Design and Implementation of Nine-segment Wheel-less Snake Robot for Planar Terrain

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Abstract

Snake robot is interesting project in robotics. The capability of biological snake to move in unstructured terrain makes the snake robot suitable for Search and Rescue (SAR) operation. This snake robot is constructed with eighteen serial servo motor Dynamixel AX-12A to form nine segment snake robot. The CM-510 from Bioloid is used to control the position of each servo. Since each segment consists of two servo motor, one motor is responsible for vertical rotation and the other for horizontal rotation. The snake robot has no wheels. The locomotion is limited for slithering and sidewinding. For slithering, the robot can move forward and turn left/right. The robot is tested on various ground surface, i.e. ceramics, wood and glass. For the snake forms its body similar to sinusoidal wave, the number of wavelength is evaluated also. From the experimental results, wood is the best ground surface with 1.75λ for slithering forward and 1λ for slithering left/right. It is also interesting to investigate this snake robot with eight-segment and use ordinary servo motor and general microcontroller. Slithering on ramp is another interesting future works.

Keywords: snake robot, bioloid, slithering, sidewinding.

1. Introduction

Snake Robot is more and more interesting for its capability to move in various terrains, i.e. unstructured terrains. This feature is suitable for Search and Rescue (SAR) operation when natural disaster happened.

Gonzales-gomez in [1] wrote about the application of snake robot for SAR operation. The body of snake robot is suitable to find victim on earthquake. The possibilities of falling objects that can harm human during SAR operation are large.

The challenge in snake robot design is to enable snake-like locomotion with limited degree of freedom. Compare to real snake, this is almost impossible. So the idea is to design a snake robot with locomotion as close as possible to real snake.

This paper elaborates the design of snake robot with serial servo motor. Robot consists of nine segments with two servo motor for each segment. Controller for this robot uses CM-510 from Bioloid.

Scope of this paper is on mechanical design for snake robot that can move in planar terrain. From several modes of snake robot locomotion, this paper only evaluates slithering (or lateral undulation) and sidewinding. For slithering locomotion, the robot moves straight forward and turn left/right. The snake robot locomotion is also evaluated for various friction forces.

Generally, there are two kinds of snake robot design, i.e. wheel and wheel-less robot. This paper focuses on wheel-less snake robot.

2. Previous Works

Hirose started research on snake robot for his PhD dissertation in 1970s [2]. He also developed equations for snake robot locomotion, i.e. Serpenoid. Serpenoid consist of a pair of equation, one for horizontal and the other for vertical. The shape is similar to sinusoid signal but they have different frequency and phase angle. See equation (1).

$$x(s) = sJ_0(\alpha) + \frac{4l}{\pi}\sum_{m=1}\frac{(-1)^{2m}}{2m}J_{2m}(\alpha)\sin\left(m\pi\frac{s}{l}\right)$$
$$y(s) = \frac{4l}{\pi}\sum_{m=1}(-1)^{m-1}\frac{J_{2m-1}(\alpha)}{2m-1}\sin\left(\frac{2m-1}{2}\pi\frac{s}{l}\right) \quad (1)$$

Shmakov wrote about several locomotion of snake robot in [2], i.e. lateral undulation, concertina, sidewinding, rectilinier, slidepushing, saltation, burrowing and climbing. This classification makes the research on snake robot easier since we need such a definition to certain locomotion. Ref [3] also explores some snake locomotion.

SINTEF also develop a snake robot called ANNA KONDA for firefighting robot [3]. Information about this robot can be read from http://www.sintef.no. The behind this project is similar to robot for SAR operation.

Hopkins in [4] and Virgala in [5] explored several possibilities to implement snake robot. This gives good brief information about mechanical design of snake robot.

Bayraktaroglu in [6] shows the implementation of wheel-less snake robot with 9-DOF. He only implemented lateral undulation. Unfortunately, his robot could not move in pure planar terrain because the segments had yaw motion only.

Conradt, in [7] and [8], use Central Pattern Generator (CPG) to control the movement of each segment of a snake robot. Although this method is interesting to this research, it is too complicated for first research on snake robot. The CPG can be implemented on the next phase of this project.

