OVERVIEW ON SERPENTINE ROBOT : A DETAILED STUDY

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Abstract : To design an outdoor mobile Robot is more challenging work than the indoor mobile Robot because it has to have capability of operation at all weather conditions and terrains. When it is a Serpentine Robot, it is more difficult to control its motion and path. Snake like robots are being made since 1972, but nowadays many researchers are trying to achieve a snake like robot without limb. Though various works were done and various technologies were invented, but there are many opportunities left.

Serpentine robot may be limbless or with limb. Biological snakes are pervasive across the world, for their various locomotion mode and physiology they are able to locomot in wide variety of terrains and environment. It will be excellent if one is able to capture this type of locomotion in a mechanical system. The aim of this paper is to summarize the work that has already been done in this field and emphasize on future work. This paper will help one understand the mechanism of serpentine locomotion and various snake gaits.

Keywords : Serpentine robots (SR), rectilinear motion, gaits.

1. Introduction

Limbless serpentine robot is a relatively new and upcoming subject in outdoor mobile robot. Biological snake locomot by their various techniques with the help of their strong muscle. Their all types of locomotion are generated by some critical biological mechanism. Wheeled machine moves by rotating their wheel, walking machine moves by pushing their legs but snakes locomotion technique are not so easy. One watches it from the outside that a snake locomot through variety of techniques but its locomotion mechanism is understood, but it is difficult to copy in a mechanical system. To make a limbless serpentine robot, one faces lots of problems and has to overcome lots of real challenges because simulation of a natural mechanism in a man-made device is really a challenging work. If he is able to create a snake like device that could slide, glide and slither, he would open up many applications in exploration hazardous environments, inspection and medical interventions [1]. A worth-while snake robot has the capability to wriggle into confined area and traverse all terrains that will not be possible for traditional wheeled or walking robots. Serpentine robot is designed by using a number of angular drives and creating coupling at joints [2]. For controling the robot movement, one needs to control the movement of head in such a way that other parts of the robot follow it [3].

2. Biology of a snake

Understanding the snake physiology is an important step for developing a snake robot model. A short description about physical characteristics of a snake, snake skeleton and skin are stated here which are very important to design a snake like robot.

The skeleton of a snake often consists of at least 130 vertebrae, and can exceed 400 vertebrae. The range of movement between each joint is limited to between 10% and 20% for rotation from side to side, and to a few degrees of rotation when moving up and down. A large total curvature of the snake body is still possible because of the high number of vertebrae. A very small rotation is also possible around the direction along the snake body. This property is employed when the snake moves sideways by side-winding. A snake skin consists of a scaly integument that protects the animal from abrasion and prevents water loss. The integument on the snake's back and sides is thinner than that of the belly. Scales on the back and sides are more numerous than belly scales and are either smooth or keeled with noticeable ridges. Snake scales are dry and highly polished with a coefficient of friction of between 0.3 and 0.4. The skin, to which the scales are attached, is highly elastic [4].

For a snake robot, it is important to understand the mechanism of snake movement and their different types of gaits. Up to this time, only a few limbless snake robot have been made with a few limited locomotion capability in the form of single type of gait.

3. Brief overview of different locomotion of a snake

Most biological snakes employ four major types of motion.

3.1 Lateral Undulation

The body of the snake forms a series of S shaped curves. The back portion of each of these curves pushes against the ground thereby propelling the snake forward. It is swimming like motion to form this type of motion at least three contact points are required, where two points are used for creating a forward pressure and another point for balancing the body. As this motion depends on sliding friction between the snake body and ground that is why it is not efficiently use in low friction surface and also

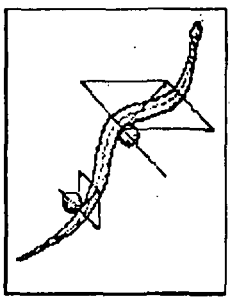

Figure 1 : lateral undulation

it is not so effective for shorter body length and large heavy body snake because may be they don't able to make required curve for their shorter length or for their large heavy body [5].

3.2 Side Winding

The snake makes contact with the ground at only two points while moving its body in a 'sinusoidal' motion. As a result of which the snake moves sideways rather than forward. Side winding is least dependent on friction with the surface. This mode of locomotion technique mainly uses those snakes that are living in the desert (though some non-desert dwellers also use it), where the sand simply gives way under any kind of push. In this motion, dwellers do not progress forward but actually go sideways. Relatively larger amount of energy is expended by attempting this type of motion. This motion is mostly used in low friction ground. In this motion, static contact with the ground is needed. Two points of contact are required for formation of this motion, the segment that is not connected with ground is lifted and simultaneously moved by side and a new contact point is made. Then the previous contact point is also lifted and move in side, and repeating this movement, snake moves in a specific side. To perform this motion, snake needs a complex

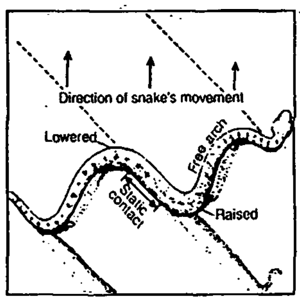

Figure 2 : Side winding.

anatomy and skeleton structure with strong muscle. Snake can move up to 3 km/h by side-winding motion [5].

