

IOT-Enabled Smart Mining Safety and Surveillance Robot Using ESP32 and DTMF Communication

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Abstract

Underground mining environments expose workers to severe risks including toxic gases, temperature fluctuations, structural instability, and low-visibility conditions. Traditional inspection techniques require human entry into potentially hazardous zones, increasing operational risk and delaying hazard identification. This paper presents the design and implementation of an IoT-enabled mining safety and surveillance robot capable of remote teleoperation and real-time environmental monitoring. The proposed system utilizes an ESP32 microcontroller for cloud-based IoT communication and an Arduino Uno for DTMF-based navigation control. Environmental parameters including air temperature, humidity, air quality index, soil temperature, and soil moisture are continuously monitored using integrated sensors and transmitted to the Blynk IoT dashboard for real-time visualization. A smartphone-based live surveillance system is also integrated for navigation assistance and remote visual inspection. Experimental evaluation demonstrated stable operation, low control latency, and reliable cloud-based hazard alerting. The proposed system provides a practical, scalable, and cost-effective solution for improving safety in underground mining operations.

Keywords: IoT, Mining Safety, ESP32, DTMF, Robotics, Environmental Monitoring, Blynk, UGV

1. Introduction

Mining remains one of the most hazardous industrial activities due to underground environmental uncertainty and the possibility of toxic gas accumulation, tunnel collapse, and extreme temperature exposure. Conventional monitoring approaches often require workers to physically enter unsafe locations before environmental conditions are verified. Such practices increase the probability of injury and operational delays. The integration of robotics and Internet of Things (IoT) technologies provides an effective alternative to conventional mining inspection systems. Robotic inspection platforms reduce direct human exposure while enabling continuous environmental monitoring and remote surveillance. Unlike conventional mining monitoring systems that rely solely on Wi-Fi communication, the proposed architecture combines DTMF-based teleoperation with IoT-enabled environmental monitoring to improve operational reliability in underground signal-restricted environments [1][2].

2. Literature Review

Recent advancements in mining safety systems have emphasized the use of robotics, wireless sensor networks, and IoT platforms for hazardous area monitoring [3]. Existing systems primarily rely on Wi-Fi or RF communication, which suffer from attenuation and instability in underground environments [4]. DTMF-based communication offers improved reliability because it operates through GSM voice channels instead of conventional radio-frequency transmission. Research studies have also demonstrated the effectiveness of multi-sensor monitoring for environmental analysis in industrial safety systems [5]. Cloud-based monitoring platforms further improve accessibility and enable real-time decision-making through remote dashboards and automated alerts.

3. Proposed Methodology

The proposed system employs a dual-controller architecture consisting of an ESP32 microcontroller and an Arduino Uno. The Arduino Uno handles DTMF signal decoding and motor navigation, while the ESP32 performs

sensor acquisition and IoT communication. The overall architecture of the proposed system is illustrated in Figure 1.