Gomez in [9] proposed modular robot with 2-DOF for each segment. This enables the robot to move on the planar terrain without any help from the environment. Ref [10] also explain the movement of 2-DOF segment for snake robot. Ref [11] shows design of a segment in snake robot. Each segment has two servo motors for horizontal and vertical movements. This idea is interesting for this research.

3. Implementation

Each segment of snake robot is built using components from Bioloid. Using [9], [10], and [11], each segment is supported by two serial servo motors, Dynamixel AX-12A, see figure 1. Total segment is nine, so total serial servo motor for this robot is eighteen.

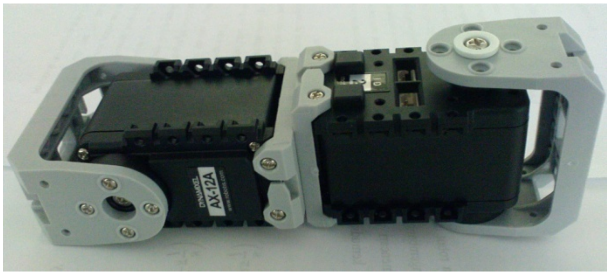

Figure 1. One segment of snake robot consist of two serial servo motors.

As the robot uses serial servo motor, it is easier to control these motor with CM-510 controller from Bioloid also. CM-510 has special port for Dynamixel AX-12A. The servo motors are connected serially and finally it is connected to CM-510.

This arrangement makes the wiring simple. Besides, the wire can be made short and good looking.

Figure 2. Nine segments forms the body of snake robot with its head on the left

Figure 2 shows the body of snake robot after all segments are connected to each other. Length of the robot is 130 cm and its weight is around 620 g.

Figure 3. The CM-510 controller from Bioloid

In order to make the robot can move without disturbing from cables, this robot is controlled remotely via Bluetooth. RC-100A is remote control for the snake robot. It is part of Bioloid Premium Kit.

Here, there is no CPG implementation. This is due to limitation of the CM-510 capability.

The CM-510 is programmed with RoboPlus software. The RoboPlus consist of RoboPlus Task and RoboPlus Motion. Figure 3 shows the CM-510 controller.

The RoboPlus Task handles the main program. Here, the communication via Bluetooth is handled. The CM-510 control each serial servo motor based on the command from RC-100A. Figure 4 shows the RoboPlus Task program.

```
{
    WAIT WHILE  ( Remocon Arrived  ==  FALSE  )
    ReceiveData  = Remocon RXD

    RemoconButton  = ReceiveData  &  U+L+R+2+4
    IF ( RemoconButton  ==  U )
        CALL Forward
    ELSE IF ( RemoconButton  ==  L )
        CALL Turn_Left
    ELSE IF ( RemoconButton  ==  R )
        CALL Turn_Right
    ELSE IF ( RemoconButton  ==  2 )
        CALL Sidewinding_Left
    ELSE IF ( RemoconButton  ==  4 )
        CALL Sidewinding_Right
}
```

Figure 4. The RoboPlus Task program

Figure 4 also shows that this research focuses on forward slithering, turn left/right slithering, and sidewinding. These are basic locomotion of snake robot.

The RoboPlus Motion is such a routine for a motion. Here, the servo position is defined for each locomotion. Figure 5 shows the RoboPlus Motion program.

	Pause	Time
STEP 0	0	1
STEP 1	0	1
STEP 2	0	1
STEP 3	0	1
STEP 4	0	1
STEP 5	0	1
STEP 6	0	1

	Value
ID[1]	550
ID[2]	598
ID[3]	550
ID[4]	680
ID[5]	474
ID[6]	680
ID[7]	550
ID[8]	598
ID[9]	550
ID[10]	426
ID[11]	550
ID[12]	344
ID[13]	474
ID[14]	344
ID[15]	550
ID[16]	426
ID[17]	550
ID[18]	720

Figure 5. The RoboPlus Motion program

In the CM-510, each servo motor has such and ID. This ID is used to address the command from the CM-510. Figure 5 shows that the system has eighteen motor with ID from 01 to 18. Each ID has unique value and this value will be transferred to next ID. This is controlled also in the RoboPlus Motion. The position of each servo motor makes the body of the snake robot move horizontally and vertically simultaneously.

