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The Spherical Surveillance Robot

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Abstract: In hazardous industrial and polluted environments where human presence is risky to health, existing robots fail due to instability in detecting air quality. This paper introduces an ESP32-powered spherical surveillance robot, designed for deployment in toxic air zones. Featuring a robust spherical body with dual wheel stabilization, where two large drive wheels for propulsion (movement) and two small caster wheels for balance. The system integrates an ESP32 CAM module for real-time video streaming, navigation and a gas sensor (MQ-Series) for detecting air quality and toxic gases in the environment, all coordinated by the Blynk IOT platform for a custom web dashboard, remote control and data visualization, and a web server for monitoring (Streaming).

The design ensures omnidirectional mobility across different rough terrains, detection of the threshold value of carbon monoxide, and an extended operation (~ 2 hours) due to a Li-ion battery.

Enabling proactive industrial safety without jeopardizing human safety, the prototype achieve 90% accuracy in navigation and seamless WI-FI range up to 100 ft (20-100 m) for various regions, surpassing Bluetooth technology limitations.

The ESP32 system reduces power by 30% and extends wireless reach, advancing a cost-effective surveillance robot for multiple applications.

Keywords: ESP32, spherical robot, surveillance, IoT, Blynk, ESP32-CAM, MQ-135, L293D motor driver, real-time monitoring, Wi-Fi, embedded systems, PCB design.

I. INTRODUCTION

Traditional surveillance mainly consists of CCTV, that are fixed in location and viewing angles. Most of them can't change their viewing angle or can't change their position as per need when a certain event takes place. And also, a traditional camera can be damaged or tampered with by external factors. So, to fix this issue, a Mobile robot can be used for this type of surveillance task.

But even in traditional robots that use wheels and legs are prone to losing balance and damaging external moving parts, getting stuck, and they need a separate steering mechanism that increases their complexity. So special type of spherical robot can be used to get over this disadvantages, the outer spherical shell protect all their internal parts from any damages, the low centre of mass give it balance and stop it from toppling, this robot can move in all direction with versatility and heftiness without getting stuck and due to its special spherical system no separate steering mechanism is required, this robot is quite, versatile and compact making it best for surveillance in places where human and other machine can't go. This robot uses an ESP-32 microcontroller for the control system and other operations, and it uses an ESP-32 Cam module for live video streaming, which will be controlled by Blynk IoT, which is also used for controlling the movement of the robot platform on any device connected. It contains L293D to control 2 motors connected to its sphere shell. It also contains MQ-135 for specialised use of industrial applications for sensing gas levels in different spaces, and all of this is powered by a regulated power supply, which uses lithium-ion rechargeable batteries. This robot can be controlled by any device connected to the internet, and can also stream video. This research paper discusses system architecture in section 2, previous related research and work done are discussed in section 3, hardware design and simulation are discussed in section 4, application and future scope are covered in section 5 and conclusion, and references are given in section 6.

II. SYSTEM DESIGN

This system consists of 3 main functioning layers, the first one is the Control Layer, containing an ESP32 microcontroller for processing and other operations, the second layer consists of monitoring, which contains an ESP32 Cam module for video monitoring and MQ-135 sensor to monitor the level of different gases in the surrounding air, like carbon dioxide, carbon monoxide, methane, and SO2. The third and the last layer is the User Interface layer, which contains the Blynk IoT dashboard for controlling and monitoring the robot and a separate web server for the streaming live video on devices . All these layers work together. Sensor output and video data are processed on board the user command, and processed data is sent wirelessly and instantly, creating a live closed-loop communication system.

A. Block Diagram

Fig. 2.1 shows a block diagram of the complete system, the power supply supplies power to all the component being ESP32, the MQ-135 sensor, the motor driver, the ESP-32 Cam and the motors. The ESP-32 is the main control block in this system; it receives data from the MQ-135 sensor and video data from the ESP-32 CAM module. The ESP-32 and Blynk IoT along with webserver to communicate with each other to stream data and send user commands to each other. This ESP32 then converts the user commands to the motor driver and to motor 1 and motor 2, which decide the direction of movement of the robot. This allows 360-degree movement of the robot.

