SNAKE ROBOT

A PROJECT REPORT

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in partial fulfilment for the award of the degree

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BACHELOR OF TECHNOLOGY

IN

ARTIFICIAL INTELLIGENCE ENGINEERING

श्रद्धावान् लभते ज्ञानम्

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CHAPTER 1: ABSTRACT

This project is to design a snake-like robot that can provide the locomotion as the real snake. The shape and sizes of the snake-like robot is dependent on its own application as different application may require different sizes and shapes. In order to make the snake-like robot function and move like a real biological snake, snake-like robot may construct of multiple joints which enable the snake-like robot to have multiple degree of freedom, which give it the ability to flex, reach and approach a huge volume in its workspace with infinite number of configurations. This mobility can enable the robot to move around in more complex environments. So, the application for this snake-like robot could be very useful in hard-to-reach places or hazardous environments.

CHAPTER 2: INTRODUCTION

Bio inspired robots are those that imitate features of fauna that we see around. By borrowing movement strategies from nature, robots could gain new functionality Although big industrial robots in vehicle factories, for instance, remain anchored in place, other robots will be more useful if they can move through the world, performing different tasks and coordinating their behaviour. Developing such robots that can bounce and land securely without risking harm to the mechanism, or developing body and facial expression of satisfaction and excitement are simple tasks for human and fauna to do however greatly complex to build. Recent technological developments have allowed one to easily animate graphically the appearance and conduct of biological creatures. The overall idea is looking to nature to see how things can potentially be done differently, how we can improve our automated systems. Biologically inspired robotics has enabled today's robots to operate in a variety of unstructured and dynamically changing environments in addition to traditional structured environments. As a result, intelligent robots will soon be ready to serve in our home, hospital, office, and outdoors. It is clear that bioinspired methods are becoming increasingly important in the face of the complexity of today's demanding applications. Biological inspiration in robotics is leading to complex structures with sensory-motor coordination, in which learning often plays an important role in achieving adaptation. This special issue is focused on the theoretical and technological challenges of evolutionary transformation from biological systems to intelligent robots.

Snakes are almost unique among the terrestrial vertebrates in their lack of legs. However, the lack of legs does not appear to have placed restrictions on the ability of snakes to move around. On the contrary, snake locomotion is stable, robust, and versatile. The speed of snake locomotion is, however, relatively slow, although certain species can move at speeds up to 11 km/h. Some snakes display specialised forms of motion. For instance, certain snakes can jump to heights of up to 1 m by curving their body into a vertical S-shape to serve as a spring, and then jump by stretching their body. Other snakes are able to glide through the air by throwing themselves from trees and forming their body in an aerodynamically favourable manner. In the following, the four most common types of biological snake locomotion are presented.

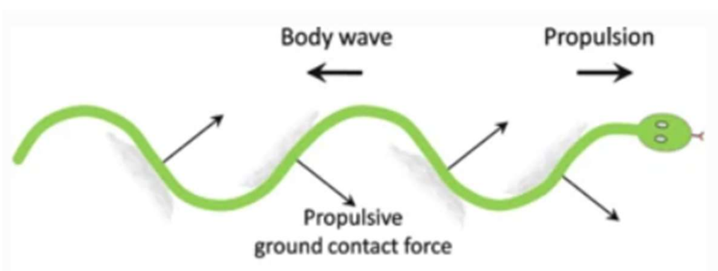

Fig 1: Lateral undulation motion of a snake

Lateral undulation, also called serpentine crawling, is the fastest and most common form of snake locomotion and is illustrated in Fig.1. During lateral undulation, continuous waves are propagated backwards along the snake body from head to tail. During this wave motion, the sides of the snake body push against irregularities in the surface, thereby pushing the snake forward. This form of locomotion is therefore not suitable on slippery surfaces. As the snake progresses, every point along the body passes the same point on the ground, and there is never any static contact between the ground and any point along the body. During swimming, the same wave motion is produced, but the body then pushes against the resistance of the water. The weight distribution of a snake during lateral undulation is not uniform, but rather distributed so that the peaks of the body wave curve are slightly lifted from the ground.

The employed locomotion method of snakes sometimes depends on the size of the snake and sometimes on the substrate over (or through) which it is moving. In fact, an interesting difference between snake locomotion and legged forms of locomotion is that the basic repeating motion that leads to propulsion of legged animals to a large extent depends on the progression speed of the animal. On the other hand, the basic repeating motion that leads to propulsion of snakes largely depends on the environment, and not on the speed. Considering the large number of muscles involved in the motion of a snake and also the large number of contact points that are sensed by its nervous system, it is fair to say that the coordination of snake movements is both impressive and complex. Simply speaking, the snake produces a relatively simple motor command which is modulated by local reflexes. This explains how every point in the body is able to follow the same trajectory.

