Fabrication of a Modular 3D-Printed SnakeBot for Terrain Adaptation

Lakshyada Pradhan[1], Aryan Butaney[2], Aryan Singh[3], Rabinder Henry[4]
[1234]*UGDx School of Technology, Atlas SkillTech University, Mumbai, India*

***Abstract*—This work presents the mechanical, computational and structural design of a snake-like robot. The robot consists of 10 articulated segments with two degrees of freedom (2-DOF), inspired from serpentine locomotion in nature. The entire mechanical framework is 3D-printed using low density internal mesh structure, designed to reduce weight while maintaining shell stiffness. Each segment contains a compartment for servo motors, wiring, sensors and microcontroller. The control system is based on an ESP32 microcontroller for low-level actuation. The assembled bot demonstrated sidewinding, lateral undulation and serpentine crawling across different surfaces.**

***Index Terms*—Snake robot, modular robotics, 3D printing, serpentine locomotion.**

I. INTRODUCTION

Snake inspired robots have a unique advantage for movement and locomotion in confined and unstructured environments due to their long, slender, articulated bodies. Their ability to propel themselves using wave-like motions in narrow spaces makes them useful for inspection, search and rescue, and exploration tasks. Most research-grade snake robots are expensive to build; this work, in contrast, uses 3D-printed segments and low-cost servos.

The development of a simplified snake robot that preserves key locomotion characteristics while remaining affordable is the primary objective of this paper. The proposed SnakeBot adopts a modular architecture with serially connected yaw joints. The robot features lightweight, 3D-printed segmented shells with low-infill designs, integrated wiring channels, and servo motor housings. An ESP32 microcontroller handles actuation and gait control.

This platform gives students hands-on exposure to kinematics, locomotion planning, embedded control, and additive manufacturing.

II. DESIGN OBJECTIVES

The following design objectives were established for this project:

- Creating a modular snake robot built from 3D-printed components.
- Limit the maximum length to ≤ 1 meter for safe classroom use.
- Implement 2-DOF joints per segment using servo motors for simplicity.
- Provide individual compartments for internal housing for servos, microcontrollers, and power source.
- Enable basic locomotion patterns: Serpentine wave and Sidewinding.
- Use safe low-voltage operation (≤ 7.4 V).

III. SYSTEM SPECIFICATIONS

A. Mechanical Dimensions

Table I. Mechanical Dimensions

Parameter	Specification
Number of Segments	10
Length	0.95 m
Width per Segment	60 mm
Height per Segment	55 mm
Joint DOF	2 DOF yaw
Material	PETG and ABS
Shell Structure	Low-density mesh frame

B. Actuators

Table II. Actuators

Joint	Motor
Segment Yaw	MG996R / 15–20 kg·cm metal-gear servo

C. Electronics

Table III. Electronics

Component	Specification
MCU	ESP32
Power	12V adapter to 5V output
Sensors	Camera, Sound, Temp & Humidity
Communication	UART / I2C between modules

IV. MECHANICAL DESIGN

The structure of each segment includes a 3D-printed shell body with ribbing for strength, servo components, side channel for wires, joint connector block for attaching to the next segment and all the segments are connected using M3 screws.
The body has a low-density mesh and to reduce print time and weight the outer shell is 1.6-2mm thick, infill density is 10-15% with a honeycomb filling. The mesh openings allowed on underside for airflow.

Each joint provides ±45° of yaw rotation. Forward kinematics are governed by:

$$\theta_i(t) = A\sin(\omega t + \phi_i) \qquad (1)$$

Where A = amplitude, ω = angular frequency, and φi = phase offset. Phase offsets generate traveling waves along the body of the robot.

V. ELECTRONIC STRUCTURE

The low-level micro controller handles servo PWM generation. It has 16 channels at works at 50Hz. It can also be used to generate gait, control Wi-Fi and IMU polling.
The sensors used are camera module (ESP32-CAM), temperature and humidity (DHT11), and sound sensor (MAX9814).
The power is distributed through a 12V wall-adapter sent to a buck convertor. The power is lowered from 12V to 6V. The converted power flows through the ESP32, the servos, and the sensors.

