Jurnal
Teknologi

Full Paper

Development of a Flexible Serpentine Robot for Disaster Surveillance Operations

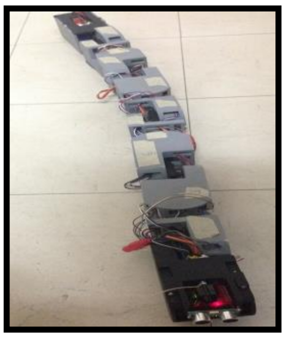
Argel A. Bandala, John William F. Orillo

Electronics and Communications Engineering Department
De La Salle University, Taft Avenue, Manila, Philippines 1004

Article history
Received
25 July 2015
Received in revised form
30 November 2015
Accepted
13 January 2016

*Corresponding author
argel.bandala@dlsu.edu.ph

Graphical abstract



Abstract

This paper presents the development of a snake robot with vision system. This can be used for disaster aid and lessen the danger that the rescuers may encounter. The design of the snake robot considers the use of its own body segments for motion using rectilinear motion rather than using wheels. The use of segments enables the snake to move on flat and uneven terrain. Servo motors will be used for the movement of each joint and it will be powered by a lithium-polymer battery. Accelerometers and gyroscopes will serve as the input and orientation sensors, a head-mounted camera will be used to detect its location and where it is moving. An Arduino Pro Mini will be used for the controller and will be configured to receive commands from an XBee wireless transmission transceiver from the base computer. A graphical user interface in a base computer will serve as the interface of the robot's operator and the robot. Its main movement will be based on a biological snake's rectilinear motion which is embedded in the robot's control system.

Keywords: Snake robot, mobile robot, serpentine robot, rectilinear motion, disaster, rescue.

1.0 INTRODUCTION

Disasters can strike at any moment and the effect that it can have on the surroundings are unpredictable. In the aftermath of the disaster, search and rescue is very important in terms of saving the people who survived the disaster. But rescuing people is dangerous also to the rescuers especially when the damage of the disaster to the buildings around it is fatal. Unexpected accidents may happen which can also turn the rescuers to victims. The idea of increasing the safety when it comes to rescuing people gave the idea of creating a robot which can explore the rubbles produced by the disaster. This robot is capable of giving the rescuers an insight of what they should expect and to help them know the location. Potential survivors that the rescuers are going to rescue can be searched and located by the robot. This greatly reduces the risk of injuring the rescuers and this may help in speeding up the survivor retrieval operations.

Most of the snake robots that are implemented make use of wheels in order to move from one point to another [1]. But when traversing in an uneven surface, big wheels will be needed but having big wheels cannot guarantee that the robot can still pass through all the obstacles that it will encounter during rescue. Another problem that robot with wheels may encounter is scaling steps or climb stairs, thus, limiting their movement on the ground upon which they are placed. This problem can be solved by using biological snakes as a reference for how the snake robot will move [2]. This paper created a snake robot which utilized segment movement rather than wheel movement to generate motion.

Through the use of segments, the robot can move through rough terrain and it can also scale obstacles which can block its path. Like how the snake moves in its environment, the segments give more flexibility/maneuverability since the segments can be moved in such a way that the snake robot can either move around or over an obstacle. Sensors were also installed in able to detect obstacles that the snake may encounter while it is moving and also another sensor which will be used to detect whether the segments are elevated or in an inclined plane.

Also, most of the snake robots implemented is tethered to be able to provide communication from the user to the robot and also to be able to provide power to the whole snake. The problem with having a tether during a rescue/survey operation is that the tether might get entangled which will then hinder the motion of the robot snake. This instance can make the operation a failure since the robot snake cannot move further unless the tangled tether gets fixed. This problem was solved in this paper. The developed snake robot does not utilize tethered communication. To be able to provide motion without having a tether, batteries are used in order to power the motors and the other components that are on the snake. Wireless technology was also used in order to relay the commands that we will send to the robot and also to be able to send and receive the information that the robot receives.

2.0 SNAKE ROBOT BODY DESIGN

The design of the robot was patterned to how biological snakes look like and how it moves. To be able to simulate the motion of the snake the group created segments which are connected to each other via servo motors which enable the segments to move.