The inspiration for snake robots comes from biological snakes. Snakes display superior mobility capabilities and can move over virtually any type of terrain, including narrow and confined spaces. They are good climbers, very efficient swimmers, and some snakes can even fly by jumping off branches and using their body to glide through the air. Also, a snake robot is a highly articulated robot manipulator arm with the capability of providing its own propulsion. These capabilities have spurred an extensive research activity investigating the design and control of snake robots. A snake robot is a robotic mechanism designed to move like a biological snake. Inspired by the robustness and stability of the locomotion of biological snakes, snake robots carry the potential of meeting the growing need for robotic mobility in unknown and challenging environments. These mechanisms typically consist of many serially connected joint modules capable of bending in one or more planes. The many degrees of freedom of snake robots make them challenging to control, but provide potential locomotion skills in irregular and challenging environments which may surpass the mobility of wheeled, tracked and legged robots.

Fig 2: Snake robot climbing a tree

CHAPTER 3: APPLICATIONS OF SNAKE ROBOTS

Snake is one of the creatures that exhibit excellent mobility in various terrains. It is able to move through narrow passages and climb on rough ground. This property of mobility is attempted recreated in robots that look and move like snakes. Snake robots most often have a high number of degrees of freedom (DOF) and they are able to locomote without using active wheels or legs. Snake robots suit a wide range of applications. One of many examples is rescue missions in earthquake areas. The snake robot could crawl through destroyed buildings looking for people. It could also carry small amounts of food or water to people trapped by the building prior to the arrival of rescue personnel. The snake robot can also be used for surveillance and maintenance of complex and possibly dangerous structures such as nuclear plants or pipelines. In a city, it could inspect the sewer system looking for leaks or aiding fire-fighters. Also, snake robots with one end fixed to a base may be used as a robot manipulator which can reach hard-to-get-to places. In comparison to wheeled and legged mobile robots, the snake robots have high stability and good terrain ability. The exterior can be completely sealed to keep dust and fluids out.

The world has been suffering from many natural and man caused catastrophic disasters during the last decades, like massive earthquakes, fire break outs, floods, airplane crash. In such events, collapsing of houses and buildings in large areas is almost inevitable. Hence, searching for victims and subsequent rescue operations from the rubble of collapsed buildings are major problems that must be faced and planned well ahead from the actual disasters. However, these operations are very dangerous for human workers and even for trained police dogs. Snake robot is a very useful tool in climbing into ruins to detect people. Snakes acquire many advanced motion capabilities: their body can function as “legs” when moving; as “arms” when traversing branches; and as “fingers” when grasping objects. However, it is their long, slender and smooth articulated body shape that makes them especially suited to enter and move inside small cracks and gaps, such as encountered in the disaster sites. The same performance can be expected from mechanical snakes that inherit these physical characteristics. Snake robot knows all force it touching and know environment. Force feedback control is used to cross obstacle. In order to inspect narrow and unstructured environments such as disaster sites, snake-like robots should have rugged construction, but at the same time be sufficiently sensitive to detect contact with their environments. In addition, control which allows the robot to adapt to its environment is also essential. Future applications of snake robots include agriculture, sanitation, firefighting, surveillance and maintenance of complex and possibly dangerous structures or systems such as nuclear plants or pipelines, intelligent services, media (for investigative reporting), exploration, research, education, military, disaster management, and rescue & search operations, inspection and maintenance in industrial process plants, archaeological exploration and subsea operations. Snake robots; thus, holds a lot in future (in terms of applicability) and great scope for India.