3.3 Concertina

Concertina is a special types of snake motion unlike the continuous, simultaneous body movements in lateral undulation, the concertina gait uses a progressive, body extension pattern. The body starts compressed, folded in a posture similar to an accordion. Extending a front section, the snake

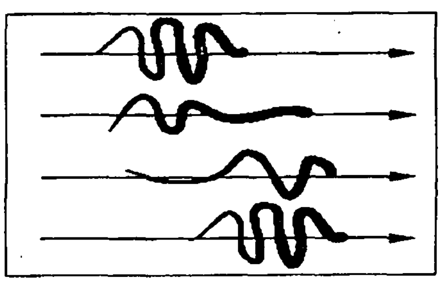

Figure 3 : Concertina.

reaches forward a distance, while the back sections remain stationary. The stationary sections provide a foundation for the moving section. The moving sections use the foundation for leverage to extend forward. The extension is undone, as the snake begins to refold its body, by drawing its back section forward. In this phase the front section acts as the foundation, while the back section is in motion. The pattern results in a series, alternating between pushing against a back foundation and pulling against a front foundation. Static friction is the key; thus, this gait is more useful on Low friction surfaces [5].

3.4 Rectilinear

The snake propels itself in a straight line by moving scales on its stomach in a wave like motion. Rectilinear motion helps the snakes to access very confined spaces.

3.5 Other types of serpentine gaits

Slide pushing is used on flat grounds. The snake takes the shape of a 'S'. The curvature, result of the contraction wave, progresses through the snake tail ward and contacts with the environment in sequence on the left, then on the right, as the wave propagates, the curvature slips backward.

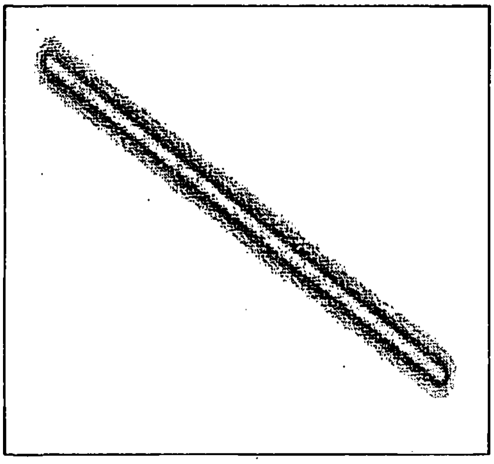

Figure 4 : Rectilinear motion.

As a reaction to the slip friction, a propulsion force appears which results in a sinusoid trajectory of the gravity center. Waves of bending pass backward along the body, exerting a thrust against vertical projections in the surroundings. This mode of displacement is very energy consuming since about two thirds of the movement quantity are lost.

Swim is a special type of motion technique which is used in under water. Long and thin fish and reptiles, such as eels and snakes, swim by undulating the whole body like in the lateral wave motion; the waves of bending pass tail ward so that the water exerts a net forward reaction on the animal. And by this forward reaction force body goes ahead. Accordeon like snake gaits, is used to locomot on flat grounds or in tunnels [6].

4 Model

4.1 Motivation

The important source of inspiration for researchers in developing mathematical models and control mechanism for snake robot is the physiology of biological snakes and caterpillars. Understanding the snake physiology is an important step for developing a snake robot model. As this type of model have a lot of degree of freedoms, their construction pattern is interesting for manipulators e.g. to work with dangerous materials.

4.2 Mechanical model

Serpentine robots, designed by inspiration from nature and movement of snakes, were made for the first time by Hirose [7]. A lot of work has been done on the construction of snake-like robots with elegant and flexible motion which can move in two or three dimensions [8].

4.2.1 Mechanics of mechanical model

4.2.1.1 Architecture of the model

Robotic snakes are composed from at least two or more similar "belly" modules chained together in some way. In most cases, there are additional "head" or "tail" modules providing special sensors, actuators or power-supplying components. The inter-module connection points may be joints or simply stiff connectors. Some snakes (ACM) use passive wheels to lessen friction. Others (NEC-Snake) use additional plates that can be used to improve stability in working or spanning situations [9].

4.2.1.2 Various joints use in serpentine model

The modules are connected by some various joints.

4.2.1.2.1 Simple joints (1 DOF)

Simple joints are used to allow a robot for bend into horizontal or vertical direction. They are easy to control and very cheap.

4.2.1.2.2 Ball-and-socket joints (2 DOF)

Mostly used in architectures that use stiff tubes as a frame for the robot. Ball-and-socket joints are somehow difficult to be controlled with actuators. There are some approaches to construct special-purpose joints for use within robot snakes. They are somewhat expensive but allow the connected modules to act mostly independent from each other.

4.2.1.2.3 Flexible connection (2 DOF)

Flexible connection can be implemented by using rubber or other elastic material that can be bend easily in any direction. It is easy to use in a combination with string-and-winch actuators.