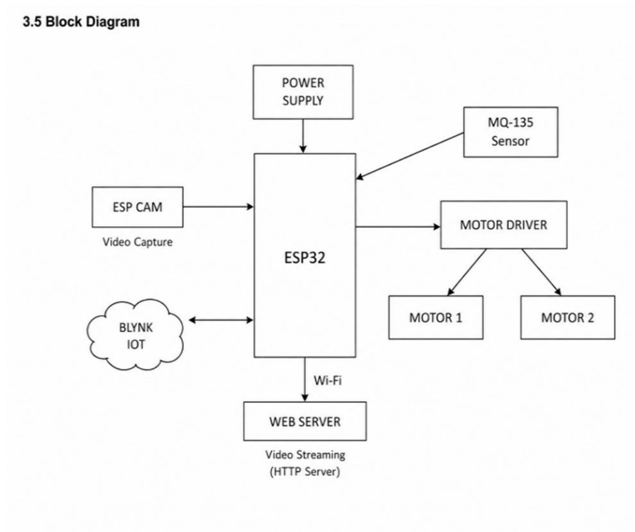

Fig. 2.1 System Block Diagram

B. Circuit Diagram

Fig. 2.2 shows the complete circuit schematic diagram in Proteus. The circuit contains the ESP32 devkit as the main control device. The ESP32 Devkit is connected to the two 7805 regulated power rails, which provide a stable 5V power supply to the circuit. Two LEDs are used to indicate the power output status. This circuit is connected to the ESP32 Cam module and motor drive connector, which are named as Motor drive 1 and 2, respectively. The circuit also includes an MQ-135 gas sensor. At the regulator output, the capacitors C1, C2, and C3 three capacitor are connected for decoupling, which helps reduce fluctuation in input voltage and reduce noise. The resistors R1 and R2 are used as pull-down resistors for setting the proper LED bias condition. This overall circuit makes sure stable and reliable working of the robot.

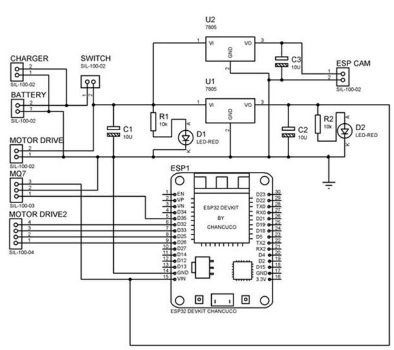

Fig. 2.2 Circuit Schematic (Proteus)

C. PCB Layout

Fig. 2.3 includes the PCB layout, which is custom-designed for this project. It includes a footprint for the ESP32 module, and it includes a header row for motor drive, which is used for connection in motor control. This PCB includes traces for power regulation, which helps in the distribution of power across different parts of the system.

The PCB includes a path for the MQ sensor, and this PCB also contain Ground planes. These ground planes help in reducing electromagnetic interference, which causes interference with Wi-Fi signal and motor PWM signals. We made PCB traces compact and efficient, this make PCB size small and can be easily fitted in the chassis of the robot shell.

