Rescue Operation & Surveillance by Slow Snake Robot

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***Abstract*—Snake robots have gained significant attention due to their potential applications in search and rescue operations, industrial inspections, and exploration in confined or hazardous environments. However, traditional snake robot designs have faced several limitations, such as poor obstacle avoidance, inefficient locomotion on varied terrains, lack of flexibility, and suboptimal integration of vision systems. Many existing projects also suffer from issues like complex control systems, low-quality hardware components, and limited autonomy.**

This paper presents a Slow Snake Robot that overcomes these challenges through innovative design and advanced functionality. The robot features a highly flexible modular structure and is equipped with a high-resolution camera for real-time vision-based navigation. By employing robust obstacle avoidance algorithms and adaptive locomotion strategies, the robot can navigate efficiently through complex terrains without external control. Unlike traditional designs, our project emphasizes seamless integration of sensors, actuators, and microcontrollers to achieve smoother, more realistic movements

***Index Terms*—Microcontroller, Rescue Operation, Snake Robot, Camera Module.**

I. INTRODUCTION

Snake robots are a unique category of robots that are capable of traversing areas where wheeled or legged robots would not be able to move. The first qualitative research on snake locomotion was done by J. Gray in 1946 [1]. The first working biologically inspired serpentine robot was made by Shigeo Hirose in 1972 [2]. Various structures of snake robots have been designed to realize navigation [3]. They mimic the motion of actual snakes so that they can navigate through small spaces, climb over obstacles, and traverse rugged terrain. Our project is focused on creating a flexible, 3D-printed snake robot that navigates with the aid of special motor controls, which allows it to twist and bend for improved mobility in various environments. [4] used a decentralized state-of-the-art compliant controller to realize the autonomous navigation of snake robots through densely cluttered environments.

To enhance the functionality of the robot, we are employing an ESP32-CAM module, which offers live video streaming, enabling users to view what the robot views in real-time. Manual control through WiFi is facilitated by the Blynk app, making it simple to control the robot remotely. With the integration of IoT, robotic control, and object detection, our snake robot finds application in numerous tasks like surveillance, exploration, and search-and-rescue operations.

II. WORKING PRINCIPLE

A. Startup

The ESP32-CAM connects to Wi-Fi and initializes the motors, ultrasonic sensor, and camera.

B.Manual Mode (Blynk App)

The user can control the direction of the robot through the Blynk interface on a smartphone.

C. Autonomous Mode

The ultrasonic sensor repeatedly measures the distance to objects in front of the robot. If an obstacle is detected within a set threshold, the ESP32-CAM triggers a response to avoid the object by adjusting motor speeds. The robot can reroute itself autonomously to prevent collision, based on real-time sensor data. [5] adopted a simplified model to control the path-following of snake robots, but the average model cannot fully capture the complex dynamic characteristics of the actual system.

D. Camera Feedback

The ESP32-CAM streams video, which is accessible through the app, helping the user assess the robot's path or surroundings, useful for remote monitoring.

III. CIRCUIT DIAGRAM

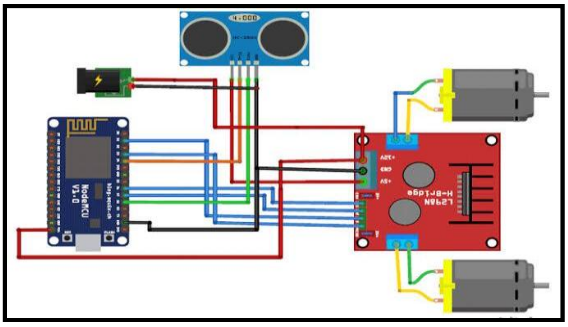

Fig 1.1: Circuit Diagram

Figure 1.1 shows the circuit links a NodeMCU (ESP8266), an L298N motor driver, an HC-SR04 ultrasonic sensor, and two DC motors to form an obstacle-avoiding
robot. Motor movement is controlled by the NodeM CU using distance information from the ultrasonic sensor. The L298N motor driver allows the motors to move in forward, backward, or turning directions. Upon detecting an obstacle, the NodeMCU controls the motors to evade it, making the robot completely autonomous.

