

Development Of a Multi-Legged Spider Robot with Esp32 Microcontroller

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Abstract—This project presents the design and development of a Bluetooth-controlled four-leg spider robot using an ESP32 microcontroller and twelve servo motors. Each leg of the robot consists of three servo motors, providing three degrees of freedom and enabling precise control of leg movements. The robot is controlled wirelessly through a mobile application using Bluetooth communication, allowing the user to perform directional movements such as forward, backward, left, and right, along with six predefined dance gestures. The ESP32 microcontroller serves as the central control unit, receiving commands from the mobile application and generating appropriate PWM signals to control the servo motors in a synchronized manner. The system is powered by two 3.7 V, 4000mAh lithium-ion batteries, and a buck converter is used to regulate the voltage to ensure stable operation of both the controller and servo motors.

Index Terms—Microcontroller, Bluetooth communication, Robotics, Servo motors, PWM signals, Lithium-ion battery.

1. Control Unit
2. Actuation System
3. Wireless Communication Unit
4. Power Supply Unit

I. INTRODUCTION

This project focuses on the design and implementation of a 4-leg spider robot using 12 servo motors and an ESP32 microcontroller, controlled wirelessly through a Bluetooth-based mobile application. Each leg of the robot consists of three servo motors, enabling multi-degree-of-freedom (DOF) movement. This configuration allows the robot to perform basic

locomotion (forward, backward, left, right) as well as expressive dance gestures (D1–D6). The ESP32 microcontroller is chosen due to its high processing capability, integrated Bluetooth, low power consumption, and suitability for real-time control applications. The robot is powered using two 3.7 V, 4000mAh lithium-ion batteries, and a buck converter is used to regulate the voltage to 5 V required by the servo motors and control electronics.

The primary objective of this project is to demonstrate how coordinated servo control and wireless communication can be used to build an intelligent robotic platform capable of controlled motion and gesture execution. The project is intended as an educational and demonstrative system, suitable for academic learning, robotics research, and future enhancements such as autonomous navigation or sensor-based intelligence.

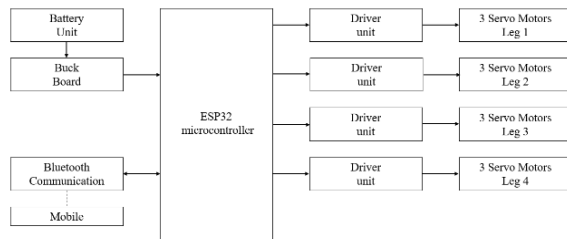
II. RELATED WORK

Leg-based robotic systems have been an active research area for several decades due to their superior mobility compared to wheeled robots. Unlike wheels, legs allow robots to step over obstacles, maintain balance on uneven terrain, and adapt their posture dynamically. Biological inspiration plays a major role in legged robot design, with insects, spiders, quadrupeds, and humans serving as natural models. Early legged robots were primarily developed for research purposes and required complex mechanical structures and high computational power. However, with the advancement of low-cost servo motors,

embedded controllers, and lightweight materials, compact legged robots have become feasible for academic and educational applications.

Spider robots, in particular, are inspired by arachnid locomotion. Their multiple legs provide excellent static stability, as at least three legs can remain in contact with the ground at all times. This feature reduces the need for complex balancing algorithms and makes spider robots suitable for beginners and educational projects. The literature shows that even four-leg (quadruped) spider robots can achieve stable walking patterns with proper gait planning and servo coordination.

III. SYSTEM ARCHITECTURE



The spider robot system follows a modular architecture, where each subsystem performs a dedicated function. The major subsystems include:

1. Control Unit
2. Actuation System
3. Wireless Communication Unit
4. Power Supply Unit
5. Mechanical Structure

The ESP32 acts as the central controller, coordinating all subsystems. Commands from the mobile app are processed by the ESP32, which then generates PWM signals to control the servo motors. Each movement or dance gesture is executed through predefined motion algorithms stored in the microcontroller.

This modular design allows easy troubleshooting, future upgrades, and expansion of the system.

A. Embedded Control Unit (ESP32)

The ESP32 microcontroller is the core of the system. It is responsible for:

- Receiving Bluetooth commands
- Interpreting control instructions
- Generating PWM signals
- Synchronizing servo movements
- Managing timing and delays

IV. HARDWARE IMPLEMENTATION

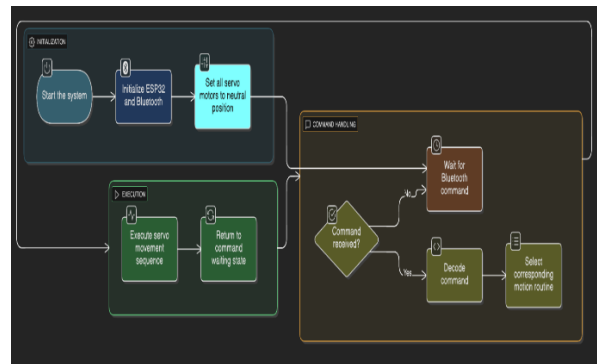
Wireless communication between the robot and the user is achieved using Bluetooth. The ESP32's built-in Bluetooth module eliminates the need for additional hardware.

