10][11], and Hirose's group has also developed a 3-dimensional robot equipping with larger passive wheels [8].

One of the snakes' assets is their ability to immediately respond to a new environment by changing modes. According to the characteristic of ground, a real snake creeps by using diverse locomotion modes. In this paper, we discuss the biological snakes' locomotion mode on the diverse ground, and describe the development of a snake-like robot with the adaptability for the ground.

2 The Locomotion Mechanism

The snake is a vertebrate, an animal with a backbone, and has the largest number of vertebrae of any animal: between 100-400 vertebrae, depending on the species. Although only a few limited motions and amplitudes are possible between adjacent vertebrae, concatenation of these articulations can produce large angular excursions. The vertebrae of the snake form ball-and-socket joints with additional projections that eliminate torsional motion to protect the spinal cord. This remarkable design uses a series of surfaces to allow the limited lateral and ventral excursions (respectively 10-20 degrees and 2-3 degrees for most snakes) but eliminate torsion which would otherwise twist the spine.

Snake skeletons have only three types of bones: skull, vertebrae and ribs. Snake skeletal form and structure is quite simplified in number and type. The interesting lessons from snake skeletons are the simplicity of a repeated structure and the relatively limited motions between adjacent pieces. These aspects are worth examining in a mechanism design.

Our snake-like robot is made of many same joint units, the joint unit has one degrees of freedom. See in Fig. 1.

![Fig.1 One-DOF joint](image_url)

Two adjacent joint units are assembled vertically, and form a module. Concatenation of these modules can produce a locomotion mechanism.

As shown in fig.2, we develop a mathematical model for an articulated snake robot consisting of n rigid links.
with torque actuators at $n-1$ joint.

$$
\Delta \theta_i \ (\text{yaw })
$$

$$
\Delta \phi_i \ (\text{pitch })
$$

Fig 2 The model of snake robot

We define two DOF of joint as one rotate around the Pitch axis represent by $\phi_i$ and another around the Yaw axis represent by $\theta_i$. $\alpha_{r0}$ and $\alpha_{s0}$ are the initial winding angles of two waves, $n_t$ and $n_s$ are the numbers of links in each locomotion plane, $s$ is the displacement of tail along the Serpoidoid, $K_s$ is the number of the wave shape, $i$ is the $i$th link, $L$ is the whole length of the robot body, $\delta \phi$ is the phase difference between two waves out of phase. $s$ is the displacement of tail along the serpentine curve. $K_i$ is the constant. Based on these, in this study the 3-dimensional locomotion is described by the composition of the horizontal serpentine curve from the bending angle around Z axis and the vertical serpentine curve from the bending angle around X axis.

3 The Locomotion Mode

Snakes use many modes of terrestrial locomotion. The kind of locomotion a snake uses in any particular instance depends on several factors such as the characteristic of surface it is crawling on and its speed. In fact, a real snake can even use two modes in different parts of the body. There are four primary modes of snake locomotion. Serpentine movement is the movement to be seen typically in almost all kinds of snake. Concertina movement involves alternately pulling up the body into bends and then straightening out the body forward on the surface and the back part of the body is pulled up into bends again, and so forth. Sidewinding movement is the gliding method used by snake such as the rattlesnake which live in the desert. Rectilinear locomotion is movement in a straight line.

3.1 Serpentine movement

Serpentine movement is obtained by when we hold the $\phi_i$ invariable, and make the $\theta_i$ variant as following:

$$
\theta_i(s) = -2\alpha_{r0} \sin \left( \frac{K_r \pi}{n_t} \right) \sin \left( \frac{2K_r \pi}{L} s + \frac{2K_r \pi}{n_t} i \right) + K_i l
$$

(1)

3.2 Concertina movement

Concertina movement is obtained by when we hold the $\theta_i$ invariable, and make the $\phi_i$ variant as following:

$$
\phi_i(s) = -2\alpha_{s0} \sin \left( \frac{K_s \pi}{n_s} \right) \sin \left( \frac{2K_s \pi}{L} s + \frac{2K_s \pi}{n_s} i \right) + K_i l
$$

(2)

3.3 Sidewinding movement

Sidewinding movement is a three-dimensional locomotion. This gait is driven flat by three-dimensional rolling of each joint without using the special friction condition between the body and the ground such as lateral undulation. The body-shape curve is described by the composition of the bending motions about X axis and Y axis with a phase difference. has the following form:

$$
\begin{align*}
\theta(s) &= -2\alpha_{s0} \sin \left( \frac{K_s \pi}{n_s} \right) \sin \left( \frac{2K_s \pi}{L} s + \frac{2K_s \pi}{n_s} i \right) \\
\phi(s) &= -2\alpha_{s0} \sin \left( \frac{K_s \pi}{n_s} \right) \sin \left( \frac{2K_s \pi}{L} s + \frac{2K_s \pi}{n_s} i + \delta \phi \right)
\end{align*}
$$

(3)

4 Apperception of the Ground

From the discussion of the Biological snakes’ locomotion mode, we know that snake can adapt movement mode according to the different grounds. The behavior of snake is based on apperception of the ground.