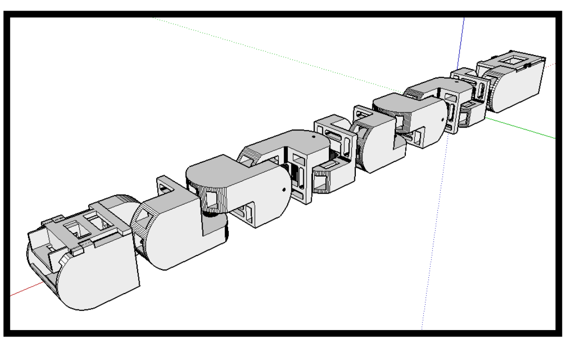


Figure 1 Design of the segments of the robot snake

Shown in figure 1 is the snake robot consists of 10 segments, including the head and the tail segment. All of the segments will contain servo motors which will enable it to move either up and down or left and right, depending on the orientation of the segment and the servo motor. The components that are located on the head segment is the Arduino, Adafruit, IMU (Inertial Measurement Unit), XBee, servo motors, ultrasonic camera and a camera. The camera is also connected to a smaller servo motor so that it can lessen the displacement of the camera whenever the robot is moving.

The other segments are made to be identical so that the parts can be easily replaced and so that the execution of the algorithm can be simpler. Each segment has its own servo motor for movement and the orientation of the segments alternate between Pitch and Yaw. Holes were also created in the segments so that wires can pass through it.

The tail segment then contains the Lithium-Polymer battery which powers all of the servos in the robot. It also contains two 9V battery which is used to power the Arduino and the camera separately. A safety circuit, which contains a fuse and three switches, was also added to the tail segment.

3.0 SNAKE ROBOT MOVEMENT

3.1 Linear Progression

There are different methods on how snakes move namely, the lateral/horizontal undulation, concertina motion, sidewinding and the linear progression [3]. For the movement of the snake robot, the group decided to use linear progression since it is better suited for fitting into tight and cramped spaces that it might encounter during the rescue mission [4].To send commands to the XBee, a GUI was created which contained the specific set of movements that the snake can execute. For its general functions it has move, climb, scan, and reset. Then under movement it contains the button for forward movement, backward movement, left and right movement, rudder control, shimmy left/right, and also reset. Then under the climb function are the buttons for climbing up, climbing down, and also shimmy. The GUI can also control the LED, Camera, and Ultrasonic sensor which are all located in the head segment. The scan command then contains the commands for scanning the vicinity by manually controlling the head segment. It contains 2 different modes which is high and low, and the buttons for controlling the snake manually which is the up, down, left, and right button. An orient button was also added to re-orient the snake when it topples to its side. The GUI displays the video feed that is being transmitted by the camera wirelessly.

3.2 Equations

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

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

There are several ways to obtain the motion of the snake robot but the researchers focused on using equations 1 and 2, which was created for the general movement of snake robots. This formula was first created by Shigeo Hirose, which he created by observing and studying the movement of serpenoids and from that he then created the parameters wherein the robot can imitate the movement of actual snakes [5]. Hirose also created another formula which is the one used by researchers who also study snake-like motion.

Another researcher, named Saito, further developed the formula that Hirose created, equations 3 and 4 thus ending up with his own formula which is used for the lateral undulation movement of the snake robot [6].

$$x(s) = \int_0^s \cos(a \cos b\sigma) + c\sigma)\, d\sigma \qquad (3)$$

$$y(s) = \int_0^s \sin(a \cos(b\sigma) + c\sigma)\, d\sigma \qquad (4)$$

Equation 5 formula has variables which can be changed to meet the user's parameters. These variable changes the Serpenoid curve, which is then implemented on the snake robot, by changing the height of its curve, number of phases on the snake itself, and the curvature of the snake.

$$\phi_i(t) = \alpha \sin(\omega t + (i-1)\beta) + \gamma, \ \ (i = 1, \dots, n-1) \qquad (5)$$

Where:

$$\alpha = a \left|\sin\left(\frac{\beta}{2}\right)\right|;\ \beta = \frac{b}{n};\ \gamma = -\frac{c}{n}$$

4.0 MOVEMENT FLOWCHART

Based from the flowchart, which can be seen in figure 2, the snake waits for the input of the user until it executes the command. There are different

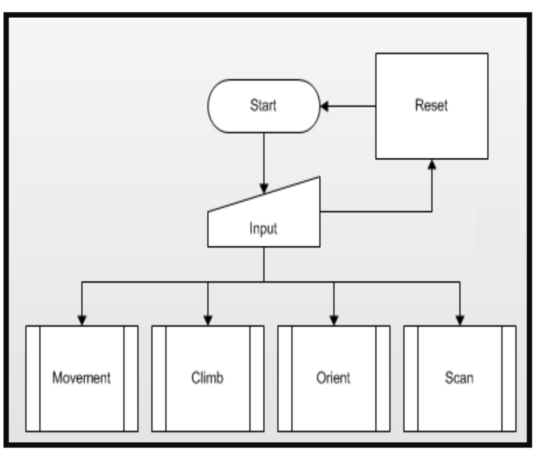


Figure 2 Movement function flowchart

general processes which can be executed based on the user's command and each general process contains more sub-processes which can be executed by the snake robot.

