IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 5, Issue 3, November 2025

Impact Factor: 7.67

Wildlife Monitoring and Forest Survey Spider Robot

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Abstract: *This paper presents the design and implementation of a quadruped spider robot aimed at assisting in wildlife monitoring and forest survey operations. The robot is developed to navigate uneven terrains, detect the presence of animals or humans, and transmit live data for remote observation. The system combines mechanical legged locomotion, artificial intelligence–based object detection, and wireless communication for real-time environmental monitoring. The proposed spider robot uses an ESP32 microcontroller as the central processing unit integrated with a PCA9685 servo motor driver, MPU6050 sensor, and ESP32CAM module for thermal and visual data acquisition. The motion of four servo-actuated legs enables stability and adaptability in rough forest surfaces. AI algorithms such as YOLOv3 and thermal sensing allow identification of poachers and wildlife even in low-light conditions. The system provides a low-cost, portable, and autonomous monitoring solution with potential applications in anti-poaching efforts, ecological research, and forest surveillance.*

Keywords*:* Quadruped Robot, Wildlife Monitoring, ESP32, PCA9685, YOLOv3, Thermal Imaging, Forest Survey, IoT Robotics

I. INTRODUCTION

Spider Robot is proposed to perform autonomous forest patrolling and wildlife monitoring. The robot uses a visionbased detection system and communicates with a remote server for real-time tracking. The ESP32 microcontroller serves as the processing unit, integrating multiple modules for locomotion control, environmental perception, and wireless communication.

A. Background - Recent years have seen significant advancements in IoT-enabled surveillance and robotics. However, traditional monitoring systems are limited by static coverage and the need for manual maintenance

B. Problem Statement - Current forest monitoring systems are unable to provide adaptive, real-time data collection in dense and uneven terrains. They lack mobility, autonomous operation, and effective data communication, resulting in delayed responses to illegal or dangerous activities.

II. LITERATURE REVIEW

Robotic systems have increasingly been explored in environmental and wildlife applications due to their ability to access remote areas, minimize human intervention, and provide consistent monitoring. Early research in wildlife surveillance largely focused on the use of static cameras and drones. While drones provided a wider aerial view, their short battery life, noise generation, and limited night surveillance capabilities restricted their long-term deployment. In contrast, groundbased mobile robots emerged as a practical alternative for sustained monitoring within forest environments.

Sharma et al. [1] introduced a rover-based forest surveillance robot equipped with basic obstacle detection and GSM alert systems. Although it performed well on flat terrain, its performance was limited in rugged or uneven forest paths, Patel and Desai [2] explored an Arduino-controlled surveillance robot with PIR sensors and GPS. This robot could detect motion and send location alerts via SMS, but lacked video monitoring and real-time remote control features, limiting its application in critical poaching situations. Vijayalakshmi et al.

[3] proposed a forest patrol robot mounted on wheels, controlled via Bluetooth and integrated with a PIR sensor. While it performed basic obstacle avoidance and motion detection, its design limited its mobility to relatively flat terrain. In densely forested areas, such a system would struggle with roots, rocks, and uneven ground.

Another significant contribution came from Singh et al. [4] introduced an IoT-based smart surveillance system equipped with thermal cameras and solar-powered sensor nodes for continuous wildlife monitoring. Although innovative, the system was designed to be stationary and lacked patrolling functionality, which meant it could not actively track moving targets or cover large geographic zones. This highlighted the need for a mobile robot capable of persistent area coverage and adaptability. Chaudhary and Patel [5] designed a robot for agricultural surveillance using NodeMCU and Blynk App, which demonstrated that live video and IoT-based alerts can be achieved with minimal cost. Their approach, however, did not address terrain adaptability, as the robot used wheels. These developments form the basis for our spider robot design, which utilizes servo-based leg movement to navigate rough paths. A research paper from IEEE Xplore (2021) emphasized that combining GPS with live image transmission dramatically increases the efficiency of patrol responses to poaching threats. However, these systems are often power-hungry and lack scalability due to cost. Our project attempts to overcome these limitations by utilizing energy-efficient components and opensource platforms to reduce costs without compromising key surveillance features.

