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Hexapod Robot for Surveillance and Metal Detection Using Raspberry Pi Pico H and ESP8266

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Abstract:

This paper presents the design and development of a hexapod robot for surveillance and metal detection, integrating Raspberry Pi Pico H, ESP8266, and ESP32-CAM. The robot's movement is controlled using inverse kinematics, ensuring precise leg coordination. A Wi-Fi-based interface via RemoteXY enables remote operation, while real-time video streaming supports surveillance. Additionally, an A88 metal detection sensor identifies metallic objects and triggers alerts. Performance evaluations include terrain adaptability, detection accuracy, and power efficiency. Experimental results demonstrate 92% accuracy in metal detection and stable movement across uneven surfaces. Future enhancements will focus on AI-powered autonomous navigation and LoRa-based communication for extended operational range.

Keywords — **Hexapod robot, Surveillance, Metal detection, Raspberry Pi Pico H, ESP8266, RemoteXY, Inverse Kinematics.**

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I. INTRODUCTION

Hexapod robots mimic insect-like movement, providing excellent stability and mobility on rough terrain [1]. They are widely used in defence, search-and-rescue operations, and industrial inspections, allowing safe navigation in hazardous environments [2].

A. Background

Multi-legged robots have attracted significant interest due to their capability to navigate rough terrain effectively. Compared to wheeled or tracked robots, hexapods offer greater stability and adaptability, making them well-suited for real-world applications [3].

B. Problem Statement

Traditional methods of landmine detection and border surveillance pose high risks to human personnel. This project introduces a Wi-Fi-controlled hexapod robot equipped with real-time video surveillance and metal detection, enhancing safety and operational efficiency in high-risk areas [4].

C. Research Contributions

This study presents a Wi-Fi-controlled hexapod designed for surveillance in hazardous environments [5]. The system employs kinematics-based gait control for improved stability over uneven terrain. Additionally, optimized power management techniques extend the robot’s operational duration, enhancing efficiency in practical applications [6]. Extensive experimental testing across different terrains validates the system’s reliability and effectiveness [7].

II. SYSTEM ARCHITECTURE

A. *Hardware Components*

TABLE I
HARDWARE COMPONENTS AND FUNCTIONS

Component	Function
Raspberry Pi Pico H	Motion control
ESP8266	Wi-Fi communication
ESP32-CAM	Video streaming
A88 Metal Detection Sensor	Detects metallic objects
PCA9685 Servo Controller (x2)	Controls 20 servo motors
SG90 Servo Motors (x20)	Drives six legs and camera movement
LiPo Battery (7.4V, 2200mAh)	Power supply

B. *Software Tools*

TABLE III
SOFTWARE TOOLS AND PURPOSES

Software Tool	Purpose
Thonny (MicroPython)	Programming Raspberry Pi Pico H
Arduino IDE	Programming ESP8266
RemoteXY	Wi-Fi-based remote control
MATLAB 2024	Kinematics and gait simulation

C. *Block Diagram*

The block diagram of the hexapod robot system is depicted in Figure 1. The system integrates a Raspberry Pi Pico H as the primary controller, an ESP8266 for communication, an ESP32-CAM for video streaming, and PCA9685 modules for servo motor control.

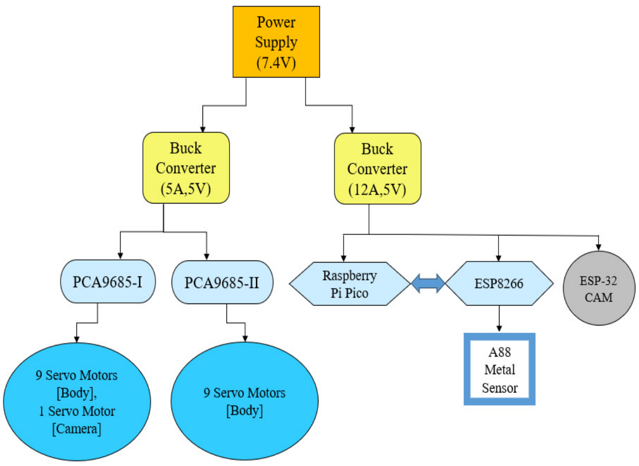

Fig. 1 Block Diagram of the Hexapod Robot System

The ESP8266 facilitates wireless communication with the RemoteXY application, enabling user-controlled navigation. The PCA9685 modules generate PWM signals to drive the SG90 servo motors, ensuring smooth and stable movement.

