Dynamic optimization of snake robot with environment detection and analysis

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Abstract. Recent developments of snake robots have seen increasing interest in the aid of robotic systems to assist in disaster operations. This paper presents a design of snake robot for dynamic optimization to maneuver in various environments. The robot makes utilization of the friction between the body of the robot and the environment to move in. The components of snake robot chassis fabricated using 3D printing. Environment parameters such as temperature and moisture can be used to analysis the hazardous scenario. Obstacle avoidance techniques were also incorporated. Such a model was also simulated using the V-REP to verify its movements capabilities and to compare with real-time operation. Zig-bee module were utilized to wirelessly control the snake robot in remote areas for search and rescue operations. This paper describes the dynamic optimization of snake robot and presents experimental results of the robot locomotion through various environments.

1. Introduction

Recently, interest in bio-inspired robots has increased. In present, the most of the death of the people is due to disasters. To solve this problem, rescue robots have to develop with efficient robotics technology to save human being in disaster. The robot needs to be small enough to get into places inaccessible by humans. However, the robot must be able to surmount obstacles in disaster areas [1]. The robot should be controlled wirelessly and have camera for detection of persons trapped in disaster areas [2].

Snake robots are propelled by the structure of real snakes. But still, there is a large scale between the locomotion efficient of snake like robots and real snakes. They can move in irregular terrain, swim in underwater, climb and even glide in air by some species. They can move by undulating their bodies to exploit roughness in the terrain for locomotion which allows them to adapt in various sorts of situations [3]. Previous projects equipped tactile sensor in snake robot for contact type obstacle avoidance [4].

Fabricating a snake robot with such activity is a most attractive one. The development of such a robot is motivated by the way that diverse applications might be use in testing constant operations, hazardous situations, pipe in and out examination, and search and rescue. Snake robot utilizes walls/external objects in a scattered environment for obstacle avoidance [5] [6].
The mechanism of the robot has serially connected joint modules which have the capability to bend in various planes. The high degrees of freedom of snake robot makes difficult to control but provide efficient locomotion skills in scattered and irregular environments which better than the mobility of more prevailing wheel and leg robots [7].

Most of the previous robots use passive wheels to generate anisotropic friction for locomotion [8]. This robot generates anisotropic friction by undulating the bodies which makes hard to slip to sideways.

For the locomotion of snake robot, still none of the robots completely imitate the locomotion of biological snake. Most of the snake robot gait is a periodic mode of motion [9]. There are several types of locomotion for snake robot, where the movement is carried by using wheels, legs or slide by their bodies.

This robot moves in a specific gait, which is a serpenoid curve motion, like a lateral undulation motion. The lateral undulation locomotion has advantages over legged or wheeled motion are:

- Stability
- Terrain ability

![Figure 1. Serpentine Locomotion of biological Snake](image)

The lateral undulation locomotion has better stability than the wheel and legged one, because the connection between the body and wheels may be jammed [10].

Terrain ability is the ability of moving in an irregular terrain. Comparing the lateral undulation motion robot to the robot using wheels or legs, this robot has better terrain ability than the other gaits. For example, wheels and legs robot will stuck or jammed at a hole but this problem won’t happen in lateral undulation motion robot [11] [12].

2. Methodology of work

The process towards making the snake robot have different steps of process which starts from designing, modelling, fabrication and control of the robot.

First step is to determining the problem. The second step is analyzing the problem and developing a model. The next process is to develop the 3D model using modelling software. Next stage is to select the material for fabrication. Then, is to fabricate the model.

Finally, snake robot is modelled for search and rescue operation with obstacle aided locomotion and dynamic optimization.

The snake robot has three distinct parts of assignment, to be specific mechanical, electrical and programming. The programming part controls the progression of the snake robot by programming the servo motor associated with PWM pins and ready to lift the body in required movement for step climbing and hindrance helped motion [13] [14].
To generate a sine wave using PWM pins, will use two pins for positive half cycle and negative half cycle. Creating a sine wave has its importance particularly with devices like microcontrollers which keeps running on digital voltages. The sine wave is alluded to as the fundamental of all sort of waveform since the mix of sine waves can create any required wave. In microcontroller frameworks the simple yield like sine wave is created with the assistance of digital pulses itself which are produced such that their width is balanced comparing to the amplitude variations of a sine wave.

The robot motion should optimize by changing the amplitude, phase and frequency values to get an optimized sidewinding motion. The experimental results should compare with the simulation results using MATLAB [14] [15].
2.1. Mechanical Specification

Table 1. Mechanical specification of snake robot

| SPECIFICATIONS      | DETAILS                              |
|---------------------|--------------------------------------|
| Number of joints    | 12                                   |
| Size of link (mm)   | 100x80x80                            |
| Weight of link (Kg) | 0.168                                |
| Motion Range of joint [deg] | [-90, +90]                      |
| Actuators           | Dual shaft servo motor                |
|                     | 16Kg.cm Stall Torque                 |
| Sensors             | Ultrasonic Sensor, Temperature Sensor (DHT11) |
| Battery             | 7.4v 4400mah                         |

2.2. Servo Motor

The following cad model is the dual shaft servo motor chosen for snake robot.

![Figure 3. CAD model of Servo motor](image-url)
The dual shaft servo meter has the dimensions 39.88mmx19.81mmx36.32mm. Command signal for this servo motor is pulse width modification. The gear is made up of metal and its total weight is 59g. It has 2 ball bearings.

Sine curve equation is given to the servo motor using PWM pins to get the serpentine locomotion where it's similar to serpenoid curve.