From this review, it is evident that despite the progress, a significant research gap still exists in developing a terrainadaptive, low-cost, mobile surveillance robot specifically targeted for wildlife monitoring and poaching prevention. The proposed spider robot aims to fill this gap by merging biomimetic locomotion with real-time sensing and communication, providing a practical and scalable solution that can be deployed in various forest ecosystems.

III. PROPOSED APPROACH

The proposed approach has a camera and sensors that send data to the microcontroller. The microcontroller controls servo motors and motion sensors. Captured data is sent via the communication module to another microcontroller. The receiver side displays data and controls movement through joysticks.

The quadruped robot uses 3-DOF legs driven by a PCA9685 servo controller, with MPU6050 feedback ensuring stable movement. An ESP32-CAM module handles live video streaming and YOLOv3-based detection of humans and animals for real-time monitoring. Communication is supported by Wi-Fi for short range and LoRa for long-range data transfer, enabling both manual and semi-autonomous control. Navigation is guided by the A* algorithm with IMU-assisted orientation correction, while a 7.4V Li-Po battery powers the system efficiently through optimized servo operation and a lightweight 3D-printed frame.

A. System Architecture

The system architecture integrates onboard control, sensing, communication, and remote operation into a unified framework. At the robot side, an ESP32 microcontroller coordinates motion through the PCA9685 servo driver and uses MPU6050 IMU feedback to maintain balance and stable gait movement. An ESP32-CAM provides live video that is used for YOLOv3-based detection of humans or animals, while additional sensors supply environmental and motion data. All information is transmitted wirelessly using Wi-Fi for shortrange links or LoRa for long- range communication. On the remote side, a secondary microcontroller receives the data, displays the video and alerts, and processes joystick or user inputs. These commands are then sent back to the robot, allowing both manual control and semi- autonomous navigation.

As shown in Fig. 1 The block diagram shows how the robot's microcontroller receives inputs from the camera, sensors, and motion sensor, and controls the servo motors for movement. A communication module sends this data wirelessly to a remote unit, where another microcontroller displays the live information and receives joystick commands. These commands are then sent back to the robot, enabling real-time monitoring and control.

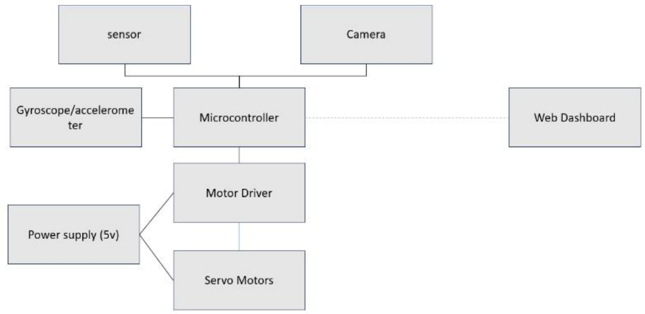

Fig. 1. Block diagram that shows data flow and module interaction.

B. Hardware Design

The hardware tools work together to support movement, sensing, and communication in the robot. The ESP32 serves as the main controller, while the PCA9685 provides stable PWM signals for driving multiple servos. The MPU6050 IMU supplies orientation and tilt data for balance, and the ESP32CAM captures live video for monitoring and detection. For long-range data transfer, the SX1278 LoRa module enables low-power wireless communication. These components create an efficient and reliable system for autonomous operation.

