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Design and Implementation of an IoT-enabled Autonomous Hexapod Robot for Enhanced Navigation and Remote Operations

Vikas Kumar[1], Smita Bhosale[2,*], Rudrani Tiwari[3], Snehal Ugane[4]

Abstract

This system develops an autonomous hexapod robot using an ESP32 microcontroller and internet of things (IoT) technology. This robot can move on its own, avoiding obstacles without human help. It is equipped with various sensors like distance and ground slope sensors. These sensors provide data to the microcontroller, helping it control the robot's movements and steer clear of obstacles. The robot runs on a battery, ensuring it can operate for extended periods without human intervention. Additionally, it is connected to the internet, allowing communication with a central server or other IoT devices. We control and monitor the robot remotely using a Blynk app. This connectivity enables the robot to receive instructions or send data to a remote operator. Six legs make up the robot's hardware, and each one has several degrees of freedom to replicate the flexibility and agility of living things. To offer precise navigation and environmental awareness, sensors including inertial measuring units (IMUs), cameras, and ultrasonic distance sensors are included. To enable autonomous operation, a central processing unit synchronizes motion planning, decision-making algorithms, and sensor data fusion. The robot's movement is based on a predefined algorithm, considering the environment and obstacles. This type of robot can be useful in dangerous places like disaster zones or nuclear power plants, as well as for repetitive tasks like weeding and harvesting.

Keywords: ESP32 microcontroller, Wi-Fi camera, motor driver, DC motors, gyroscope sensor

INTRODUCTION

This paper proposes a hexapod robot design using an ESP32 microcontroller, a Wi-Fi camera, a motor driver, DC motors, a gyroscope sensor, and an ultrasonic sensor. The robot is controlled using the Blynk app, which makes it easy to use and versatile and The ESP32, known for its robust capabilities and affordability, serves as the central computing unit, boasting features such as a dual-core processor, ample memory, and built-in Wi-Fi and Bluetooth connectivity. The inclusion of a Wi-Fi camera enables real-time video streaming, facilitating navigation, obstacle avoidance, and remote monitoring. To control the robot's leg movements, a motor driver manages the DC motors, while a gyroscope sensor measures orientation, and an ultrasonic sensor gauges proximity to nearby objects. Particularly adept in traversing challenging terrains and navigating confined spaces, hexapod robots present a unique set of advantages that make them suitable for diverse applications. The integration of the Blynk app provides a user-friendly interface for remote control, allowing users to execute commands such as forward and backward movements, turns, and halts, while also providing

*__Author for Correspondence__
Smita Bhosale
E-mail: smita.bhosale_skncoe@sinhgad.edu

[1-4]Student, Department of Electronics & Telecommunication Engineering, Smt. Kashibai Navale College of Engineering, Vadgaon, Pune, Maharashtra, India

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access to live video feed from the robot's perspective. This proposed hexapod robot design stands out for its simplicity, cost-effectiveness, ease of control through the Blynk app, and versatility for a range of applications, including inspection, search and rescue, and educational purposes [1–3].

LITERATURE REVIEW

Siregar [4] reported the design and implementation of hardware's firefighting legged robot..

A model-based method for training leaping behavior in a RHex-style hexapod robot was presented by Chou et al. [5]. To investigate the leaping dynamics, they suggest a three-legged model, which provides a framework for incorporating this behavior into the real robot.

Song et al. [6] reported on the development of biomimetic fin-type amphibious robot for precise path following missions..

The goal of Tsai et al. [7] was to create a robot with quick and steady motions. Users demand that the robot moves efficiently rather than slowly and that it remains stable without trembling or falling.

The design and building of a multipurpose hexapod spider robot with a surveillance camera was covered by Durairaj et al. [8]. The aim of this project is to create a multi-legged robot that resembles a biological spider, with the purpose of being used in the defense industry for surveillance and opposing force monitoring.