![Sine Curve](image)

**Figure 4.** Serpenoid curve

When \( V = 6.0 \), torque and no-load speed is 16kg.cm and 0.16sec/60deg.

When \( V = 7.4 \), torque and no-load speed is 18.2kg.cm and 0.14sec/60deg.

Therefore, the speed of the servo motor is decreased when increasing in voltage.

2.3. Module

The figure 4. is the module which two servos will be placed for roll and yaw joint.

![Module](image)

**Figure 5.** 3D model of Module
The figure 5. is the frame where two servos are connected by alternate sides, which one servo is used for yaw joint and another is used for rolling joint.

2.4. Single Module

The figure 6. is the assembly of the servo motor and frame. Two servos assembly with the frame makes the yaw and rolling joint.

Each module will have two active joints and this module helps to generate body friction with the environment.

![Figure 6. Assembly of single module](image)

One module consists of two active joints which means two servo motors will be connected in the module for yaw and rolling motion.

2.5. Snake Robot Assembly
3. Control Interface

The control interface is divided into three parts: pc, wireless and snake robot. The pc will analysis and display the sensor parameters and display of video in real time. The pc software with GUI providing master control of the robot. The bluetooth module on pc and robot side will make highly secure one to one communication.

The snake robot consists of 6 modules which has 12 servo motors, a DHT11 temperature sensor and Arduino Mega as its microcontroller. All the servo motors are supplied with a 7.4v 4400mah battery to power up and the control signal is from the Arduino mega controller.

Figure 7. Snake robot assembly using aluminium brackets

Figure 8. Block diagram of control interface
4. Locomotion

4.1 Sidewinding Motion

Sidewinding is a movement utilized by snakes when they are on moving landscape, for example, sand. This movement is really a blend of the serpentine and rectilinear movements. To accomplish this movement the robot must be reconfigured. A side section associating one fragment to the C-section of the following portion is unscrewed and pivoted 90 degrees. This is done along the whole length of the snake. The odd servos will be situated concerning serpentine movement and even servos will have situated with respect to rectilinear movement. Sidewinding movement is accomplished by sending a flat cosine wave down the odd numbered servos and a vertical cosine wave (counterbalance from the level wave by 90 degrees) down the even numbered servos. The outcome is a sideways movement.

Signal modulation changes a sine wave to encode information. The equation representing a sine wave is as follows,

\[ A \cdot \cos(2\pi ft + \phi) \]  

(1)

Where \( A \) is the amplitude, \( f \) is the frequency, \( t \) is the time and \( \phi \) is the phase of the sine wave.

\[
\text{serial.write}(90 + \text{amp} \cdot \cos \left( \text{freq} \cdot \text{count} \cdot \frac{\pi}{180} - n \cdot \text{lag} \right))
\]  

(2)

In the equation (2), the Arduino command is used in a loop to create the sidewinding motion. Where \( n \) is the quantity of the present segment and takes esteem from 1 to 12, \( \text{amp} \) decides how wide the wave is (i.e. how much the "S" shape is bended), \( \text{freq} \) (along the variable delay Time) decide the speed of the snake, \( \text{counter} \) is the loop variable that takes the snake through its serpentine motion and \( \text{lag} \) is the consistent precise contrast between segments. The term \( \pi/180 \) is used to change degrees to radian.

5. Experimental Results

A test setup has been built to exhibit the proposed plan of snake robot. The actuator utilized for investigations is a dual shaft servo motor. Each link has 2DOF movements of roll and pitch which used to ground and lift the parts. The quantity of links is additionally in charge for curvature of the snake robot locomotion. This system is motivated by regular snakes that have more number of vertebrae. Every one of the vertebrae is considered as one link of the snake robot. Extensive quantities of connections are exceptionally hard to control in view of high degree of freedom and so the modest number of links will produce results on the fine curvature. In this manner, in this trial we set a snake robot with 12 segments. The changing of the speed by directing the frequency of the sidewinding locomotion velocity is approved by the experiment.

| S.No | Amplitude direction | Amplitude | Frequency | Speed     |
|------|---------------------|-----------|-----------|-----------|
| 1    | Amplitude Horizontal| 30        | 1         | 0.206km/hr|
|      |                     | 30        |           |           |
| 2    | Amplitude Horizontal| 35        | 1         | 0.258km/hr|
|      |                     | 35        |           |           |
| 3    | Amplitude Horizontal| 40        | 1         | 0.396km/hr|
|      |                     | 40        |           |           |
| 4    | Amplitude Horizontal| 45        | 1         | 0.365km/hr|

Table 2. Testing the sidewinding motion with different amplitudes
| Amplitude Vertical | 45 |
|--------------------|----|
| Amplitude Horizontal| 50 |
| Amplitude Vertical  | 50 |

From the table 2., it can conclude that the amplitude value = 40cm and frequency =1Hz is optimum value to get maximum speed for sidewinding motion.

Figure 9. Sidewinding motion of the robot (optimized)

The figure 9. represents the optimized working of the robot for each second (max 9secs). For completion of one curve the time taken is 2secs and it can be seen in the figure 9. from t=1sec to t=3sec.

6. Conclusion

This paper presented an experimental result to get maximum speed for sidewinding motion to the proposed design. The sidewinding motion is obtained by placing the servo motor in horizontal and vertical direction to ground and lift the parts. Experimental results demonstrated the effectiveness of the sidewinding motion.

Future work will investigate the simulation and experimental results for serpentine motion with obstacle avoidance using ultrasonic sensor.

7. References

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