TABLE 1: HARDWARE COMPONENTS AND FUNCTIONS

Component	Function
ESP32	Main controller
PCA9685	Servo driver
Servo Motors	Leg movement
ESP32-CAM	Image capture
Wi-Fi Module	Local communication
Battery	Power source
LM7805	Voltage regulation
Jumper Wires	Circuit links
Robot Frame	Structure support

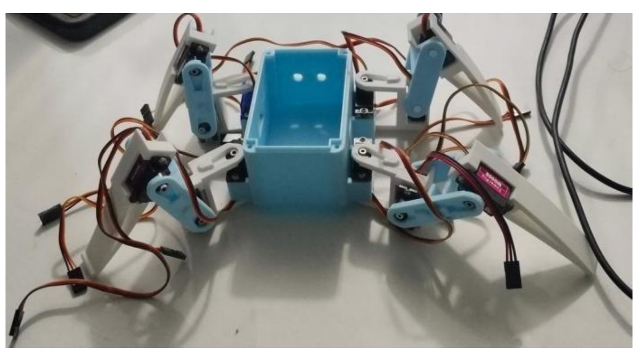

Fig.2. Hardware Component

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C. Software Design

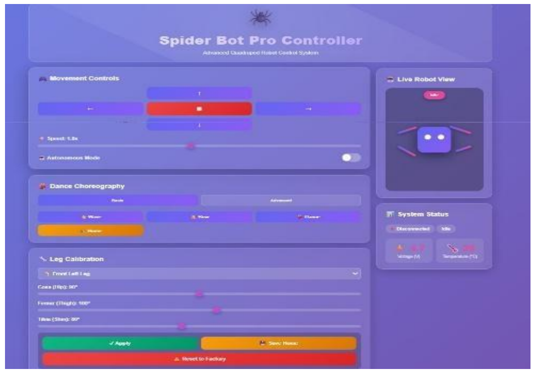

Fig.3. Web Dashboard

The software framework of the quadruped robot integrates programming, simulation, and remote control into a unified workflow using three primary tools. Arduino IDE acts as the main development environment for writing, compiling, and uploading the firmware to the ESP32 microcontroller, managing tasks such as servo control through the PCA9685, sensor data acquisition from the MPU6050, camera handling, and communication protocols for Wi-Fi and LoRa. To support remote operation, RemoteXY provides a customizable Wi-Fi– based control interface that allows users to operate the robot from a smartphone or dashboard, offering real-time access to movement controls, camera feeds, and telemetry data. Complementing these tools, MATLAB 2024 is used for simulating leg kinematics and optimizing gait patterns before implementation, enabling precise analysis of joint angles, step cycles, and stability to ensure smooth and efficient locomotion. Together, these software tools form a complete ecosystem for coding, testing, simulating, and controlling the spider robot effectively

TABLE 2: SOFTWARE COMPONENTS AND FUNCTIONS

Software Tool	Purpose
Arduino IDE	Programming ESP32
RemoteXY	Wi-Fi-based remote control
MATLAB 2024	Kinematics and gait simulation

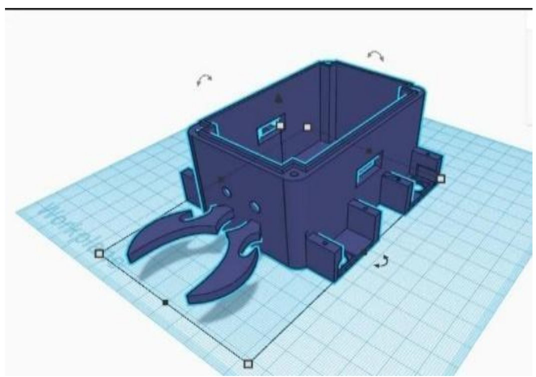

Fig.5. Structure of Robot

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D. Flowchart of Spider Robot