One of the main flowcharts of the robot snake is for the forward motion, which can be seen in Figure 3. This flowchart shows the adaptability of the snake robot by utilizing the ultrasonic sensor that is located in the head segment. Once the forward motion is selected the snake starts to move forward until either the user selects reset or until the ultrasonic sensor detects that an obstacle is in its path. Once an obstacle is detected the head segment pans upward while the ultrasonic sensor continues to read values until it obtains a value, which signifies that there is no obstacle present already, which then stops the panning of the head segment. The Arduino then stores the final value of the servo that was used to pan the head segment and checks if it is on the "too low", "goldilocks", or "too high" condition and based from the condition that was selected it executes a new set of commands. The obtained value is relayed through the servos after a given set of time thus making the snake adaptable to the obstacle that it is climbing.

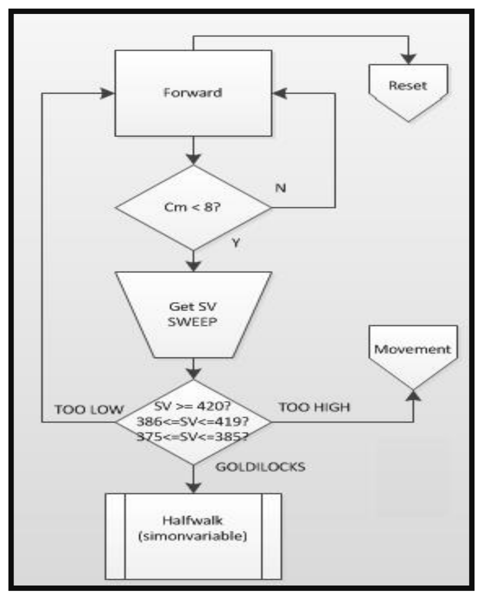


Figure 3 Forward motion flowchart

5.0 ROBOT DESIGN

The segments created were easier to handle and use since it is specifically designed for the components used. Through the trial and errors that the group did prior to the creation of the models, the previous faults from the other designs were corrected as well as ensuring that the possible errors that may be encountered were taken into consideration. The structural integrity of the re-designed 3D-printed snake robot body segment, proven by the drop tests, showed that it is capable of receiving damage without breaking. Simple ruptures of the links are fixed breakage. The complete model which also shows the length for each links can be seen in figure 4.

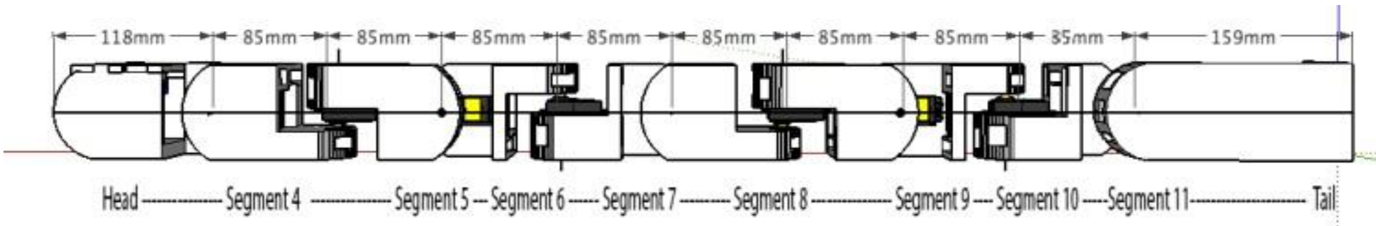


Figure 4 Complete Model of the 3D-Printed Snake Robot

There is an equidistant interconnection between the links for the body except for the head and the tail segments which are longer than the body segment due to the size of the materials located inside. The naming convention used for the segments followed the servo ports wherein the servo motors were connected in the Adafruit Servo Driver. Through this, the group aims to lessen, or avoid all-together, the confusion when it comes to the coding and repair of the segments.

6.0 DATA AND RESULTS

Testing the movement of the snake on different terrains and observe the effect of the terrain on the speed of the snake robot. The terrains that were tested included rocky surface, pavement, grass, vinyl, tiles, and tunnel. An obstacle course was also created to test its movement on a ramp, on a left and right turn, on a tunnel, and on an 18.5cm-high obstacle which is to be climbed by the snake robot.