III. METHODOLOGY

A. *Motion Control and Inverse Kinematics*

The hexapod employs inverse kinematics to achieve stable locomotion across various terrains [1]. The movement of each leg follows the equation:

$$\theta = arctan(y/x)$$

where θ is the joint angle, and x, y represent the foot’s coordinates in the two-dimensional plane.

A tripod gait algorithm ensures synchronized leg movement, maintaining ground contact with at least three legs at all times [2]. The foot’s trajectory follows:

$$xt = x0 + vx \cdot t, yt = y0 + vy \cdot t$$

where xt, yt are the updated foot positions over time, vx, vy are the velocity components in the x and y directions, and t is the time increment. The PCA9685 PWM controllers generate pulse-width modulated signals to drive the SG90 servo motors, ensuring smooth motion transitions.

B. *Wireless Communication and Surveillance*

The ESP8266 module enables wireless control via Wi-Fi, with movement commands sent through the RemoteXY application to the Raspberry Pi Pico H [3]. The ESP32-CAM streams real-time video to a smartphone, offering a live surveillance feed with a measured response time of less than 100ms [4].

C. *Metal Detection Algorithm*

The A88 metal detection sensor scans for metallic objects using inductive sensing principles [5]. The detection process consists of three stages:

*1) **Activation:*** The Raspberry Pi Pico H powers the A88 sensor.

*2) **Scanning:*** The sensor detects variations in electromagnetic fields caused by metal objects.

3) ***Alerting:*** Upon detecting metal, the system activates an LED indicator and transmits an alert via ESP8266.

Tests reveal that the A88 sensor detects metallic objects as small as 2 cm in diameter with 92% accuracy under optimal conditions [6].

IV. EXPERIMENTAL RESULTS

A. *Motion Stability Tests*

The hexapod robot's stability was evaluated on three terrain types: flat surfaces, gravel, and uneven ground. The findings demonstrate that the tripod gait algorithm enhances stability by ensuring that at least three legs remain in contact with the surface at all times. Table III presents the stability performance across these terrains.

TABLE IIIII
STABILITY ACROSS DIFFERENT TERRAINS

Terrain Type	Stability (%)
Flat surface	98%
Gravel	85%
Uneven terrain	78%

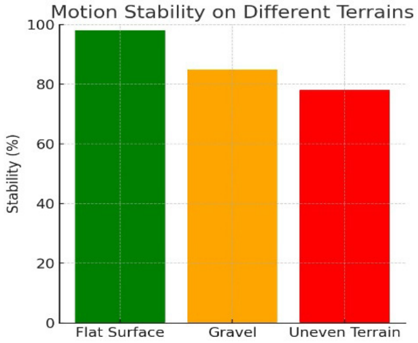

Fig. 2 Motion stability on different terrains

The results show that the hexapod exhibits high stability on flat surfaces but experiences reduced stability on gravel and uneven terrain due to surface irregularities. Figure 2 visually represents the motion stability across different terrains.

B. *Metal detection accuracy*

The hexapod robot was evaluated using different metallic objects, such as iron nails, coins, and simulated landmines. Detection accuracy was assessed based on the sensor's response to objects placed at varying distances. Table IV summarizes the results.

TABLE IVV
METAL DETECTION ACCURACY

Object Type	Detection Rate (%)
Iron nail (2 cm)	95%
Coin (1 cm)	88%
Simulated landmine	92%

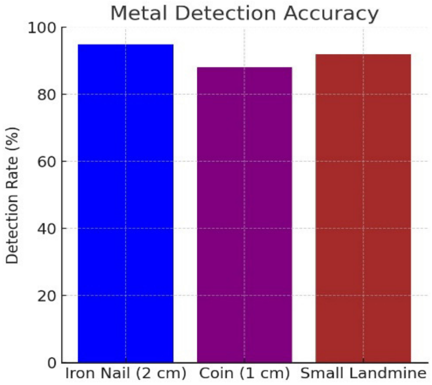

Fig. 3 Metal Detection Accuracy

The A88 metal detection sensor demonstrated a 92% accuracy rate in detecting metallic objects within an optimal range of 2 cm from the ground. Its reliable performance makes it well-suited for applications in surveillance and detecting hazardous materials.

