

AI Driven Virtual Ranger For Providing Safety of Forest Areas

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Abstract

Forests are essential for ecological balance, biodiversity, and environmental sustainability, yet face increasing threats from illegal logging, fires, and unauthorized human activities. Conventional monitoring methods, including manual patrolling, watchtowers, limited CCTV, and satellite observation, are often slow and ineffective in large or remote areas. This paper proposes an IoT-based intelligent forest monitoring system for real-time surveillance and early threat detection. The system integrates temperature, gas/smoke, and AI-powered acoustic sensors with a camera module, enabling detection of fire hazards and unauthorized activities. Alerts are transmitted via Wi-Fi or GSM to a cloud platform for AI-driven processing and decision-making. Real-time notifications are delivered through a web dashboard, SMS, email, or push notifications. The proposed approach enhances forest protection by providing timely, automated, and accurate alerts, supporting sustainable ecosystem management and rapid response to threats.

Keywords: *IoT(Internet of Things), AI (Artificial Intelligent), Forest Monitoring*

1. Introduction

The core concept of this project is to develop an AI-driven Virtual Ranger system for enhancing the safety and monitoring of forest areas using Internet of Things (IoT) technology and intelligent data analysis. The system continuously observes environmental parameters such as temperature, smoke or gas levels, abnormal sounds, and visual data from the forest environment. These parameters help in identifying potential threats like forest fires,

illegal logging, and unauthorized human activities.

This project integrates AI and IoT concepts to enable real-time monitoring and scalability, allowing the system to be expanded with additional sensors and deployed across multiple forest locations. Environmental sensors and microphones collect real-time data, which is processed through embedded systems and transmitted to a cloud platform for storage and analysis. AI-based sound recognition algorithms detect suspicious activities such as chainsaw operations or wood cutting. When any abnormal condition is identified, the system immediately sends alerts to forest authorities, enabling quick response and improved forest protection.

2. Related Work

Forests play a crucial role in maintaining environmental stability and biodiversity; however, increasing human activities such as illegal logging, poaching, and accidental forest fires have made forest protection a significant global challenge. Traditional forest monitoring methods rely heavily on manual patrolling, watchtowers, and limited surveillance infrastructure, which often results in delayed detection of illegal activities and environmental hazards. With the rapid advancement of technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and wireless sensor networks, researchers have begun exploring automated solutions to improve forest monitoring systems. These technologies enable real-time data collection, analysis, and alert generation, allowing authorities to respond quickly to potential threats. [1]

Several studies have proposed IoT-based forest monitoring systems that utilize environmental sensors to detect fire hazards and unauthorized activities. These systems typically integrate temperature sensors, smoke sensors, and gas sensors connected to microcontrollers that continuously monitor environmental conditions in forest areas. When abnormal conditions such as sudden temperature increases or the presence of smoke are detected, alerts are transmitted to monitoring centers through wireless communication networks. Such systems demonstrate that IoT-based sensing technologies can significantly enhance early fire detection and reduce damage to forest ecosystems. [2]

Recent research has also focused on acoustic monitoring techniques to detect illegal logging activities. In these systems, microphone sensors are deployed in forest environments to capture sound signals, which are then analyzed using machine learning algorithms to identify abnormal patterns such as chainsaw sounds or tree-cutting activities. AI-based sound recognition models can classify audio signals and detect suspicious events with high accuracy. These intelligent acoustic monitoring systems provide an effective approach for identifying illegal logging activities in real time, especially in remote forest regions where manual monitoring is difficult. [3]

In addition to sensor-based monitoring, some studies have explored the use of camera modules and computer vision techniques for forest surveillance. These systems use image processing and deep learning algorithms to analyze visual data captured from cameras installed in forest areas. The captured images or videos are processed to identify human presence, illegal activities, or environmental threats. By combining visual monitoring with sensor-based detection, these systems can provide reliable verification of detected events and improve the overall accuracy of forest protection systems. [4]

Although previous research has demonstrated the effectiveness of IoT and AI technologies in forest monitoring, many existing systems focus on a limited set of sensors or specific threat detection mechanisms. Therefore, there is a need for an integrated intelligent monitoring system that combines environmental sensing, acoustic analysis, and visual surveillance to provide comprehensive forest protection. The proposed AI-Driven Virtual Ranger system aims to address these limitations by integrating multiple sensors, AI-based sound recognition, and cloud-based monitoring to enable real-time threat detection and rapid response for improved forest safety and conservation. [5]

3. Objective

The primary goal of this project is to enhance the safety and protection of forest areas by developing an intelligent monitoring system capable of detecting environmental threats and illegal human activities in real time. Forest ecosystems are increasingly threatened by issues such as illegal logging, forest fires, and unauthorized intrusion, which often go unnoticed due to the limitations of traditional monitoring methods. These activities can lead to severe environmental damage, loss of biodiversity, and disruption of ecological balance. To address these challenges, this project focuses on implementing an AI-driven virtual ranger system that continuously monitors forest conditions using environmental sensors, acoustic detection, and visual surveillance. The system aims to identify abnormal events such as sudden temperature rise, smoke presence, chainsaw sounds, and unauthorized human movement. By providing instant alerts to forest authorities, the proposed system helps enable quick response and effective forest protection, thereby supporting environmental conservation and sustainable ecosystem management.