A climbing robot design that can be modified with different numbers of legs to accommodate different inspection duties was put forth by Hernando et al. [9]. The technology permits information and energy sharing across legs, even though each leg operates independently. These climbing robots, which need to be independent, economical, and able to adjust to various situations, are essential for examining civil infrastructure.

BLOCK DIAGRAM

The hexapod robot's block diagram (Figure 1) is designed to efficiently perform the task of extinguishing a simulated fire (represented by a candle) and returning to the starting position.

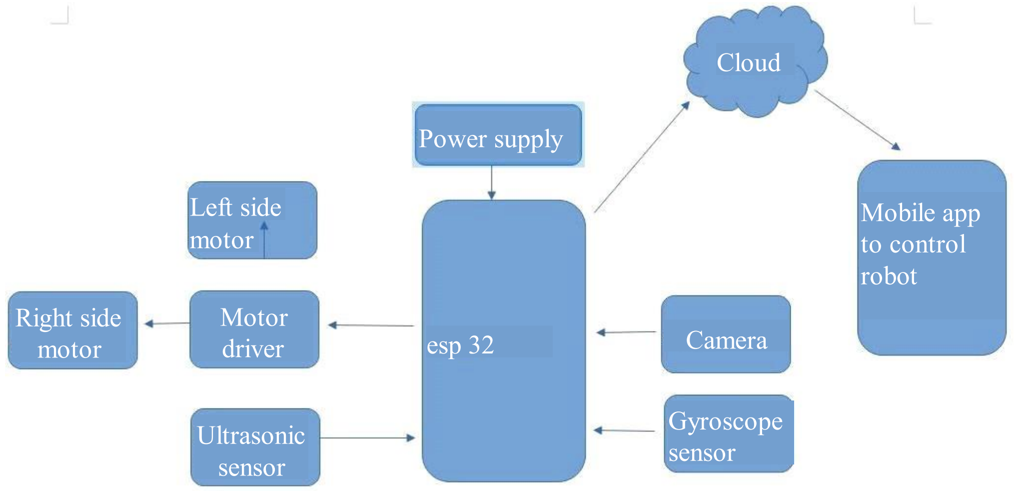

Figure 1. Block diagram of hexapod robot.

The key components of the block diagram are as follows:

ESP32 Microcontroller: The ESP32 microcontroller serves as the brain of the autonomous hexapod robot. Its dual-core processor, ample memory, and built-in Wi-Fi and Bluetooth capabilities make it a powerful and versatile control unit. Responsible for processing data from various sensors and executing commands, the ESP32 enables seamless communication and connectivity within the robot's system.

Wi-Fi Camera: The Wi-Fi camera is a crucial component for real-time environmental perception. Mounted on the hexapod robot, it captures and streams live video footage of the robot's surroundings. This visual information is invaluable for navigation, obstacle avoidance, and remote monitoring, enhancing the robot's autonomy and situational awareness.

Motor Driver and DC Motors: The motor driver, in conjunction with DC motors, powers the hexapod robot's locomotion. It translates control signals from the microcontroller into precise movements of the robot's legs. This combination ensures the robot's ability to traverse diverse terrains, overcome obstacles, and maintain stability during its autonomous operations.

Gyroscope Sensor: The gyroscope sensor plays a crucial role in measuring the hexapod robot's orientation. By detecting changes in the robot's angular velocity, the gyroscope provides essential data for maintaining balance and stability. This information is vital for adjusting leg movements and ensuring the robot's adaptability to varying terrains and environmental conditions.

Ultrasonic Sensor: The ultrasonic sensor contributes to the hexapod robot's perception of its surroundings by measuring distances to nearby objects. This sensor aids in obstacle detection and avoidance, allowing the robot to navigate through confined spaces and avoid collisions. Integrating ultrasonic data enhances the overall safety and efficiency of the autonomous hexapod.