The ESP32 continuously listens for Bluetooth data from the mobile application. Each command is mapped to a specific motion routine. For example:

- F → Forward movement
- B → Backward movement
- L → Left turn
- R → Right turn
- D1–D6 → Dance gestures

The ESP32 executes these routines by adjusting servo angles in a coordinated manner.

V. SOFTWARE DESIGN



The mechanical structure of the spider robot is designed to support:

- Weight distribution
- Servo mounting
- Leg articulation

The robot body houses the ESP32, power system, and wiring, while each leg is attached symmetrically to maintain balance. The legs are designed with sufficient clearance to allow free movement without collision.

The robot operates purely on predefined motion routines. Each routine is a sequence of servo angle changes with controlled timing delays.

Movement Types

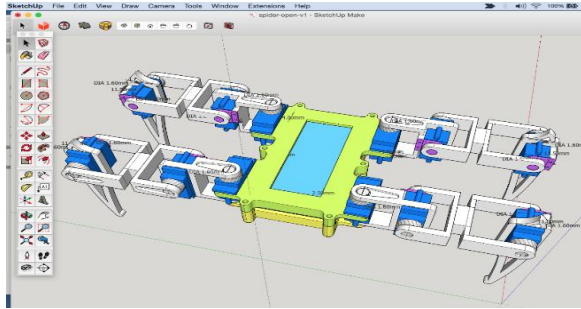
- Forward
- Backward
- Left

Dance Gestures

- D1: Wave motion
- D2: Body shake

- D3: Leg lift dance
 - D4: Twist motion
 - D5: Bounce movement
 - D6: Freestyle combination
- These gestures demonstrate multi-servo coordination and enhance the visual appeal of the robot.

VI. EXPERIMENTAL ANALYSIS



This presents the experimental results obtained from the implementation of the Bluetooth-controlled four-leg spider robot and provides a detailed discussion on its performance. The robot was tested under various operating conditions to evaluate its movement accuracy, stability, responsiveness, and gesture execution capability.

The primary focus of the evaluation was to verify whether the robot could successfully perform:

- Directional movements (Forward, Backward, Left, Right)
- Six predefined dance gestures (D1–D6)
- Stable operation under battery-powered conditions
- Real-time response to mobile application commands

All tests were conducted under controlled indoor conditions using a flat surface to ensure consistency in results.

The robot was powered using two 3.7 V, 4000mAh lithium-ion batteries with a buck converter regulating voltage to 5 V. Stable voltage output throughout testing. No ESP32 reset during high-load servo movement. Battery backup sufficient for extended testing sessions. This confirms that the power system design is suitable for servo-driven robotic applications. The delay between pressing a button on the mobile app and robot movement was measured. The Response time is < 200ms. There will be an Immediate execution of commands with no noticeable lag. The Bluetooth-based control proved reliable and efficient for real-time operation.

VII. DISCUSSION

During testing, the heart rate measurements showed excellent accuracy compared to clinical pulse oximeters, with an average deviation of less than ± 3 beats per minute. The SpO₂ readings were also reliable, maintaining accuracy within $\pm 2\%$ of standard medical-grade equipment. The temperature readings remained consistent, showing deviations within $\pm 0.5^\circ\text{C}$ compared to a digital thermometer. The developed smart wearable system effectively meets the objectives of Real-time physiological monitoring, data visualization, and cloud-based alerting. The results Confirm that such a wearable IoT-based solution can provide proactive healthcare assistance, especially for individuals at high risk of heart disease.

VIII. FUTURE SCOPE

Although the proposed system performs reliably under manual control, there is significant scope for future enhancements to improve functionality, intelligence, and real-world applicability. Some possible future developments are outlined below:

Autonomous Navigation: Sensors such as ultrasonic sensors, infrared sensors, or LiDAR can be integrated to enable obstacle detection and autonomous movement without human intervention.

Artificial Intelligence and Machine Learning: AI-based algorithms can be implemented for adaptive gait control, terrain analysis, and intelligent decision-making, allowing the robot to adjust its movement based on environmental conditions.

Vision-Based Control: A camera module can be added to enable image processing and computer vision applications such as object detection, line following, or gesture recognition.

Wireless Range Enhancement: Bluetooth communication can be replaced or supplemented with Wi-Fi, LoRa, or IoT-based cloud control to increase operating range and enable remote monitoring.

Sensor-Based Feedback System: Integration of IMU (accelerometer and gyroscope) sensors can improve balance control and posture stabilization, especially on uneven terrain.

Improved Mechanical Design: Advanced 3D-printed materials or lightweight alloys can be used to improve strength, durability, and load-carrying capacity.

IX. CONCLUSION

The system effectively integrates embedded control, wireless communication, mechanical design, and power management into a single functional robotic platform. The ESP32 microcontroller proved to be a reliable and efficient control unit, handling Bluetooth communication and simultaneous control of twelve servo motors without performance degradation. The use of built-in Bluetooth eliminated the need for additional hardware modules, thereby reducing system complexity and cost.

The robot demonstrated stable locomotion using predefined gait patterns for forward, backward, left, and right movements. The crawl-based gait ensured that at least three legs remained in contact with the ground at all times, providing good balance and stability. In addition to basic movements, the robot successfully executed six dance gestures (D1–D6), showcasing coordinated multi-servo control and synchronized motion.

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