VI. LOCOMOTION ALGORITHMS

A. Serpentine Locomotion

Classical sine-wave propagation is implemented for serpentine locomotion:

$$\theta_i = A\sin(k_i + \omega t) \qquad (2)$$

This produces lateral undulation suitable for flat and lightly textured surfaces.

B. Sidewinding

Sidewinding employs a phase shift between vertical and horizontal sinusoidal waves:

$$\theta_i(t) = A\sin(\omega t + \phi_i) \qquad (3)$$

Contact reduction is applied for sandy or granular terrain to improve forward progress.

VII. SOFTWARE ARCHITECTURE

The layers of the system include a low-level control layer (MCU), mid-level locomotion layer, perception layer, and user interface layer.
The control layer (MCU) manages the PWM servo motor drivers, sensor readings, and ensures system safety. The locomotion layer handles snake gait equation and joint angle sequencing via PWM to achieve smooth motion. The perception layer captures images and videos through the camera, and enables live video streaming. The user interface layer consists of a web server for live feed, control dashboard, status telemetry.

VIII. EXPERIMENTAL RESULTS

Tests were performed on two surface types: a vinyl floor and a wooden table. These surfaces represent smooth, low-friction environments representative of indoor use cases.

Table IV. Experimental Metrics

Test	Result
Serpentine speed	~0.18 m/s
Sidewinding speed	~0.15 m/s
Control latency	< 20 ms

It was observed that the low – density shell reduced weight.
The microcontroller heating was observed after 30+ minutes, rest intervals are required.
The accurate wave propagation was achieved. The modular assembly simplified repairs during trials.

Please find the attached picture of completed SnakeBot in Fig. 1.

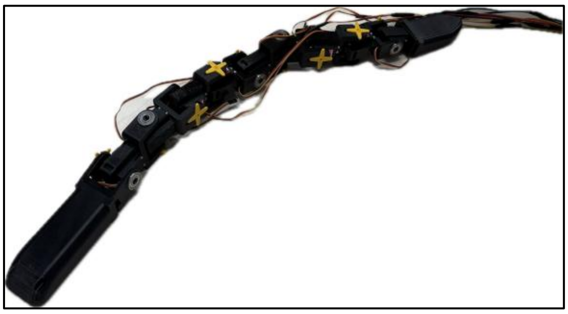

Fig. 1 Assembled SnakeBot

IX. EDUCATIONAL IMPACT

This platform exposes students to a broad range of engineering disciplines, including modular robotics, nature-inspired engineering, servo control, gait generation, embedded programming, additive manufacturing, and system integration. This work aligns well with the multidisciplinary project-based learning framework of NEP 2020.

X. DISCUSSION

The advantages of the project are that it was completely 3D printed. The repairing is easy because of the modular assembly. It supports multiple locomotion modes.

The prototype is limited to smooth surfaces only and the torque it restricted. Structurally it is not waterproof and does not have enough space for electronics.

To enhance the model in future a rolling gait can be achieved along with customized actuators. To make the body waterproof a soft robotic outer skin can be designed. Additionally, the control system can be wireless with ROS2 support.

XI. CONCLUSION

This paper presents the fabrication of an additively manufactured, bio-inspired snake robot built for educational purposes. The robot successfully demonstrates serpentine locomotion patterns and modular assembly while maintaining low cost. Future enhancements of the snake robot can also be directed toward search-and-rescue missions during natural disasters. Its architecture provides a foundation for studies in bio-inspired robotics and embedded systems.

ACKNOWLEDGMENT

The authors thank the UGDx School of Technology, Atlas SkillTech University, for providing laboratory infrastructure and resources in support of this work.

REFERENCES

[1] H. Yamada, "Bio-inspired Snake Robots," IEEE Robotics Magazine, 2019.

[2] S. Hirose, Biologically Inspired Robots: Snake-like Locomotors and Manipulators, Oxford Press.

[3] A. Gupta et al., "Educational Robotics Platforms Using 3D Printing," in Proc. IEEE EDUCON, 2023.

[4] M. Tesch et al., "Parameterizing Serpentine Motion," in Proc. IEEE ICRA, 2015.

[5] B. Siciliano and O. Khatib, Springer Handbook of Robotics, Springer.