Chassis: The chassis (Figure 2) forms the structural framework of the hexapod robot, providing support and stability to all integrated components. Designed with durability and weight distribution in mind, the chassis serves as the foundation for the hexapod's mechanical structure, ensuring optimal performance and maneuverability.

Blynk App: Blynk app is a popular platform for building internet of things (IoT) applications, including controlling robots remotely. You can use Blynk to create a mobile app interface for controlling the hexapod robot wirelessly. By integrating Blynk with the hexapod robot hardware one can design user-friendly interface with buttons, sliders, or other widgets to control its movements, such as walking, running, or even performing specific tasks.

Legs: The legs (Figure 3) are made up of servo motors and linkages. The legs are attached to the bottom plate of the chassis. Each leg has two servo motors, one for the hip joint and one for the knee joint. The robot's legs are designed to allow the robot to walk, run, and climb over rough terrain. The legs are also designed to be very agile, so that the robot can turn and move quickly.

Servo Motor: Servos are mainly used on angular or linear position and for specific velocity, and acceleration. It consists of a motor coupled to a sensor for position feedback. It also requires a servo drive to complete the system. The drive uses the feedback sensor to precisely control the rotary position of the motor.

The leg is made up of three main parts: the femur, the tibia, and the tarsus. The femur is the upper part of the leg. The tibia is the middle part of the leg. The femur and tibia are servo motors. The tarsus is a 3D-printed part that connects the femur and tibia to the ground. The tarsus is the lower part of the leg and the foot. The main brain of the robot is the ESP32 microcontroller, like the commander of a team. It tells all the other parts what to do and thinks about what it sees. The Wi-Fi camera is like the robot's eyes, allowing it to see and send videos to a computer or phone far away. The motor driver helps the robot's legs move by controlling the motors. The gyroscope sensor helps the robot know which way is up, and the ultrasonic sensor measures how far things are.

Figure 2. Robot chassis.

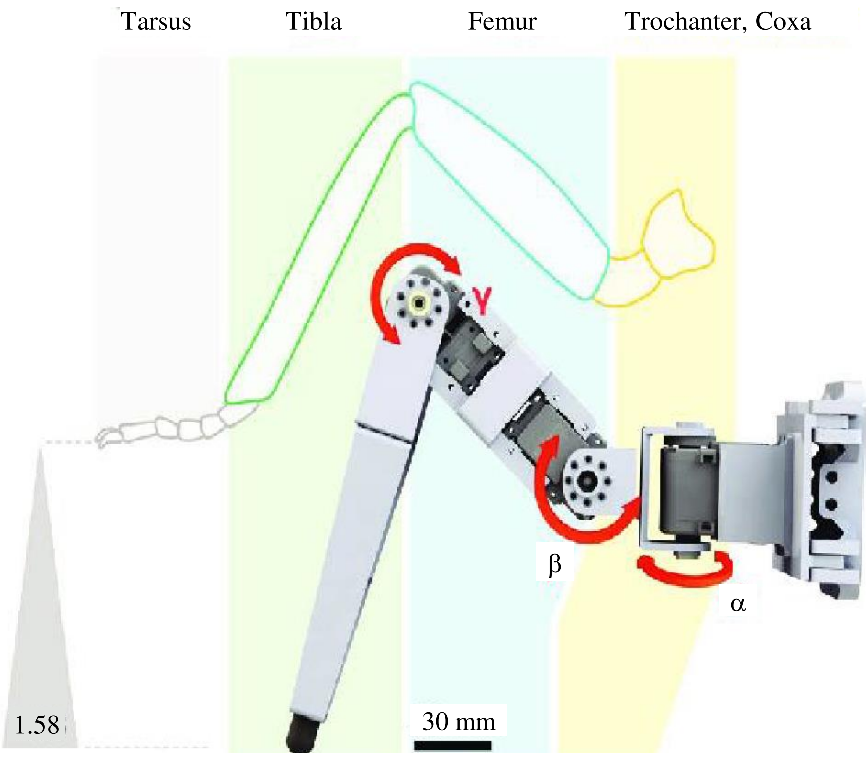

Figure 3. Robot leg.