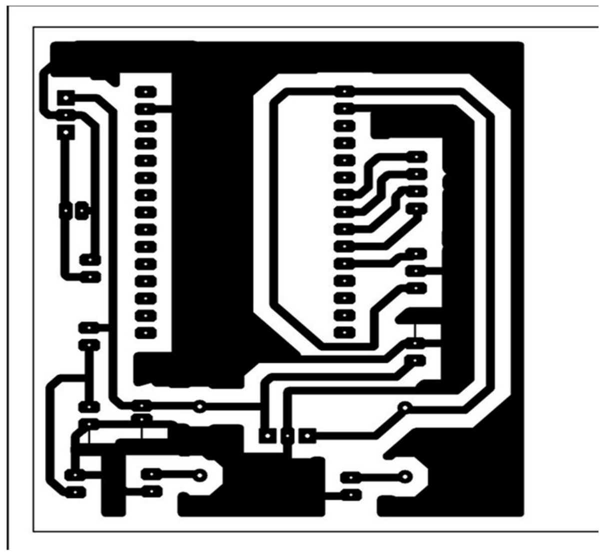

Fig. 2.3 Custom PCB Layout

D. System Workflow

Fig. 2.4 shows us the flowchart of the operation of the system, Firstly the power is switched on, and the system is initialised. At first, the ESP32 module is initialised for operation. It tries to connect to Blynk IoT through Wi-Fi connection. Until the connection is successful, the system tries to connect to Wi-Fi. Once the connection is established, the robot goes online. Then it enters the command reading loop, the instruction command sent by the user is sent wirelessly, which may include forward, backwards, right, or left. These commands are sent to the motor driver (L293D), which controls all the movement of the robot via the motor. Simultaneously with video monitoring, the MQ-135 sensor is working to sense the gas. The microcontroller streams this gas sensor data through Wi-Fi to Blynk IoT, and for live footage streaming the webserver is used that streams the live footage of ESP32 on any device connected through the host WIFI and given IP address provided. This system keeps running in this control loop. When the stop command is received, the whole operation stops, and the robot also stops. After that, the power is cut off controllably.

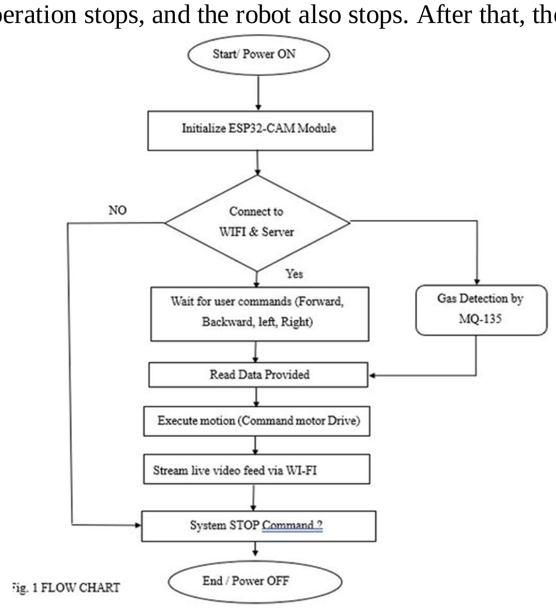

Fig. 2.4 System Workflow Flowchart

E. Methodologies

1) Hardware Design and ESP32 Integration: A custom design around the ESP32 Devkit, which gives an efficient arrangement for components. It contains two stages of a 7805 power regulator to supply a constant 5v to the circuit. The PCB also includes a header for motor drive, which helps to connect and control the motors. A separate header is provided to the MQ sensor and camera modules. The circuit also includes a battery charging mechanism for efficient use of the battery.
2) The ESP32 is a dual-core processor that operates at a 240Hz clock speed. The controller has integrated 802.11 b/g/n Wi-Fi. It generates PWM signals to control motor drive, it communicates with Blynk IoT, manages camera streaming and reads sensor data through ADC polling; all these tasks are handled simultaneously by one device, which is good for power efficiency and also utilises processing power fully.
3) Sensor Integration: The system uses MQ-135 gas sensor. It detects harmful gases and pollutants like CO2, NH3, and benzene, CO. This allows real-time air quality monitoring in industrial, household or emergency situations. This robot also includes an ESP32 Cam for video streaming. It uses the OV2640 2MP camera sensor to capture live image frames continuously in compressed JPEG format, and this format is then converted to MHPEG to be streamed over HTTP. This enables live wireless video monitoring.
4) Data Processing and Transmission: Sensor signals are received by the ESP32 controller, which passes it in ADC channel that convert analog sensor signal into digital values, then the noise is removed from the sensor using software noise filtering, which gives more accurate sensor data.