4. Proposed System

Our proposed system includes an intelligent monitoring framework designed to protect forest areas by detecting environmental threats and illegal activities in real time. The system integrates multiple sensors such as temperature sensors, gas or smoke sensors, microphones, and camera modules to continuously monitor forest conditions.

These sensors collect important environmental data, including temperature variations, smoke levels, abnormal sounds, and visual information from the surrounding forest area. By analyzing these parameters, the system can identify potential threats such as forest fires, illegal logging activities, and unauthorized human movement. Using Internet of Things (IoT) technology, the collected data is transmitted to a cloud-based platform where it is processed and analyzed using Artificial Intelligence algorithms. In particular, an AI-based sound recognition system is used to detect abnormal sounds such as chainsaw operations or tree cutting activities.

When any suspicious activity or environmental anomaly is detected, the system immediately generates alerts and sends notifications to forest authorities through web dashboards, SMS, email, or push notifications. This approach enables faster response and improves the overall efficiency of forest protection and environmental monitoring.

5. Architecture Diagram

The proposed system architecture is designed to continuously monitor forest environments and detect potential threats in real time. The system consists of multiple environmental sensors deployed in forest areas to collect important data such as temperature levels, smoke or gas presence, abnormal sound patterns, and visual information from the surroundings.

These sensors are connected to a microcontroller unit that acts as the central processing component for collecting and managing the sensor data. After the data is collected from the sensors, it is processed through embedded programming and transmitted using an IoT communication

module such as Wi-Fi or GSM to a cloud-based platform. The cloud server stores and analyzes the incoming data to identify abnormal environmental conditions. In addition, an AI-based sound recognition algorithm analyzes audio signals captured by the microphone sensor to detect suspicious sounds such as chainsaw operations or tree cutting activities. The camera module provides real-time images or video for visual verification of detected events. Once the data is analyzed and any abnormal condition is identified, the system automatically generates alerts and sends notifications to forest authorities through a web-based monitoring dashboard, SMS, email, or push notification systems. This architecture enables continuous monitoring, quick threat detection, and rapid response, thereby improving the safety and protection of forest ecosystems.

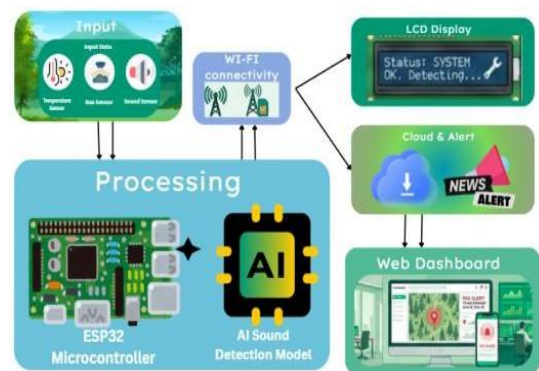


Fig.5.1: Architecture Diagram

6. AI Sound Recognition Module

In the proposed system, the AI-based offline sound detection module continuously monitors the forest environment by capturing audio signals through its dual onboard microphones. The captured sound is internally processed by the module's built-in voice recognition chip, which filters noise and compares the input with predefined and user-trained sound patterns. Based on this comparison, the module classifies the sound as either normal environmental noise or abnormal activity such as chainsaw operation, gunshots, or human presence. When a match is detected, the module generates a

corresponding signal and communicates it to the microcontroller via I2C or UART protocols. The microcontroller then analyzes the signal and, if a potential threat is identified, activates an alert system by turning on a buzzer and displaying a warning message on an LCD screen. This real-time detection and alert mechanism enables quick response to forest threats, making the system efficient and reliable for remote monitoring applications.

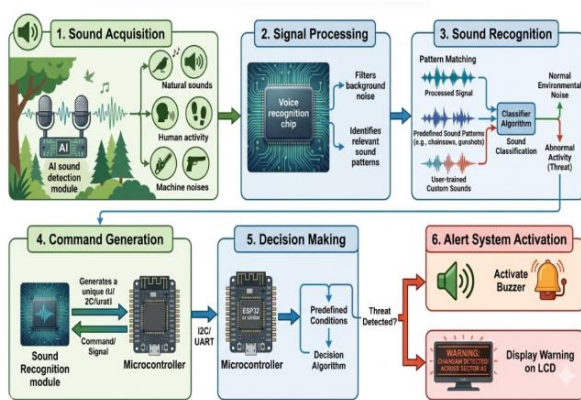


Fig.6.1:AI module Diagram

7. Implementation

7.1 Sensor Data Acquisition Module

In this module, environmental data is collected from different sensors deployed in the forest area. The system uses sensors such as the LM35 temperature sensor, MQ6 gas sensor, and sound detection module to monitor environmental conditions continuously. These sensors are connected to the ESP32 microcontroller, which acts as the central processing unit of the system. The LM35 sensor measures the surrounding temperature, while the MQ6 sensor detects the presence of harmful gases or smoke in the environment. The sound detection module captures environmental sounds in the forest area. The collected sensor data is transmitted to the ESP32 microcontroller for further processing. This module ensures real-time data acquisition for monitoring forest conditions and identifying potential threats.