IV. COMPONENTS

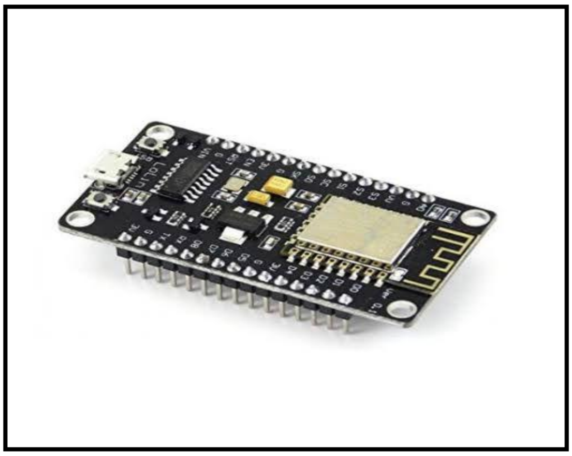

Fig 1.2: Microcontroller (ESP8266) :

Figure 1.2 ESP8266 is a small and low-cost Wi-Fi microcontroller that can be used to control different devices using the internet. This means you can connect it to a Wi-Fi network and send or receive data, allowing you to control things like lights, motors, sensors, or even home appliances from anywhere in the world.

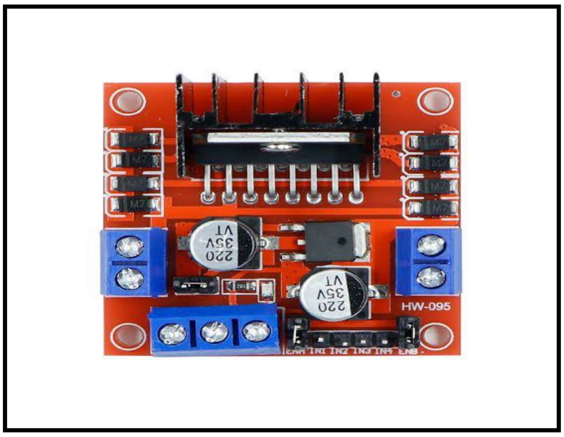

Fig 1.3: Motor Driver(L298N) :

Figure 1.3 L298N is a motor driver module that can control the speed and direction of two DC motors at the same time. It works using a dual H-Bridge circuit, which allows the motors to move forward, backward, or stop based on the signals it receives from a microcontroller like Arduino or ESP8266.

Fig 1.4: Camera Module (ESP32 CAM)

Figure 1.4 The camera module is used to capture a video feed, which means it records live video. This video is then sent to a microcontroller (like an ESP8266, Raspberry Pi, or Arduino with a camera module). The microcontroller processes the video data and can do different things with it.

Fig 1.5: Ultrasonic Sensor

Figure 1.5 Ultrasonic sensors, like the HC-SR04, are used to detect obstacles by measuring the distance to objects. They work by sending out sound waves that are too high for humans to hear. [6] introduced a Model Predictive Control (MPC) method that incorporates obstacle positions. These sound waves travel through the air until they hit an object, then they bounce back to the sensor.

V. DESIGN DETAILS

A. 3D-printed Body Design

The body is segmented and flexible, allowing it to mimic the snake's natural undulating motion. The segments are designed to house the motors, ultrasonic sensor, and wiring securely.

B. ESP32-CAM Placement

Positioned at the front, the ESP32-CAM module offers a clear field of view for video streaming and monitoring, useful for remote inspection or exploration.

C. Motor and Sensor Configuration

Two 100 RPM DC motors are connected to a motor driver, which controls the speed and direction based on input from the ESP32-CAM. The ultrasonic sensor, mounted at the front, continuously scans for obstacles and feeds data to the ESP32-CAM, which processes it to make decisions for autonomous navigation.

D. Power Supply

The robot uses a portable rechargeable battery pack, ensuring sufficient power to drive the motors, ESP32-CAM, and sensors for extended operational time.

VI. METHODOLOGY

Hardware Components (Physical Parts) ESP32-CAM Module – This is the "brain" of the robot. It allows video streaming and wireless control through a smartphone.

DC Motors (100 RPM) – These small motors help the robot move forward, and backward, and change direction.

Ultrasonic Sensor – This sensor detects objects in front of the robot. If there is an obstacle, it helps the robot change direction to avoid collisions.

3D-Printed Body – The robot's body is designed to be flexible, just like a real snake. This special design allows it to slither smoothly.

Motor Driver – This part controls the motors, adjusting their speed and direction to move the robot as needed.

Software Components Blynk App – A smartphone app that lets users manually control the robot by sending movement commands.

Arduino IDE – A software used to program the ESP32-CAM. It helps connect the motors and sensors so the robot can follow instructions.

Obstacle Detection and Avoidance Logic – A smart program that processes data from the ultrasonic sensor. It tells the robot when to change direction to avoid obstacles. [7,8] proposed Reinforcement Learning (RL) based methods to avoid obstacles. However, coach-based approaches typically require a large amount of training data and time to provide sufficient experience for the robot. This can consume a lot of resources and costs, and may not be suitable for some real-world application scenarios. Takanashi et al.