The motor control signals are generated by ESP32, which are encoded into PWM signals to control motor speed and direction efficiently. These PWM signals are sent to the H-bridge motor drive(L293D). which allows a bidirectional motor. The video data and the telemetry data are sent to the cloud with less than 100 milliseconds of command response latency. This makes the operation fast and responsive, making the robot work effectively within the Wi-Fi coverage area.

F. Control Algorithm

Table 2.1 ESP32 System Control Algorithm

Step	Description
1	Initialise ESP32-CAM module, HC-SR04, MQ-135, and L293D motor driver.
2	Connect to Wi-Fi and authenticate with Blynk IoT server.
3	Enter loop: read Blynk virtual pins for user directional commands.
4	Issue PWM to L293D to drive Motor 1 & Motor 2 per command.
5	Poll HC-SR04 every 50 ms; halt motors + alert if distance < 15 cm.
6	Read MQ-135 ADC; publish gas level to Blynk dashboard.
7	Stream MJPEG frames from OV2640 to /stream endpoint at 20–25 FPS.
8	Repeat until Stop command or low-battery safe-idle triggers.

G. Hardware and Software Requirements

Table 2.2 Hardware Components

Component	Role & Key Specification
ESP32 MCU	Central control: dual-core 240 MHz, built-in Wi-Fi/BT, GPIO for PWM and ADC.
ESP32-CAM	Video: OV2640 2 MP sensor, MJPEG streaming over 802.11 Wi-Fi.
L293D Motor Driver	Dual H-bridge; bidirectional PWM motor control up to 600 mA/channel.
DC Geared Motors ×2	Omnidirectional rolling drive inside spherical shell; high-torque output.
MQ-135 Gas Sensor	Detects CO_2, NH_3, benzene; analog voltage output to ESP32 ADC.
7805 Voltage Reg.	Dual-stage 5 V regulation for ESP32 and peripheral supply rails.
Li-ion Battery	Rechargeable supply; ~2000 mAh providing ~2 h continuous operation.

Table 2.3 Software Tools

Software	Purpose
Arduino IDE	C/C++ firmware development, compilation, and ESP32 flashing.
Blynk IoT Platform	Cloud dashboard for remote directional control, video, and sensor data.
Proteus 8 Professional	Full circuit schematic entry, PCB layout, and pre-build simulation.
Platform IO (VS Code)	Advanced project management, library integration, and debugging.
HTTP Web Server	Live video streaming over any device

III. LITERATURE REVIEW

The growth for remote surveillance in dangerous areas have explored significant research in Surveillance robots with IOT integration

Irfan Rangapur, B.K. Swathi Prasad, and R. Suresh [1] Designed a spherical spy robot for surveillance in areas where it is hard for humans to reach .for internal mechanism ,they used pendulum based drive for movement and balance. Also integrated live video streaming and obstacle detection with Arduino as main controller and performed FEA structural analysis.

Aminata Diouf, Bruno Belzile, Maarouf Saad, David St-Onge [2] They conducted a systematic review of spherical robots from 1996 to 2023 era. By analyzing them ,categorized them based on pendulum ,gyroscopic and wheel based locomotion types. Along with that covered applications in tunnel inspections ,hazardous missions and reviewed control strategies

T. Akilan, Satyam Chaudhary, Priya Kumari, Utkarsh Pandey[3]Designed a robot for hazardous environments by including gas sensor, a wireless camera and a PIR sensor .they have used IOT technology for remote communication and access and Arduino as a microcontroller.