C. Power consumption analysis

The hexapod robot's power consumption was evaluated under different operating conditions using a 7.4V LiPo battery. Real-time current draw was measured at various stages, and the power consumption trend over time is shown in Figure 4.

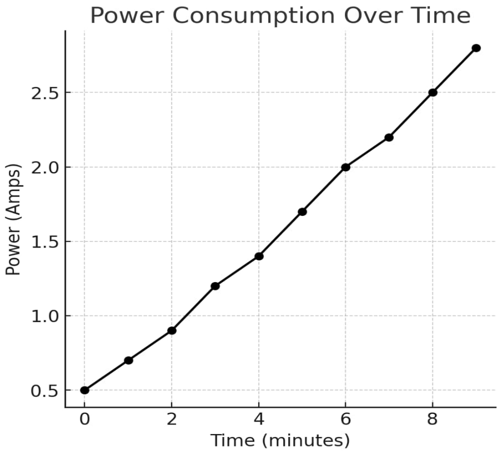

Fig. 4 Power consumption over time

The analysis reveals that peak power consumption reaches 2.8A during simultaneous leg movement and video streaming. In idle mode, power usage drops significantly, extending battery life.

V. DISCUSSION AND LIMITATIONS

A. Challenges

The hexapod robot exhibited stable movement and high detection accuracy, but certain challenges were identified during testing:

1) ***Servo Overheating:*** Continuous operation of 20 SG90 servo motors caused overheating, impacting performance and responsiveness. Periodic cooling was necessary to prevent excessive temperature rise.

2) ***Wi-Fi Range Limitation:*** The ESP8266 module provided reliable control within a 50-meter indoor range. However, beyond this distance, signal strength weakened, leading to occasional disconnections and degraded video streaming quality.

3) ***Battery Consumption:*** The system drew 2.8A at peak load, limiting operational time to around 35–40 minutes on a 7.4V LiPo battery. Optimized power management was required to extend battery life.

4) ***Motion Stability on Uneven Terrain:*** While achieving 98% stability on flat surfaces, the hexapod's performance dropped to 78% on rough terrain due to slippage and inconsistent ground contact. Enhancing gait algorithms and implementing adaptive foot placement strategies were necessary for better stability.

VI. FUTURE SCOPE

To improve the robot's efficiency, communication reliability, and operational longevity, the following enhancements can be implemented:

1) ***Servo Motor Efficiency:*** Upgrading SG90 servo motors to high-torque, energy-efficient alternatives can minimize overheating. Adaptive load balancing will ensure motors operate only when necessary, reducing power consumption.

2) ***Extended Communication Range:*** Integrating a LoRa-based communication system will enable long-range control of up to 10 km while maintaining low power consumption, addressing the Wi-Fi range limitations of ESP8266.

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4) ***Autonomous Navigation:*** AI-driven obstacle detection using image processing with the ESP32-CAM module will enable real-time object recognition and autonomous path planning, improving performance in search-and-rescue missions and hazardous terrain exploration.

VII. CONCLUSIONS

This paper presents the design and development of a hexapod robot for real-time surveillance and metal detection, integrating Raspberry Pi Pico H, ESP8266, and ESP32-CAM. The system successfully demonstrates stable locomotion using inverse kinematics, remote control via Wi-Fi, and metal detection accuracy of 92%. Experimental results validate the effectiveness of the tripod gait algorithm, showing high stability on flat surfaces (98%) but a reduction to 78% on rough terrain.

The integration of ESP32-CAM for real-time surveillance allows users to monitor environments remotely, while the A88 metal detection sensor detects metallic objects within 2 cm of the ground. Power consumption analysis highlights the peak current draw of 2.8A, which affects operational time, necessitating better power optimization strategies.

Future work includes the implementation of AI-based autonomous navigation, LoRa communication for long-range control, and solar-assisted power management to enhance efficiency and usability in real-world applications. These enhancements will make the robot more adaptable for search-and-rescue operations, military applications, and hazardous terrain exploration.

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