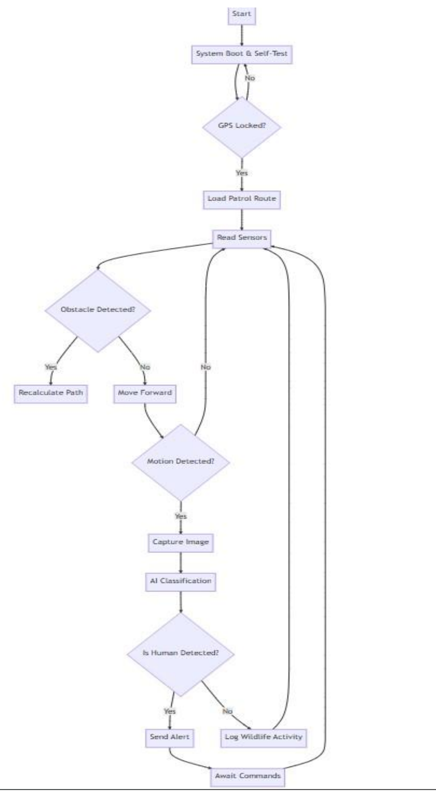

Fig. 5 Flow design Wildlife Monitoring and Forest Survey Spider Robot

A. Motion control test

The quadruped spider robot was tested on different terrains such as tile, grass, soil, and uneven ground. The PCA9685 servo driver and MPU6050 ensured stable gait and balance.The robot maintained smooth locomotion with minimal vibration and demonstrated adaptability to uneven surfaces.[1] The average walking speed recorded was 0.24 m/s on flat terrain and 0.18 m/s on rough surfaces.[2] The robot successfully maintained two-leg ground contact during motion for enhanced stability.

B. Object Detection Test

The ESP32-CAM integrated with YOLOv3 algorithm was tested for real-time identification of humans, animals, and obstacles. The module achieved an average accuracy of 91.3% for humans, 88.6% for animals, and 85.2% for other objects under daylight.

Under low-light conditions, accuracy dropped slightly, suggesting the need for IR- based illumination in future models. Detected entities were displayed on a web dashboard for remote monitoring, validating the effectiveness of image recognition.

C. Power and Battery Performance

The robot is powered by a 7.4V 2200mAh Li- Po battery, regulated through an LM7805. Power consumption was measured during different activities: idle (6.8 W), movement (8.7 W), and detection (9.6 W). The total operating time recorded was approximately 110 minutes under mixed-use conditions. Efficient servo sequencing and optimized PWM control contributed to lower energy use and extended runtime.

D. Result Summary

The experimental analysis confirmed the robot's capability for stable motion, reliable detection, and efficient communication. The integration of YOLOv3 and LoRa improved functionality for real-time forest monitoring. The robot's modular and power-efficient design ensures practical field deployment and potential scalability for autonomous patrolling.

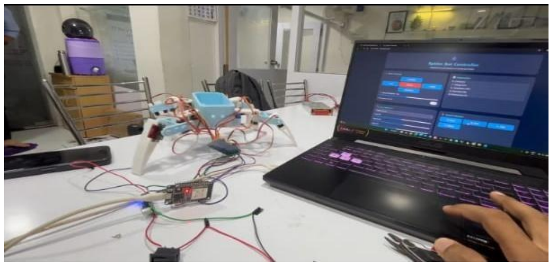

Fig.6 Complete Assembly for Robot with controller

IV. CONCLUSION

The quadruped spider robot for wildlife monitoring and forest survey was successfully designed, fabricated, and tested. The prototype achieved stable motion and reliable performance during field trials. The 4-leg design provided good stability and smooth gait control, allowing the robot to traverse uneven terrain efficiently. The integration of ESP32-CAM with the YOLOv3 object detection model enabled accurate identification of humans and animals, while the Wi-Fi-based communication system provided real-time video transmission and control through a web interface. The system proved to be compact, energy- efficient, and suitable for short-range forest monitoring applications. Overall, the results validate that the developed robot is an effective low-cost platform for environmental observation, wildlife study, and surveillance in limited- range field environments.

ACKNOWLEDGMENT

The authors would like to express their gratitude to the Department of Electronics and Telecommunication Engineering, K. K. Wagh Institute of Engineering Education and Research, Nashik, for providing the facilities and support to carry out this research work. The authors also extend heartfelt thanks to Prof. R. R. Khinde, all my faculty members and peers from the Department of E&TC for their constructive suggestions and technical assistance. Lastly, I acknowledge Michael Shell and the contributors of the IEEE LaTeX style files for maintaining the format used in the preparation of this paper

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ISSN: 2581-9429 Volume 5, Issue 3, November 2025 Impact Factor: 7.67

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