CHAPTER 4: LITERATURE SURVEY

Research on snake robots has been conducted for several decades. The research field was pioneered about 40 years ago by Professor Shigeo Hirose at Tokyo Institute of Technology, who developed the world's first snake robot as early as 1972. In the decades following the pioneering research by Professor Hirose, research communities around the world have developed several agile and impressive snake robots in efforts to mimic the motion capabilities of their biological counterpart which include designing of snake robots for locomotion in a pipe using trapezium -like travelling wave [1], designing a cost-effective modular snake robot to generate pedal wave locomotion on surfaces with irregularities, where the robot lifts its body parts to climb over obstacles [2], proposing a driving assistant mechanism (DAM) for a snake robot, which assists locomotion without additional driving algorithms and sensors [3], applying a spherical-linkage parallel mechanism (SLPM) as a flexure hinge, equivalent to the joints of a snake robot where a supporting control system was designed, and gait planning was conducted according to the characteristics of different application scenarios [4], building a robot with high degree of freedom to achieve serpentine gait and using of glossy PLA material for 3D printed parts as it has very less probability of breakage, warping during print compared to ABS [5], developed a modular soft snake robot that is capable of implementing gait cycles to mimic lateral undulation utilized by snakes for locomotion [6], designing a gripper module for a snake-like robot to perform search and rescue tasks in a narrow space [7], developed a robot capable of locomotion both on the ground and underwater due to its robust mechanical design, which has additional effectors (e.g., caudal fin, pectoral fins, thrusters) [8], developing a Compliant Omnidirectional Spherical Modular Snake Robot capable of climbing smooth obstacles by introducing compliant joints in the links interconnecting adjacent modules [9], kinematic and dynamic modelling of a wheel-less snake robot that has more potential for adapting to the environment [10], described about trends of motion, actuators, sensors, kinematic structure design, control method and applications. Focused on the various development of the snake robots based on previous snake robots' literature [11], designing a snake robot called SnIPE for inspection purposes in straight and curved provisional pipe with potential field method [12], proposing an autonomous navigation method based on the snake robot's motion characteristic constraints with non-nodes and an external assistant using its own Micro-Electromechanical-Systems (MEMS) Inertial-Measurement-Unit (IMU) and autonomous navigation positioning based on the Extended-Kalman-Filter (EKF) position estimation method [13], proposing a method that enables the robot to adapt to multiple pipe structures in a unified way which can be applied to motion that is necessary to pass between the inside and the outside of a pipe [14].

After referring to various papers, insights on different designs of snake robots have been gained. The design of the robot is affected by the aspect that is being focused. This is it depends on the purpose of its build. Some of the aspects that has been explored are Mimicking the Gait motion of a snake, i.e.; replicating a snake's slithering movement. Some papers have focused of tweaking the movement of the bot depending of the environment in which it's being used. For example: A fin has been attached to a snake bot that is used to explore under water, in order to increase its velocity. Some other papers have concentrated on achieving various kinds of configurations with a snake robot, where the body of the snake bot is made up of spheres so that it can even cross minor obstacles.

CHAPTER 5: IMPLEMENTATION

To achieve the serpentine motion, a single axis (1D) snake robot with 5 motors has been built. All the parts of the robot have been 3D printed.

1. ELECTRICAL COMPONENTS

Table 1: Electrical components required

S.No.	NAME	IMAGE	QUANTITY/SIZE
1.	MG995 Servo Motor		5
2.	Jumper Wires		7(M-F)
3.	Dot Board		SIZE: 4X7
4.	Arduino Uno		1
5.	Wheel Bearing		10
6.	RPS		1
7.	Gauge Wire (1.2mm)		2 (10 cm each)

2. 3D PRINTED PARTS

The below fig. shows the parts that were printed which include 4 servo mounts, 5 wheel rails (for 5 servo motors) and a nose servo mount, a tail servo mount, a nose cap and a tail cap.

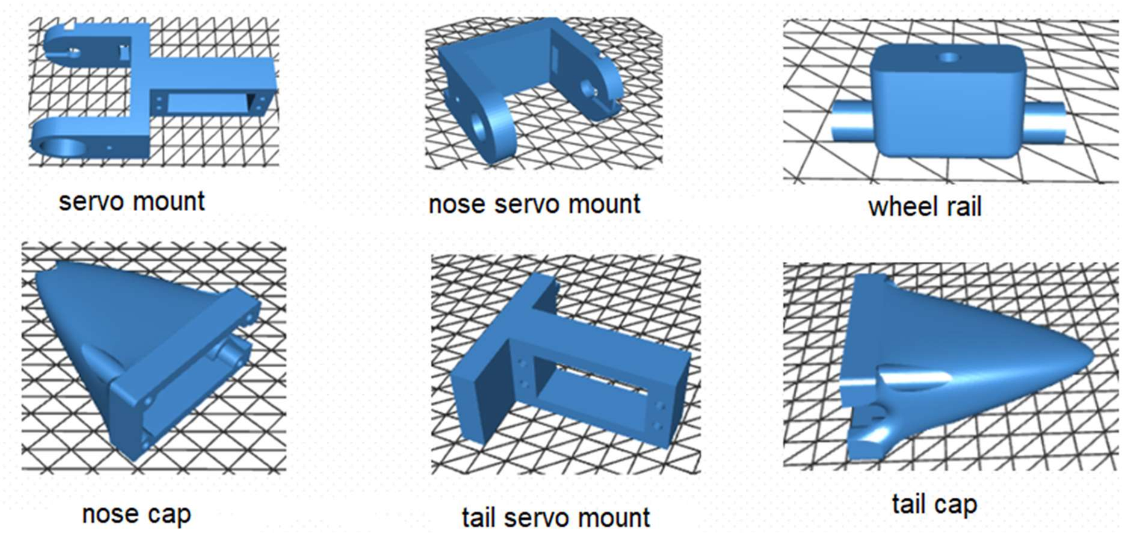

Fig 3: 3D printed parts

3. CIRCUIT CONNECTION AND SETUP

The dot board is soldered in such a way that all the servo motors are connected in parallel.