Mrs. M. Lakshmi, Varsha Kommera, SreeKavya Kilambi, and Joshitha Malasani [4] proposed a BLYNK IoT platform-controlled night vision rover using ESP32 CAM .They demonstrated remote control over Wi-Fi connection on BLYNK IOT platform with application of indoor surveillance.

Aditi Dubey, Gandharan C.M., Meghashree M., and Dr. Rekha N. [5] Designed a surveillance spy robot using ESP32-CAM and ESP32 microcontroller along with infrared and ultrasonic sensors specifically for indoor video streaming application. It fulfils the basic surveillance security concerns in households ,private or public areas.

Ingale K., Tekade O., Thakare P., Wankhade A., Wankhade P. [6] Proposed a motorized surveillance car with ESP-32 CAM and BLYNK –IOT by sensing temperature, pressure and altitude and showcasing on remote platform like a smartphone. Also showcased live video streaming over wi-fi integration.

Most of the mobile surveillance robots focused only on video streaming, very few included gas detection. The only system with gas sensing used Arduino with an open chassis and an IoT dashboard. None of the robots fulfills the need of gas sensing with mobility ,protective enclosure for interior structure and rechargeable battery backup .None of the existing research combines these applications together.

Spherical surveillance robot fills this gap very efficiently .Its main purpose is surveillance in hazardous areas through gas sensing and its unique spherical shape. Microcontroller ESP32 handles camera ,gas sensor ,wi-fi ,reading and sending data to BLYNK –IOT platform.

Thus it becomes cost efficient . BLYNK –IOT Platform gives live gas readings and video streaming on smartphone or any portable device which makes it IOT friendly. The spherical frame structure protects internal electronics from dust ,chemical and physical damage .This system Proposes to enter and operate in polluted ,chemically hazardous industrial areas and surveillance .

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IV. RESULTS & DISCUSSION

A. Simulation Result

Prior to hardware assembly, the complete circuit was entered and simulated in Proteus 8 Professional as shown in Fig. 4.1. The ESP32 Devkit schematic was connected to dual 7805 voltage regulators, motor drive headers, the ESP CAM interface, power indicator LEDs, and the gas sensor. Simulated power-on confirmed correct 5 V regulation on both rails, LED indicator activation, and proper pin mapping from the ESP32 to motor control headers. This pre-build validation eliminated wiring errors before PCB fabrication.