FORWARD			
TERRAIN	ANGLE	AVERAGE TIME (s)	AVERAGE SPEED (m/s)
ROCKY	*STRAIGHT*	28.212	0.0373
PAVEMENT	*STRAIGHT*	20.776	0.0507
PAVEMENT	*7 degrees*	27.282	0.0387
GRASS	*10 degrees*	29.838	0.0353
VINYL	*STRAIGHT*	18.295	0.0577
TILES	*STRAIGHT*	22.104	0.0479
TUNNEL	*STRAIGHT*	28.461	0.0377

Figure 5 Forward movement data of the robot

Figure 5 shows the forward movement of the robot. The fastest speed that the group has obtained is at 0.0577m/s on a vinyl surface that has no inclination. Based from the figure, the speed decreases significantly when an inclination is introduced on the path of the snake robot. The difference of terrain also affects the movement of the snake robot but doesn't have a huge impact on the speed of its movement, with movement on vinyl having the fastest speed and movement on a grass surface with the slowest speed. Nevertheless, the group was still able to achieve its target speed which is at 0.01m/s.

BACKWARD			
TERRAIN	ANGLE	AVERAGE TIME (s)	AVERAGE SPEED (m/s)
ROCKY	*STRAIGHT*	27.936	0.0378
PAVEMENT	*STRAIGHT*	20.123	0.0523
PAVEMENT	*7 degrees*	12.861	0.0819
GRASS	*10 degrees*	16.553	0.0635
VINYL	*STRAIGHT*	15.251	0.0691
TILES	*STRAIGHT*	16.725	0.0629
TUNNEL	*STRAIGHT*	27.404	0.0386

Figure 6 Backward movement data of the robot

Figure 6 shows the backward movement of the robot. The fastest speed is on the inclined pavement. The inclination helped the snake in moving backwards due to the weight of the tail segment of the robot. The speed also decreases depending on what terrain the snake robot moves in, with the movement on the inclined pavement being the fastest and the movement on the rocky surface having the slowest speed. The group was still able to meet its target speed which is at 0.01m/s.

The video feed of the snake robot was also transmitted to the base computer which then contains the GUI for sending out commands to the snake robot. The commands were transmitted from the base computer to the snake robot through an XBee component which also relays values, which are obtained from the sensors, from the snake robot to the computer.

Figure 7 Setup of the test environment

The snake robot was also successful in executing its left and right functions and it still was able to meet its target speed which is at 0.01m/s. The climbing function was also successful given that the height of the stair is inside the range that the snake robot can climb on.

An obstacle course shown in figure 7 was also created to simulate the scenario of the snake robot entering a disaster area. Boxes and tunnels were created to simulate the rubble that may be present in the area and the rubble may be arranged such that the operator wouldn't have an idea of the surroundings before the test starts and the main objective is to be able to locate the target object inside the obstacle course. Based from the testing on the obstacle course, the group has observed that there are different approaches on how to locate the target in the obstacle course and it depends on the operator. The scan function is helpful in detecting the surroundings of the snake and for checking the corners of the obstacles and for locating the target especially if it is on top of an obstacle. The camera was useful in displaying the path that the snake is traversing and it was used to locate the target in the obstacle course.

7.0 CONCLUSIONS

The development of a snake robot which uses rectilinear motion would be helpful in creating safer and faster disaster aid rescue efforts and it would open a new window for future studies. The wireless communication of the snake robot to the computer allowed the snake robot to traverse without having troubles with being tethered to a base station. For the movement of the snake robot, the group was successful in achieving their target speed which is at 0.01m/s. The video feed was also important in helping the user to determine where the snake robot is and to be able to see where it is going. Through this topic, the group explored the movement that can be performed by using rectilinear motion and was able to establish a working prototype that can be further enhanced for actual implementation.

References

[1] Gavin M. 2013. Snake Robots, 1999. [Online]. Available: http://www.snakerobots.com/index.html. [Accessed 23 June 2013].

[2] Dowling K. J. 1997. Limbless Locomotion: Learning to Crawl with a Snake Robot, Pittsburgh: Carnegie Mellon University

[3] Pope C.H. 1956. Locomotion, in the The Reptile World, New York, Wiley. 151-155.

[4] Lissman H. W. 1949. Rectilinear Locomotion in a Snake (Boa Occidentalis), Cambridge: University of Cambridge. 368-379

[5] Hirose S. 1993. Biologically Inspired Robots: Snake-Like Locomotors and Manipulators, Oxford: Oxford University Press

[6] Sato M., Fukuya M., and Iwasaki T. 2002. Serpentine Locomotion with Robotic Snakes, *Control Systems*. 22(1): 64-81

[7] Bandala A.A., Dadios E. P. 2012. Development and Design of Mobile Robot with IP-based Vision System,*TENCON 2012-2012 IEEE Region 10 Conference*. 1-5