4. Experiments

At the bottom of the body, small pieces of sand paper are set in order to add friction force with the ground surface. The ground surfaces for this experiment are wood, ceramics and glass.

Based on [11], Aiko uses three contact points for slithering. It means the robot maintains three contact points between its body and ground. Unfortunately, the robot move but it is too little. In other words, the robot does not move.

Aiko uses general microcontroller so it supports complex math operation. All angles are computed with Serpenoid equation by Hirose.

Compare to CM-510, it only supports simple arithmetic operation and rounding. It makes the computation result different.

With this result, this paper proposed two contact points. The body of the robot is formed in such a way it form a sinusoidal wave. It is said 1λ, if it forms single wave. It is said 1.5 λ, if it forms one and half wave. The experiments use 1λ, 1.25λ, 1.50λ, 1.75λ, and 2λ.

Figure 6 shows the experiments with various λ and surface ground types for forward slithering.

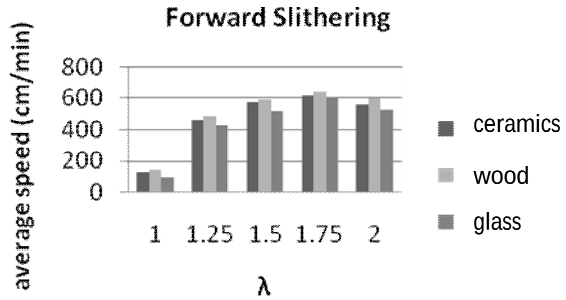

Figure 6. Forward slithering with various λ and ground surface

Although the results are slightly different for all λ except for 1λ, it is interesting to see that using higher λ can make the robot move faster. The problem is we cannot use too high λ due to mechanics limitation.

Figure 7 shows the snake robot slithers to right with various angles and ground surface. 1λ gives the fastest result because the higher λ makes the robot difficult to move.

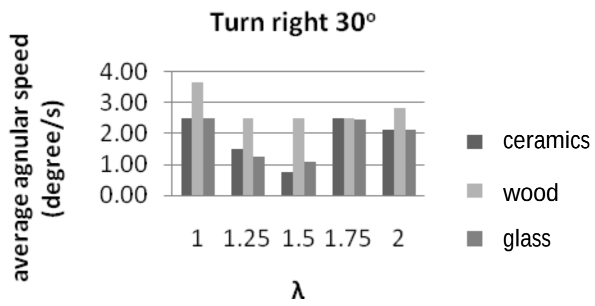

Figure 7a. Slithering right with various λ and ground surface (30^o)

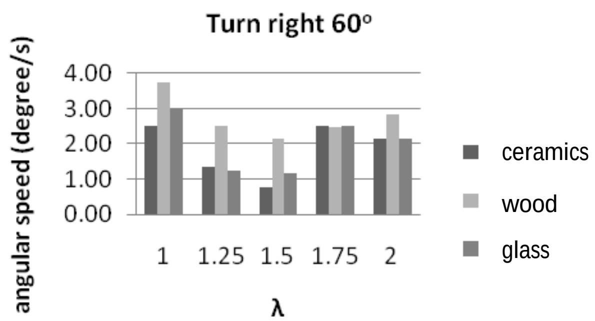

Figure 7b. Slithering right with various λ and ground surface (60^o)

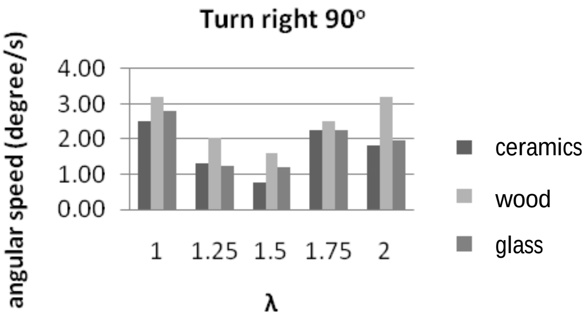

Figure 7c. Slithering right with various λ and ground surface (90°)

When the robot has to turn either right, it has to maintain its λ. The lower the value, the easier the robot can maintain its form.