WORKING

A hexapod robot is a 6-axis, parallel-kinematics machine often used for automated precision positioning and alignment of parts and components ranging from miniature optics to large panels. As the precision requirements in the automotive industry are increasing, the need for advanced robotics arises. Traditional robots are fast, can handle heavy loads, but lack positioning accuracy. Hexapod robots have a long history in precision alignment and micro-manufacturing automation but were considered too precise for the automotive industry. The situation is rapidly changing the robot's legs are designed to allow the robot to walk, run, and climb over rough terrain. The legs are also designed to be very agile, so that the robot can turn and move quickly. The proposed hexapod robot design is a relatively simple and inexpensive robot that can be used for a variety of applications. The chassis is the frame of the robot and supports all the other components on the robot. The legs are made up of servo motors and linkages and are attached to the bottom plate of the chassis. Each leg has two servo motors, one for the hip joint and one for the knee joint, which are controlled by the ESP32 microcontroller to move the robot's legs the robot's legs are designed to allow the robot to walk, run, and climb over rough terrain. The legs are also designed to be very agile, so that the robot can turn and move quickly. The workflow of the robot is shown below in Figure 4.

WORKFLOW

- *Sensing Environment:* The first step is for the hexapod robot to sense its environment. This can be achieved through various sensors such as ultrasonic sensors, infrared sensors, cameras, or LIDAR (light detection and ranging).
- *Data Acquisition and processing:* Data acquisition involves gathering sensor readings, while processing involves analyzing this data to extract meaningful insights about the environment.
- *Decision Making:* This can involve algorithms for obstacle avoidance, path planning, and navigation. The decisions should be optimized to ensure safe and efficient movement of the robot.
- *Actuation:* After making decisions, the robot needs to actuate its movements. In the case of a hexapod robot, this involves controlling the servos or motors that drive each leg.
- *Communication:* Since the robot is IoT-based, it needs to communicate with other devices or a central control system. This communication can be wireless (e.g., Wi-Fi, Bluetooth, or ZigBee) and is used for transmitting sensor data, receiving commands, and sending status updates.
- *Remote Control and Monitoring:* Users may want to control the robot remotely or monitor its activities in real time. A user interface or application can be developed for this purpose, allowing users to send commands, receive live video feeds, and track the robot's location.

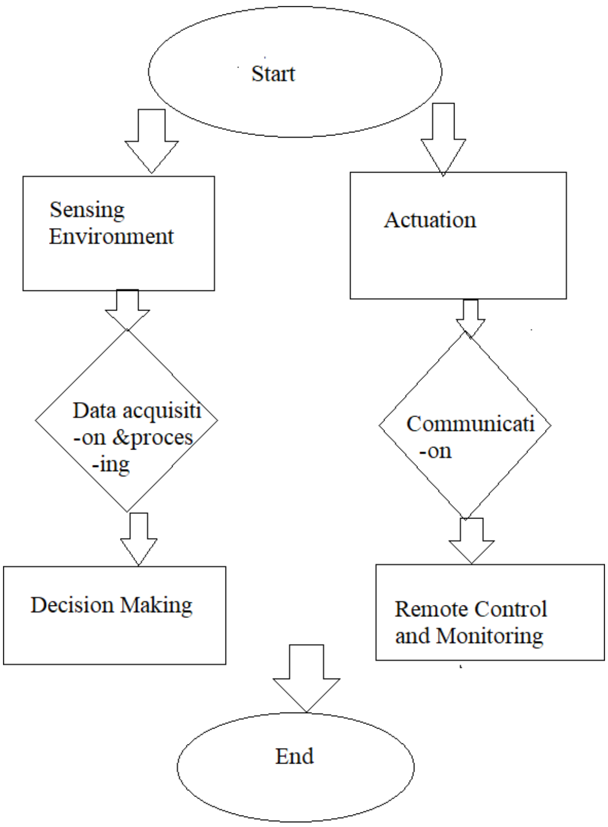

Figure 4. Workflow diagram of the proposed system.