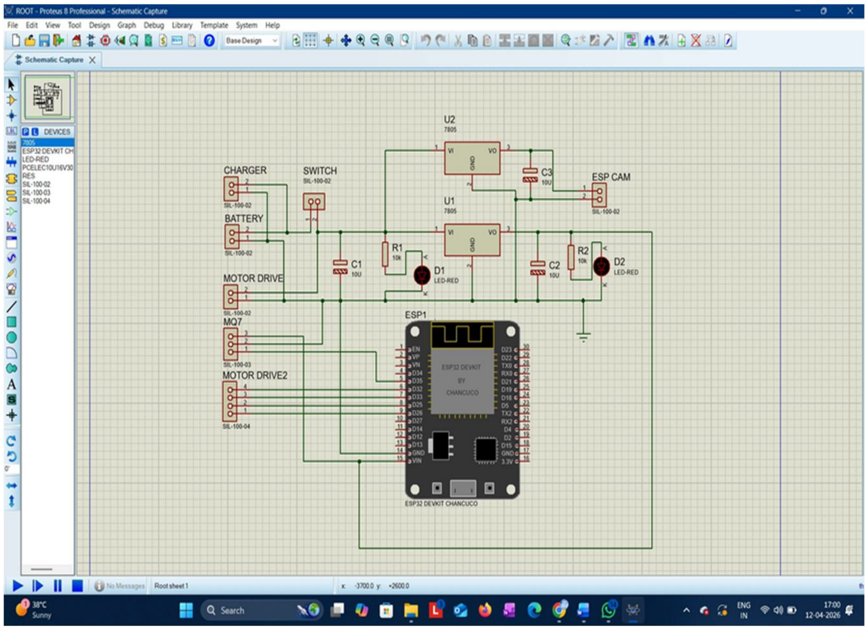

Fig. 4.1 Proteus Schematic Simulation

B. Hardware Results

Fig. 4.2 and Fig. 4.3 show the completed physical prototype. Fig. 4.2 presents the external view — the transparent spherical shell with the DC motor wheel assembly visible at the centre — demonstrating the compact integrated chassis. Fig. 4.3 shows the internal electronics: the custom yellow PCB frame mounts the ESP32 DevKit, L293D motor driver board, two DC geared motors, battery management module, and all interconnecting wiring, neatly secured within the spherical enclosure.

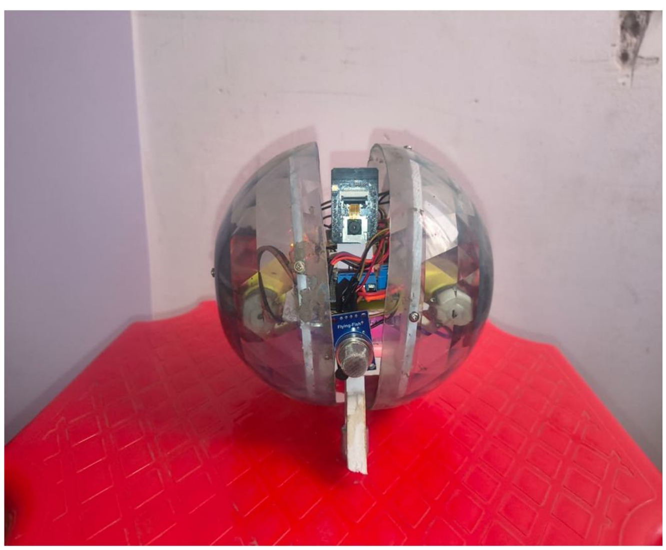

Fig. 4.2 Completed Spherical Robot (External View)

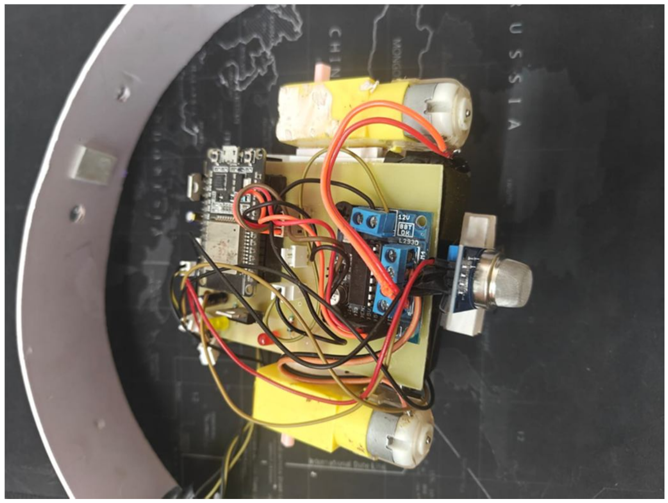

Fig. 4.3 Internal Electronics Assembly

Fig 4.4 Blynk Dashboard

Hardware evaluation confirmed stable omnidirectional rolling on flat and moderately textured indoor surfaces throughout all directional manoeuvres. Table 4.1 summarises the performance metrics recorded during hardware trials.

Table 4.1 Hardware Performance Benchmarks

Performance Metric	Measured Value
Video Frame Rate	20–25 FPS (MJPEG over Wi-Fi)
Video Latency	~0.3 s average
Wi-Fi Operational Range	Up to 25 m indoors
Battery Duration	~2 h continuous operation
Command Latency (Blynk)	< 100 ms on local network

C. Website/Blynk Interface Result

The Blynk IoT dashboard provides a mobile and web-based control panel with four directional command buttons, a live MJPEG video embed, real-time MQ-135 gas concentration readout, and an obstacle proximity alert widget. The interface remained stable across both Android and desktop browser clients with no application installation required beyond the standard Blynk app. Command response was consistently under 100 ms on the local AP network. The gas sensor readings and obstacle alerts were updated in real time, confirming end-to-end data flow from hardware sensors through the ESP32 and cloud to the operator dashboard.