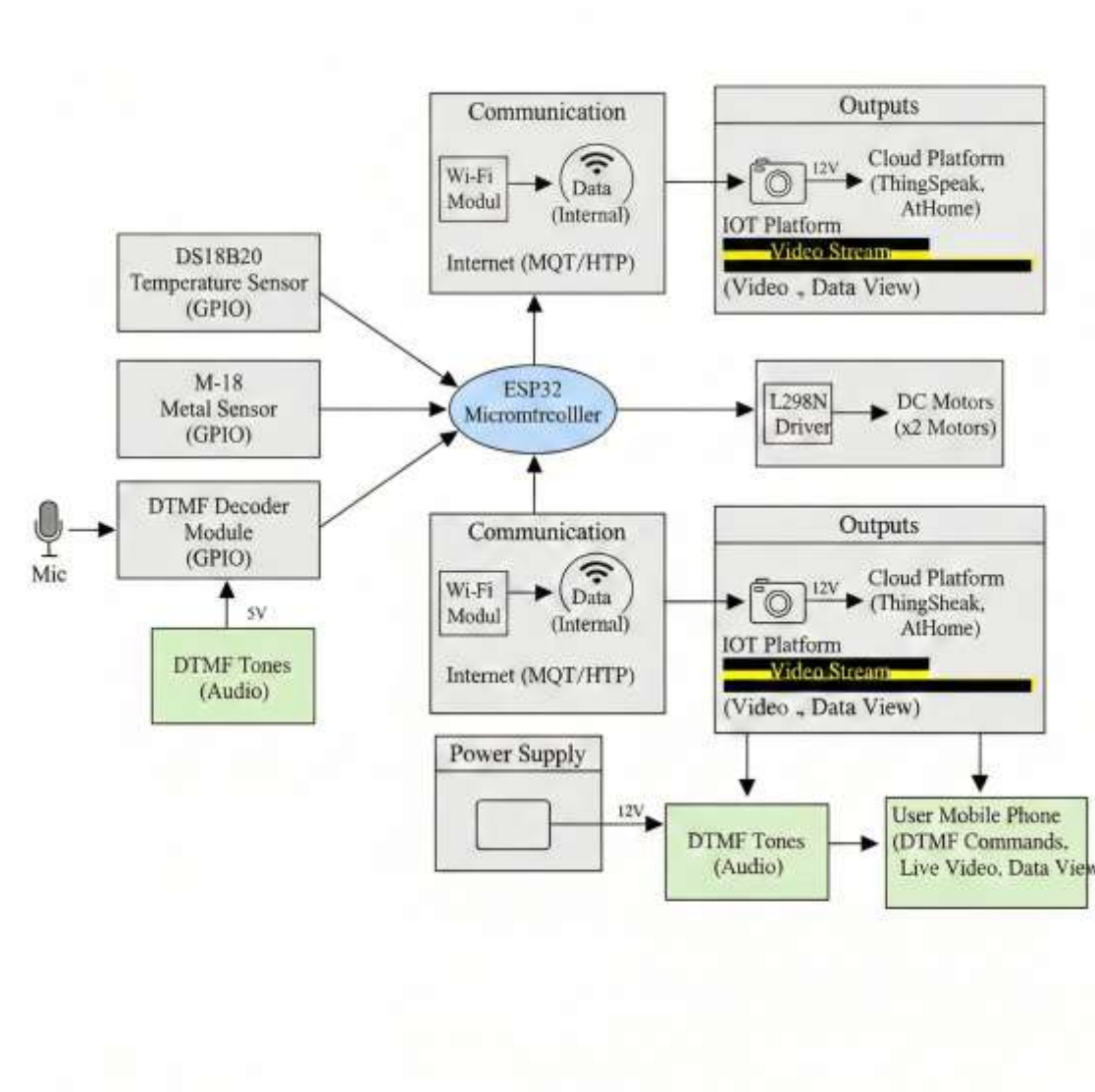


Figure 1: Proposed System Architecture

The robot integrates multiple environmental sensors including DHT11, DS18B20, MQ135, and soil moisture sensors. Sensor data is collected at regular intervals and uploaded to the Blynk cloud platform for real-time visualization. The robot movement is controlled using DTMF keypad commands transmitted through a mobile phone call. The L298N motor driver controls the DC motors responsible for navigation.

The implemented key mappings are:

- 2 – Forward
- 8 – Backward
- 4 – Left
- 6 – Right
- 5 – Stop

4. Hardware Components

Table 1: Hardware Components:

Component	Purpose	Type
ESP32	IoT communication	Microcontroller
Arduino Uno	DTMF processing	Microcontroller
DHT11	Temperature & humidity sensing	Sensor

DS18B20	Soil temperature sensing	Sensor
MQ135	Air quality monitoring	Gas Sensor
Soil Moisture Sensor	Moisture analysis	Sensor
L298N	Motor driving	Motor Driver
Servo Motor	Directional sensor movement	Actuator

5. Experimental Results and Analysis

The developed prototype was tested under simulated underground conditions to evaluate communication reliability, sensor responsiveness, and real-time monitoring performance. Experimental observations confirmed successful execution of all DTMF commands with low operational latency. The Blynk dashboard successfully displayed all environmental parameters with a stable update interval of approximately two seconds. Hazard alerts were triggered correctly whenever environmental thresholds were exceeded. The live surveillance feed enabled effective navigation and obstacle observation.

Table 2: Performance Evaluation:

Parameter	Observed Value
DTMF Response Delay	< 300 ms
Sensor Upload Interval	2 seconds
Push Notification Delay	3–4 seconds
AQI Monitoring Range	0–500
Robot Navigation	Stable on flat terrain