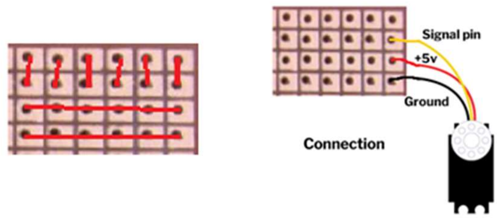

Fig 4: Dot board connection

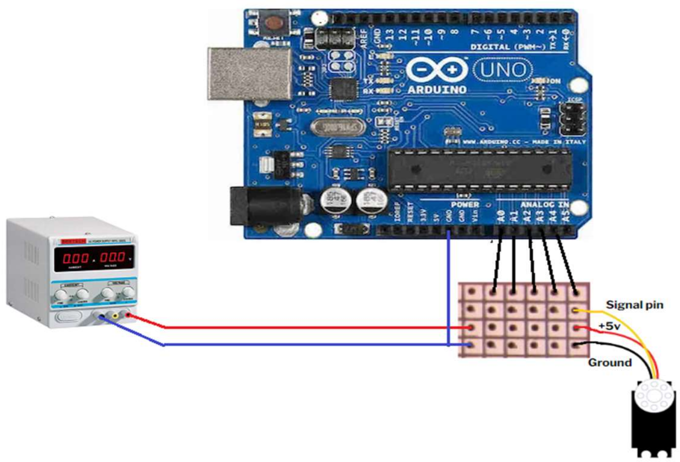

Fig 5: Circuit connection

Because the servos are wired in parallel, they all get the same voltage, but the current must be added up. Looking at the datasheet for MG995 servos they can draw up to 900mA each while running (assuming no stalling). Thus, the total current draw if all 5 servos move at the same time is 0.9A*5=4.5A. As such a normal 5v, 2A wall socket adapter won't work and hence RPS power supply was used.

- The five motors are connected in parallel using dot board.
- Servo motors have three wires: **power, ground, and signal**.
- The signal pins of the motors (typically yellow or orange) from the dot board are connected to the Analog pins(A0-A4) port in Arduino uno board.
- The terminal wires of the motors connected in parallel from the dot board are connected to the RPS.
- The terminal power wire (typically red) should be connected to the +ve of RPS.
- The terminal ground wire (typically black or brown) should be connected to a ground (-ve) of RPS.
- Arduino is connected to laptop through the adapter
- Ground port of arduino should be connected to RPS ground.

CHAPTER 6: CODE

```
#include <Servo.h>

Servo myServos[5];

float pi=3.14159;
int TotalNumberofServos=5;
float Shift = 2*pi/TotalNumberofServos;
float Wavelengths, rads;
int InteriorAngle, SetpointAngle, MaxAngleDisplacement;

void setup() {
  Serial.begin(9600);

  myServos[0].attach(A0);
  myServos[1].attach(A1);
  myServos[2].attach(A2);
  myServos[3].attach(A3);
  myServos[4].attach(A4);

  for(int i=0; i<5; i++){
    myServos[i].write(90);
    delay(15);
  }
  delay(1000);
}
```

Fig 6: Code to initialise the snake in straight line

```
void ubend(){
  for(int i=0; i<5; i++){
    if(i==2 or i==3){
      myServos[i].write(0);
      delay(100);
    }
    else{
      myServos[i].write(90);
      delay(100);
    }
  }
}
```

Fig 7: Code defining methods for ubend motion

U-shape can be obtained by rotating the 2nd and 3rd motor to 90 degree (mySeros[i].write(0)) and leaving the rest other motors default to 0 degree (mySeros[i].write(90)).

```
void slither(int offset, int Amplitude, int Speed, float Wavelengths){
  MaxAngleDisplacement=abs(offset)+abs(Amplitude);
  while(MaxAngleDisplacement>90){
    Amplitude=abs(Amplitude)-1;
    MaxAngleDisplacement=abs(offset)+Amplitude;
  }
  for(int i=0; i<360; i++){
   rads=i*pi/180.0;
   for(int j=0; j<5; j++){
      myServos[j].write(90+offset+Amplitude*sin(Speed*rads+j*Wavelengths*Shift));
     }
   delay(10);
  }
}
```