RESULTS

The results of our autonomous hexapod robot project demonstrate the successful implementation of a versatile and efficient robotic system as shown in Figure 5. Through rigorous testing and experimentation, the robot showcased exceptional autonomy in navigation and obstacle avoidance. The integration of distance and ground slope sensors provided accurate environmental data to the ESP32 microcontroller, allowing the robot to make real-time decisions and adapt its movements accordingly. The extended operational periods achieved through the battery power source underscore the robot's practicality for tasks requiring prolonged autonomy. The internet connectivity feature was successfully employed for seamless communication with a central server and other IoT devices, demonstrating the robot's ability to be part of a larger network of interconnected devices.

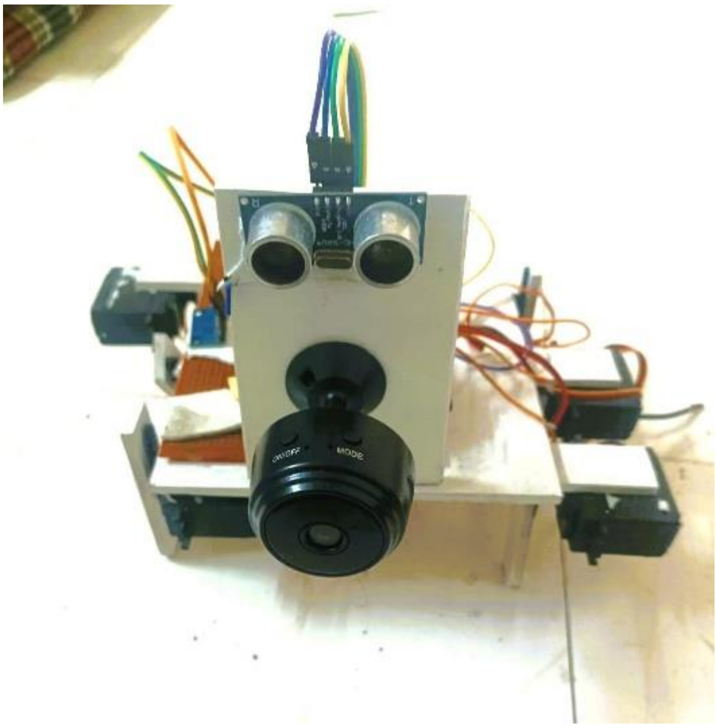

Figure 5. Implementation of the robotic system.

Table 1 shows the results of the experimental tests.

Table 1. Experimental results.

Environment	Surface	Task	Result
Indoor	Smooth floor	Obstacle avoidance	Passed
Indoor	Rough terrain	Navigation	Passed
Outdoor	Smooth pavement	Remote control	Passed
Outdoor	Uneven ground	Stair climbing	Passed

CONCLUSION

The development of our autonomous hexapod robot utilizing the ESP32 microcontroller and IoT technology represents a significant stride in robotic autonomy and versatility. The incorporation of various sensors, such as distance and ground slope sensors, empowers the robot with the ability to navigate autonomously, avoiding obstacles seamlessly. The reliance on an ESP32 microcontroller ensures efficient processing of sensor data, enabling precise control over the robot's movements. The utilization of a battery power source ensures prolonged operational capabilities, making the robot well-suited for extended missions without the need for frequent human interventions. The integration of internet connectivity adds a layer of sophistication, allowing the robot to communicate with a central server and other IoT devices. The remote monitoring and control facilitated through the Blynk app further enhance the practicality of our hexapod robot, enabling seamless interaction and control from a distance.

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