In order to measure multi-direction force, a kind of pressure sensor is used. We design a device combined three sensors, see fig.3.

![Sensor device](image)

Fig 3 Sensor device

In the device, the tactile pole can move in vertical and horizontal direction, thus can press the sensors’ tactile points; when the pole move upward, the sensor on top can feel the vertical pressure, on the condition that the
ground is soft, the top sensor can feel the vertical pressure, on the condition that the ground is soft, the top sensor can feel the pressure of the ground; while the robot moved on the land, the bottom of the pole suffered the friction of the ground, moved towards the opposite direction of the body of the robot, and pressed the side sensor, so the sensors on side faces can feel friction force and measure the magnitude of the friction. When the bottom of the pole contracts the ground and moves, it can measure pressure and friction force at the same time.

The device install on the belly of the robot, the manner of installation is that the bottom of the tactile pole is a little higher than the belly, see in Fig.4.

![Fig.4 fixing of the sensor device](image)

5 Configuration of the Control System

The snake's locomotion is simulated by multi units through controlling units' relative angles to attain corresponding purposes. Each unit is driven by a separate processor (slave) that controls the movement of the joints. A centralized controller is in the section of head. All slaves are linked via a single serial bus (CAN-Bus) to the centralized controller that coordinates their movement. See in Fig.5.

![Fig.5 Control system of the snake-like robot](image)

Centralized controller and every performing unit of the robot has the same configuration of hardware. When we have downloaded different program to it, we can get Centralized controller or performingunit. It is easy for making and changing. The dimension of controller is 46mm X 51mm X 10mm, see in Fig.6.

![Fig.6 The controller](image)

5.1 Centralized Controller

The centralized controller consists of microcontroller, sensors and CAN bus interface. The signals of sensors have been sent to microcontroller. According to the value of the signals, the locomotion mode has been selected. The value of moving had been sent to every joint by CAN bus.

5.2 Performing Unit

Every performing unit of the robot has the same configuration of hardware. Single-chip microcontroller sends the messages to the centralized controller by CAN bus and gets control command from it, then Single-chip microcontroller outputs PWM single to R/C servo. R/C servo can drive the joint mechanism to move.

6 Basic Experiments

According to the design described upper, a snake-like robot with the adaptability for the ground has been made, see in Fig.7. The specifications of robot see in table 1.

![Fig.7 The snake-like robot](image)
The operation test of this Prototype is carried out. According to the control methods that we had explained, the snake-like robot can move with three locomotion mode (Serpentine movement, Concertina movement and Sidewinding movement). On the three kinds of different ground, the snake-like robot had locomoted with three locomotion modes. We had measured the farthest distance of locomotion, see in Table 2.

<table>
<thead>
<tr>
<th></th>
<th>Serpentine movement</th>
<th>Concertina movement</th>
<th>Sidewinding movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard surface</td>
<td>2.54m</td>
<td>0.12m</td>
<td>0.53m</td>
</tr>
<tr>
<td>Sand</td>
<td>0</td>
<td>0.15m</td>
<td>0.45m</td>
</tr>
<tr>
<td>Detritus</td>
<td>0</td>
<td>0.14m</td>
<td>0.46m</td>
</tr>
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Table 2 The farthest distance of locomotion (T=10s)

On the hard ground, Serpentine movement is better than other two locomotion modes. On the sand, the snake-like robot cannot move with Serpentine movement, and can move with other two locomotion modes. On the detritus, the snake-like robot cannot move with Serpentine movement, and can move with other two locomotion modes.

When the snake-like robot is in self-motion, first, its head will swing on the ground, at same time, the signals coming from the sensors are measured by the microcontroller. Then it can select the locomotion mode according to the signals. In test, there are three kinds of the ground, soft surface, detritus and the hard surface. When the snake-like robot is moving on the soft surface, it will moved with Sidewinding movement on the soft surface after detecting, see in Fig.8. When it has gone to the detritus from the soft surface, it has changed locomotion mode to Concertina movement, see in Fig.9. After it has arrived at the hard surface, it has moved with Serpentine mode, see in Fig.10. The method for detecting the characteristic of ground is valid in test, and the snake-like robot can change locomotion mode automatically according to the different grounds.

5 Conclusions

The snake-like robot adapting to the ground is discussed in this paper. It is the mechanical model with the three-dimensional capacity, and it has various functionalities. It is a high performance model so that it has several pressure sensors. It is confirmed effectively that the snake-like robot has the adaptability for the ground, and the experiment of fundamental operation is carried out. The method for detecting the characteristic of ground is valid. Because the snake-like robot will adapt itself to the different grounds in use, so the study in this paper is very important for the application of the snake-like robot.

As a future work, on the one hand, it will be realized that detecting more different grounds. Based on the method of detecting more different grounds, it will be concretely examined the adaptability for the ground for our snake-like robot. On the other hand, some new locomotion modes adapting to the different ground will be proposed, and will be verified by our snake-like robot.

6 Acknowledgement

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References