Fig 8: Code defining methods for slither motion

This line writes to each of the 5 servos a sine wave. The base line angle is 90 degrees, the offset variable will control if the snake goes forward (offset=0) or turns left or right (offset=10 or -10). The sine wave outputs a value between [-1,1], this value can be scaled up by multiplying by the amplitude.

```
for(int j=0; j<10; j++){
  myServos[j].write(90+offset+Amplitude*sin(Speed*rads+j*Wavelengths*Shift));
}
```

Since the servo has a range of [0,180] degrees we must ensure that the above values don't give an output below 0 or above 180. The following while loop is used to constrain the amplitude to with in these bounds. Mathematically we must satisfy this condition: |offset|+|amplitude|<=90

```
while(MaxAngleDisplacement>90){
  Amplitude=abs(Amplitude)-1;
  MaxAngleDisplacement=abs(offset)+Amplitude;
}
```

To get the desired output from the sine wave we must use radians instead of degrees. Essentially 2*pi radians = 360 degrees. The following line makes this conversion.

```
for(int i=0; i<360; i++){
  rads=i*pi/180.0;
}
```

Because each servo is a little further along the sine wave than the previous servo, we must shift each successive motor in the sine wave code. This is done using the following line. The shift variable can then be seen in action in the for-loop above.

```
float pi=3.14159;
int TotalNumberofServos=10;    //change as required
float Shift = 2*pi/TotalNumberofServos;
```

The values of the following variables: Amplitude, Speed and Wavelengths can be changed to see the effect they have on the sine wave output.

CHAPTER 7: RESULTS

Fig 9 shows the snake robot after assembling the 3D printed parts and the motors together. And the required circuit connection is also set up.

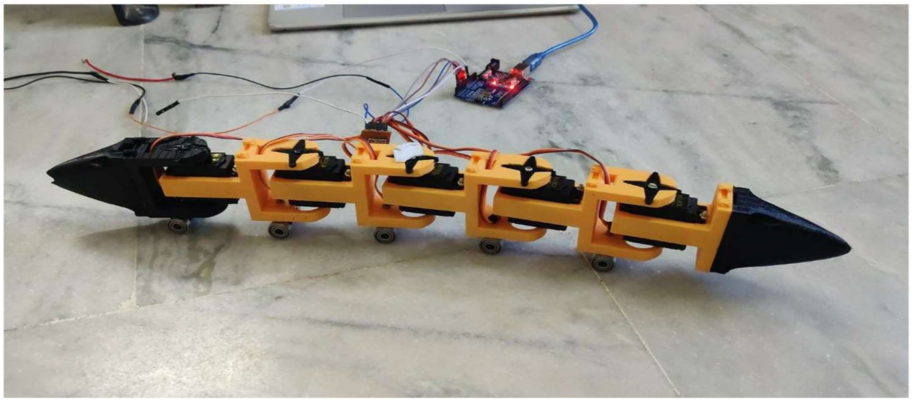

Fig 9: Assembled snake robot

Fig 10: Snake robot in Ushape

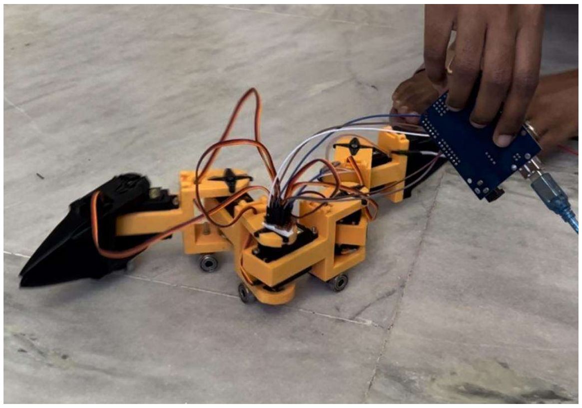

Fig 11: Snake robot in slithering motion

CHAPTER 8: CONCLUSION AND FUTURE SCOPE

In this project of building a snake robot, various 3D designs for building Bio inspired robots have been explored. Insights were gained on the applications of snake robots. All the parts of the robot were completely 3D printed which were designed such that they can incorporate five servo motors to achieve the serpentine motion. In this project, slithering motion and ushape motion have been achieved.

Coming to the future scope, this robot can be expanded and other types of motion can be explored. Many applications such as surveillance can be added by making use of sensors. A soft robot can be developed using a similar mechanism implemented in this work.

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