Movement Mechanism The robot moves by using two DC motors, which create a slithering motion similar to a snake.

Manual Control: If a person controls it using the Blynk app, they can move it in different directions by sending signals to the motors.

Autonomous Mode: If the robot is moving on its own, the ultrasonic sensor keeps scanning for obstacles. When it detects an object, it changes speed and direction to avoid hitting it.

VII. APPLICATION

A. Search and Rescue Operations

Entering Dangerous Areas: The robot can go into dangerous places where humans might get hurt, like buildings that have collapsed, tunnels filled with smoke, or areas affected by earthquakes and floods.

Finding Trapped People: It can move through small openings in the rubble to locate people who are stuck and send back information to rescuers.

Delivering Supplies: The robot can carry small items like water, medical supplies, or communication devices to trapped individuals until human rescuers can reach them.

B. Industrial Inspection and Maintenance

Checking Pipelines and Ducts: Many factories and cities have underground pipes and air ducts that need regular checking for leaks or blockages. The robot can move through these narrow spaces and inspect them without the need for human workers to enter dangerous or hard-to-reach areas.

Preventing Accidents: It can find cracks, corrosion, or damage before they become serious problems, reducing the risk of major failures or leaks.
Reducing Shutdown Time: Instead of shutting down an entire facility for inspection, the robot can check pipelines while operations continue, saving time and money.

C. Military and Defense

Scouting Dangerous Areas: In battle zones or dangerous environments, the robot can go ahead of soldiers to gather information, such as checking for enemies, landmines, or hidden explosives.
Reducing Human Risk: Instead of sending soldiers into risky areas first, the robot can provide a clear picture of the situation, allowing safer decision-making.
Night and Stealth Operations: The robot can move quietly and enter enemy areas undetected, providing intelligence without putting human soldiers in danger.

D. High Flexibility and Adaptability

Moving Through Tight Spaces: Because of its flexible, snake-like design, the robot can twist and bend to fit through narrow passages, tunnels, and complex structures where normal robots with wheels or legs might struggle.
Navigating Obstacles: It can move over rubble, around fallen objects, and through uneven surfaces, making it perfect for disaster areas or industrial sites.
Climbing and Slithering: Unlike regular robots, it can climb over obstacles or squeeze through gaps like a snake, giving it more freedom to explore difficult areas.

E. Enhanced Navigation Capabilities

Maneuvering Through Confined Areas: The robot can travel through places that are too small or crowded for larger machines, such as tunnels, caves, and dense forests.
Reaching Hidden Spaces: It can crawl into machinery, between walls, or under floors to inspect and report on areas that would normally be hard to access.
Working in Crowded Locations: Whether in a factory, underground tunnel or a collapsed building, the robot can weave through tight spaces without getting stuck.

VIII. FUTURE SCOPE

A. Smarter and More Autonomous Robots

In the future, these robots will be able to make decisions on their own using artificial intelligence (AI).
They will be able to recognize obstacles, find the best path, and complete tasks without human control.
This will make them faster and more efficient in rescue missions, military operations, and industrial work.

B. Advanced Sensors for Better Detection

Future versions will have improved cameras, heat sensors, and chemical detectors to find people, detect dangers, and analyze environments more accurately.
They will be able to see in the dark, sense movement, and detect harmful gases, making them even more useful in dangerous situations.

C. Stronger and More Flexible Design

Scientists and engineers will develop more flexible and durable materials to make the robot stronger but still lightweight.
This will allow it to survive in extreme conditions like high heat, underwater, or even space exploration.
It will also be able to climb better and squeeze through even smaller gaps.

D. Medical and Healthcare Applications

In the future, these robots could be used for medical procedures, such as entering the human body to help doctors diagnose and treat diseases without surgery.
They might assist in carrying medicine or medical tools inside disaster zones where human doctors cannot reach them easily.

IX. CONCLUSION

The proposed project can have the potential of flexible robotics in practical applications such as search and rescue, surveillance, and exploration. The Slow Snake robot's ability to operate independently, adapt to its surroundings, and make real-time decisions highlights its effectiveness and versatility. In our Proposed project more advanced sensors, Machine learning algorithms, and improved power management can be implemented to expand its capabilities further. The development of the small, flexible snake robot can demonstrate significant advancements in robotic design and autonomous navigation. The incorporation of the ultrasonic can allows the robot to detect and avoid obstacles autonomously, while the miniature camera can provide real-time visual feedback for enhanced navigation.

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Thank You For Enabling Innovation Through Your Exceptional Technology.

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