4.2.1.2.4 Special joints

Big efforts are made to develop special purpose joints for robotic snakes, that provide up to 3 DOF. Rotating joints is a special types of joints.

4.2.1.3 Use of sensors in serpentine robot

4.2.1.3.1 Tactile sensors

Bumpers are used to sense contact to the ground and solid obstacles.

4.2.1.3.2 Light sensors

Light sensors are used to measure distances to obstacles or to calculate some direction to creep to. In most cases, they are placed within the snake's "head"-module.

4.2.1.3.3 Joint-position sensors

Special sensors are used to inform the robot of the positions and bending of it's joints. These sensors may consist of potentiometers, tension-sensors, reed contacts, revolution-counters. Joint-position sensors are needed for each degree of freedom [10].

4.2.1.3 Actuators

Snake like robots should not use driving wheels for moving, but bending and stretching or other forms of changing their form (as described before). To achieve these motions, different types of actuators are used; almost all are powered by Electro-magnetic motors (e.g. servos).

4.3 Mathematical model

To achieve a serpentine motion the snake robot has to generate sinoid body-motions. Hirose [9] used a combination of trigonometric functions to calculate what he calls a 'serpenoid curve'. This curve is very similar to real snakes' movement and is used to calculate the positions for each joint. The formula used to compute this "backbone curve" follows :

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

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

Fourier functions are a primitive way to calculate the joint positions to obtain some certain backbone curve. For each time step the joint positions are saved in a table. By using masks, a continuous movement can be generated. To generate more complicated motion patterns, time/joint matrices are used [11].

5. Advantage of this model

This type of robot is more acceptable for its stability, terrainability, high redundancy and completely sealed mechanism. Small frontal area allows penetration of smaller cross-sectional areas than man-equivalent legged or wheeled vehicles.

6. Disadvantage

A large number of actuators are necessary to achieve higher degree of freedom. This provides problems to motion planning and control. The long stretched form of snakes makes thermal control somehow difficult. Transport of materials is difficult until an integral conduit is used. Robot snakes are far slower than their natural counterparts (reaching speeds up to 3.0 m/s) and far slower than wheeled vehicles.

7. Application

Serpentine robots are ideally suited for urban search and rescue, military intelligence gathering, and for surveillance and inspection tasks in hazardous and hard-to-reach environments. Snake-like robots are believed to offer several advantages over conventional wheeled or legged robots like they have low center of gravity, which makes them very stable when moving on inclines.

8. Contemporary Works

Some works are discussed below which were done in various universities and Research institutes. Summarization this various works will help us to understand various techniques for simulation of a biological motion in an artificial system.

8.1 Carnegie Mellon University

Carnegie Mellon University designed a serpentine robot, with 16 modules. Modules are connected by simple hinge joints. The idea behind the snakes is to create a robot able to adapt and transfigure itself under a variety of circumstances. It has a vision camera in front of the head by which it can search or inspect some thing [12].

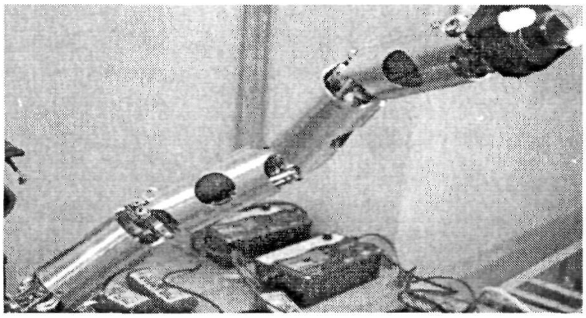

Figure 5: Robot developed at Carnegie Mellon University.

8.2 University of Michigan

The 26-pound robot developed at the University of Michigan College of Engineering is called OmniTread. It moves by rolling, log-style, or by lifting its head or tail, inchworm-like, and muscling itself forward. The Omni-Tread is divided into five box-shaped segments connected through the middle by a long drive shaft spine that drives the tracks of all segments Bellows in the joints connecting the sections inflate or deflate to make the robot turn or lift the segments. The bellows provide enough torque for the Omni Tread to lift the two fronts or rear segments to climb objects.

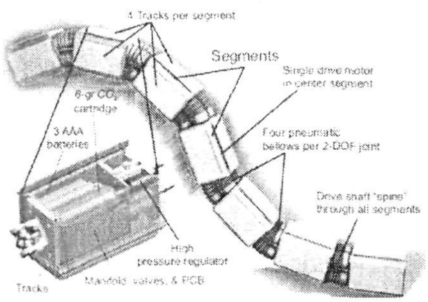

Figure 6: Snake robot developed at University of Michigan.

9. Conclusion

A number of documents have been studied related to serpentine locomotion, and it is found that biologically snake locomotion is activated by some critical biological mechanism; so simulation of this natural mechanism in a man made system is very challenging work. But if it is possible to simulate it in a man made device then it will be very useful for rescue and inspection in a narrow way or hazardous environment.

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The meeting of two personalities is like the contact of two chemical substances : if there is any reaction, both are transformed.

– Carl Gustav Jung