6. Prototype and Dashboard

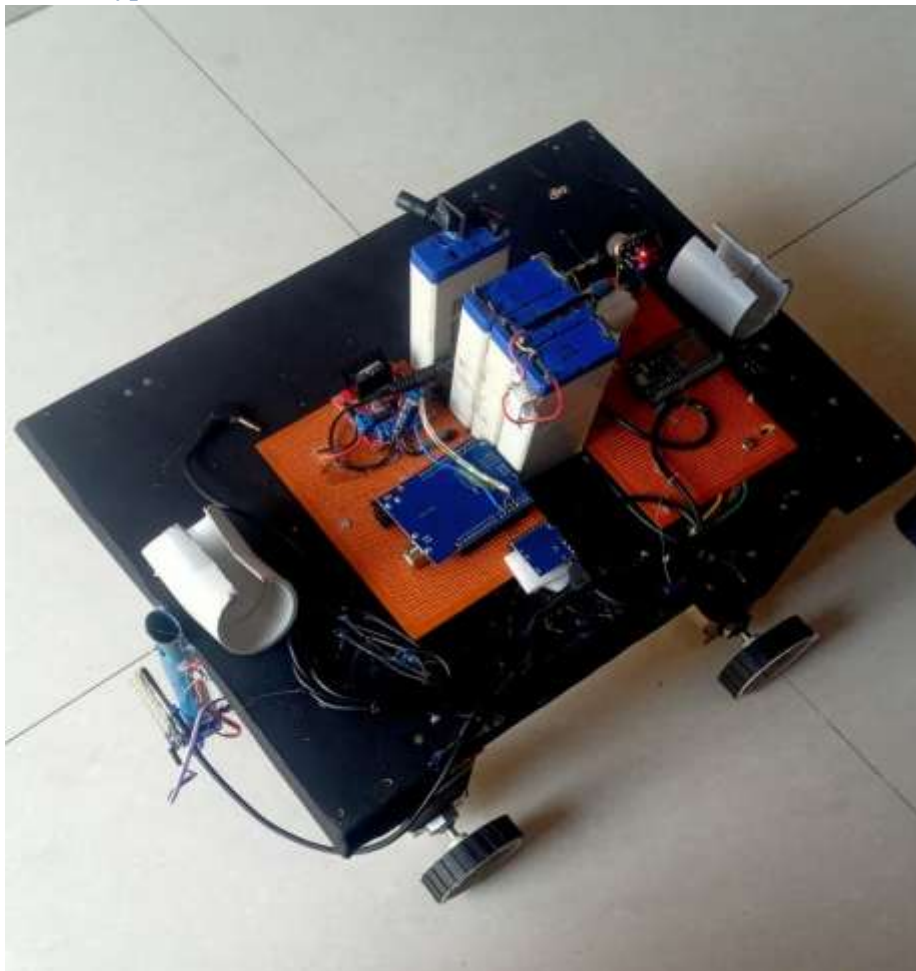


Figure 2: Developed MINING-BOT Prototype

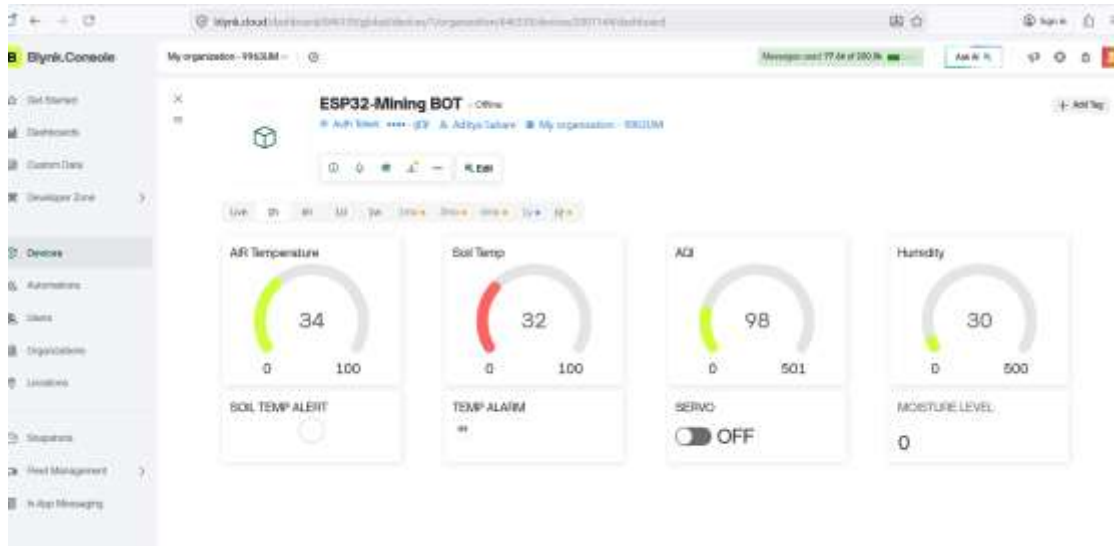


Figure 3: Blynk IoT Monitoring Dashboard

7. Conclusion

The presented IoT-enabled mining safety robot successfully integrates environmental sensing, DTMF-based navigation, real-time cloud monitoring, and live surveillance into a unified robotic platform. The system reduces direct human exposure to hazardous underground environments while providing continuous environmental monitoring and rapid hazard notification. Experimental testing demonstrated reliable operation and low communication latency. The developed architecture offers a scalable and economical solution for improving industrial mining safety systems.

8. Future Scope

- Integration of methane-specific gas sensors for enhanced hazard detection.
- Implementation of AI-based autonomous navigation.
- Integration of thermal imaging systems for rescue operations.
- Deployment of LoRa or 5G communication for long-range underground operation.
- Development of multi-robot collaborative mining surveillance systems.

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