V. APPLICATIONS, ADVANTAGES & FUTURE SCOPE

1) Applications: The Spherical Surveillance Robot suits a broad spectrum of deployments. In defence and military contexts the sealed rolling platform enters restricted or hazardous zones for remote reconnaissance without exposing personnel. In disaster management its rugged enclosed form navigates collapsed structures or debris fields to locate survivors and assess conditions. Industrial facilities benefit from the robot's ability to inspect confined machinery spaces, pipelines, and chemical zones inaccessible to personnel. Home and building security applications leverage the mobile complementary surveillance to cover blind spots of fixed cameras. The MQ-135 gas sensor adds environmental monitoring for use in toxic or industrial atmospheres. Agricultural applications include perimeter patrol, crop monitoring, and intruder detection across open farmland.
2) Advantages: The spherical chassis delivers omnidirectional mobility without a steering mechanism, while the sealed shell protects all electronics from dust, moisture, and physical impact. Reliance on the ESP32 and off-the-shelf modules keeps total component cost very low. The Blynk IoT platform eliminates the need for custom application development, offering a ready-made cross-platform dashboard. The custom PCB minimises internal wiring complexity and improves system reliability. Autonomous obstacle avoidance through the HC-SR04 reduces cognitive load on the operator during navigation, and the MQ-135 sensor adds environmental monitoring without additional processing overhead.
3) Challenges and Limitations: Internal mass balance during rapid directional changes remains a design challenge; uneven weight distribution introduces wobble on irregular surfaces. The battery runtime of approximately two hours limits extended deployments. The ESP32-CAM produces mildly unstable footage during fast rolling due to the absence of a camera stabilisation mechanism. The ESP32 Wi-Fi range restricts outdoor operation to approximately 25 metres without network extension. The L293D driver's 600 mA per channel rating limits motor power to lightweight loads, and the compact chassis restricts space for high-resolution cameras or larger battery packs.
4) Future Scope: Planned enhancements include on-device or cloud AI inference for automatic intruder detection and object tracking. GPS integration will enable autonomous patrol routing with waypoint navigation and battery-triggered return-to-base. A MEMS gyroscope gimbal will stabilise video output during motion. Extended-range communication via LoRa or 5G modules will support large-area outdoor deployment. Replacing the L293D with a higher-current L298N or TB6612 driver will unlock greater motor torque. SLAM-based autonomous environment mapping and swarm coordination between multiple spherical units represent longer-term research directions toward fully self-directed, large-coverage surveillance networks.

VI. CONCLUSION

This paper presented the complete design, PCB implementation, Proteus simulation, and hardware validation of a Spherical Surveillance Robot built on the ESP32 microcontroller. Integrating an ESP32-CAM module, HC-SR04 ultrasonic proximity sensor, MQ-135 gas sensor, L293D motor driver, and two DC geared motors within a custom PCB and protective spherical chassis, the system delivers omnidirectional mobility, real-time MJPEG wireless streaming, autonomous obstacle halting at 15 cm, and cloud-based Blynk IoT monitoring. Hardware trials confirmed 20–25 FPS video at sub-300 ms latency, reliable proximity response, and approximately two hours of battery autonomy. The platform provides a practical, low-cost alternative to static surveillance infrastructure, with demonstrated applicability to security, defence, industrial inspection, disaster response, and environmental monitoring. Future extensions to AI-based detection, GPS patrol routing, and SLAM mapping will further advance the capability of this spherical IoT surveillance platform.