Experiments for turn left are slightly different but it is not significant based on the statistical test. One important fact about turn right/left slithering is that the head of the robot must move to the direction of the turning. Otherwise, slower angular speed is gained.

Sidewinding locomotion is used by snake when the friction between body and ground surface is too low. The biological snake move parallel with its body. See figure 8.

The idea is to make a standing wave along the snake robot body. Unfortunately, it failed to move. The standing wave cannot make the robot move. The standing wave works correctly but the contact point fails to lock its position and let the other segments move. The problem is the servo motor cannot lock its position. It needs more sophisticated program for the CM-510 in order to do this task. This can be part of the future works for this research.

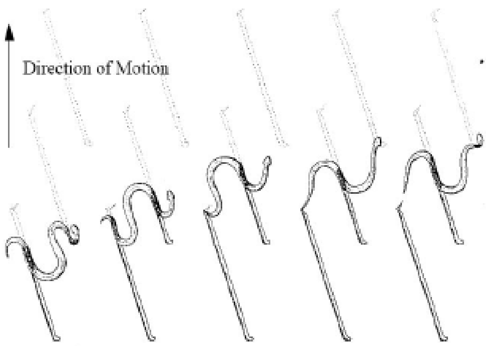

Figure 8. Sidewinding locomotion [2]

For this reason, the standing wave is modified. The modification of standing wave for this robot is shown in figure 9.

Figure 9. Modified standing wave for sidewinding locomotion.

Here, two consecutive segments form 1λ. When he standing wave is propagated, the robot can move in sidewinding locomotion.

Figure 10 shows the sidewinding experimental result for both left and right direction. Although the results are different, based on statistical difference test, it is not significant.

This modified standing wave successfully makes the robot move because the contact point is the hinge between the segments. The original standing wave failed because the contact point cannot be locked. This can be part of the future work in order to evaluate suitable λ for sidewinding locomotion.

Figure 11 shows the slithering locomotion of the snake robot. These figures are captured every second from video recording during the experiments. It is shown that the robot can mimic biological snake slithering locomotion.

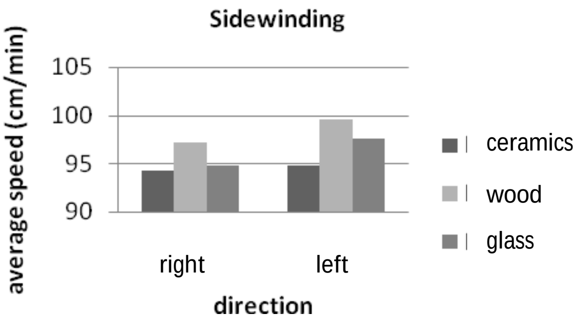

Figure 10. Sidewinding average speed for left and right

4. Conclusion

Three contact points for slithering locomotion failed to operate. The vertical wave cannot work properly. Since the three contact points operation is based on the Serpenoid equation by Hirose, it is important to investigate how to solve this problem.

Two contact points operation is based on the visual information from several videos. Unfortunately, there is no such an explanation about the equation behind this operation.

The slithering with 1.75λ gives the fastest motion compare to the other. It looks like this 'wavelength' is already optimum for this robot because when this 'wavelength' is increased, the result is not good. Since the wavelength can be considered as multiply of four, it is interesting to investigate the wavelength with 2^n segment; for this robot, the choice is eight segments.

For turning left/right operation, 1λ gives the fastest movement. Using higher λ makes the robot difficult to form the sinusoidal wave.

In order to reach the fastest movement, the head must be turned to left for the first movement of turning left slithering. The operation for turning right has the same rule.

The CM-510 has limited mathematics operation this problem must be solved if this controller will be used to continuously in this research. Besides, the CM-510 needs more sophisticated programming for sidewinding locomotion in order to lock the position of contact point.

Other future works in this research is to investigate the slithering locomotion on a ramp and give the snake robot such a sock with rubber strips on its belly. The size of the rubber strips and distance between them are important to be investigated also.

Since the serial servo motor is relatively expensive, using ordinary servo motor is an alternative. The controller can be replaced with general microcontroller with several servo controller.

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