VII. ACKNOWLEDGMENT

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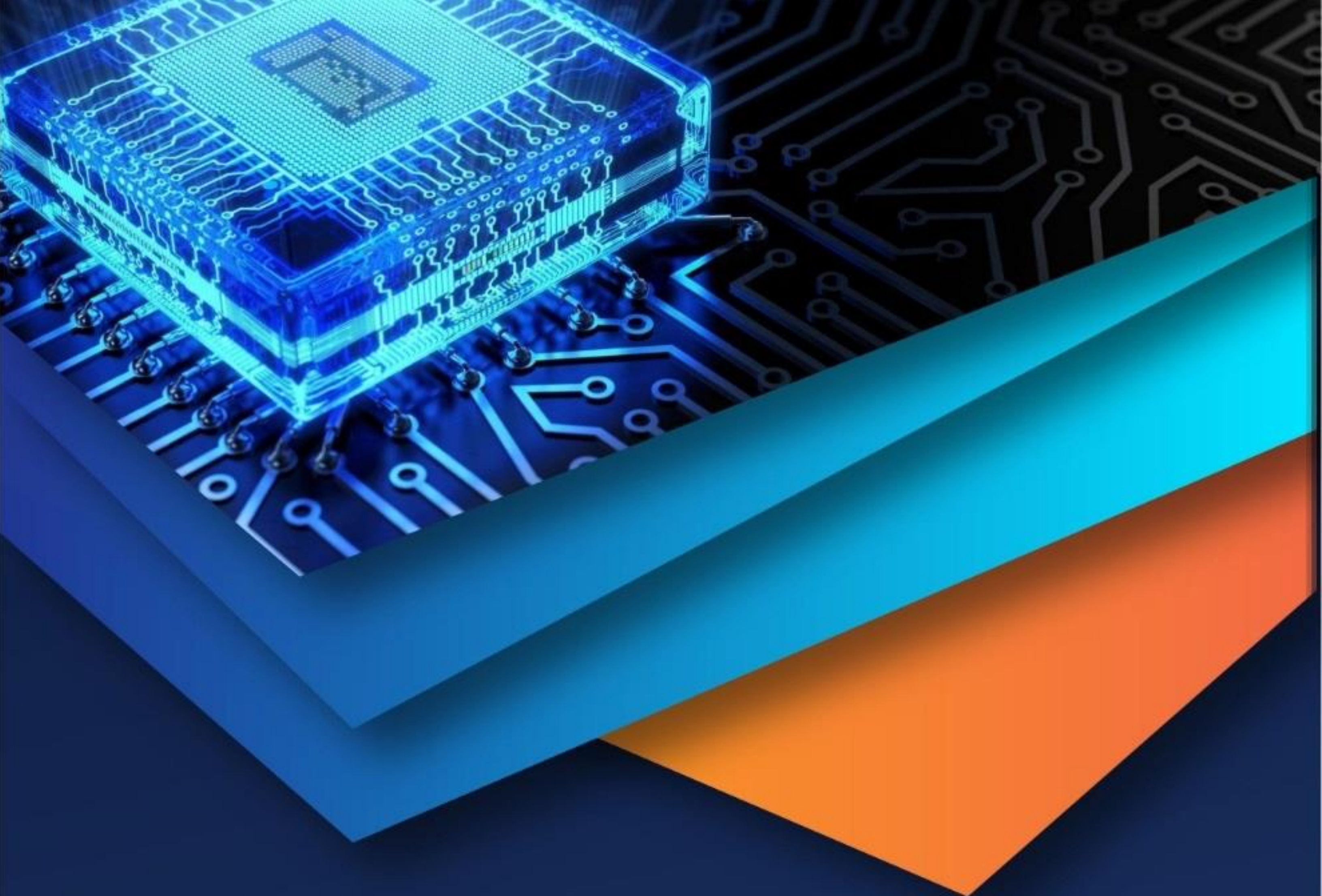

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