7.2 Sound Classification Module using AI

In this module, the captured sound signals are processed and analyzed using an AI-based offline sound recognition module. The audio signals collected from the environment are directly captured through the module's onboard microphone and processed internally using its built-in voice recognition chip, eliminating the need for external preprocessing or complex algorithms. The module compares the captured sound with its predefined command patterns (121 fixed commands) and user-trained custom sounds (up to 17 commands). Based on this comparison, it identifies and classifies the sound into normal environmental sounds or abnormal sounds such as chainsaw noise, human activity, or other suspicious activities. Due to its dual-microphone design, the module provides improved noise resistance and reliable performance even in outdoor environments. This module plays an important role in detecting illegal activities or disturbances in forest areas in real time without requiring internet connectivity or high computational resources.

7.2 Alert and Monitoring Module

In this module, the system generates alerts when abnormal environmental conditions are detected. The ESP32 microcontroller continuously monitors the data received from various sensors and the AI-based sound recognition module. If the temperature exceeds the predefined threshold or if harmful gases are detected by the MQ6 sensor, the system identifies it as a potential danger. Similarly, when the AI sound recognition module detects abnormal sound patterns such as human intrusion or machine activity, it sends a signal to the ESP32. The system then immediately activates a buzzer alert and displays warning information on the LCD display. This alert mechanism enables forest authorities to respond quickly to potential threats such as forest fires, gas leakage, or illegal activities. The alert and monitoring module ensures continuous supervision of the forest environment and enhances the overall safety and protection of forest areas.

8. Experimental Results

This This section presents the implementation of the proposed AI Driven Virtual Ranger system for monitoring forest environments using IoT sensors and AI techniques.

The figures below—Fig. 8.1, Fig. 8.2, Fig. 8.3, and Fig. 8.4—illustrate the system hardware setup, IoT connectivity, system connections, and temperature monitoring process used for environmental data acquisition.

Additionally, Fig. 8.5, Fig. 8.6, Fig. 8.7, and Fig.8.8 present the gas detection output, alert notification mechanism, code implementation, and web dashboard output screen used for real- time monitoring and system control. The final results demonstrate how the system detects abnormal environmental conditions and generates alerts through the buzzer and monitoring interface.



Fig. 8.3 System Connection



Fig. 8.4 Temperature Monitoring Output

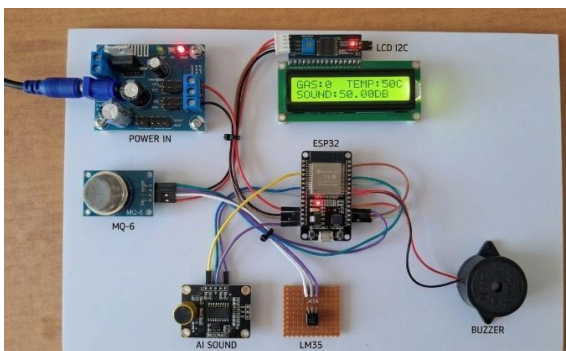


Fig. 8.1 – System Hardware Setup



Fig. 8.5 Gas Detection Output



Fig. 8.2 IoT Connectivity

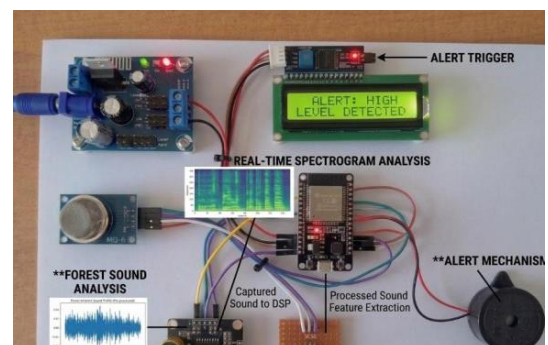


Fig. 8.6 Alert Notification Output

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C code:
1 #include <Wire.h>
2 #include <LiquidCrystal_I2C.h>
3 // LCD address (try 0x3F if 0x27 not works)
4 LiquidCrystal_I2C lcd(0x27, 16, 2);
5
6 // Pins
7 #define LCD_PIN 24
8 #define GAS_PIN 35
9
10 // Thresholds
11 #define TEMP_THRESHOLD 35 // Celsius
12 #define GAS_THRESHOLD 50 // ADC value
13
14 float temperature;
15 int gasvalue;
16
17 void setup() {
18   Serial.begin(9600);
19   lcd.begin(16, 2);
20   lcd.backlight();
21
22   lcd.setCursor(0, 0);
23   lcd.print("Fire Detection");
24   lcd.setCursor(0, 1);
25   lcd.print("System Ready");
26   delay(2000);
27   lcd.clear();
28 }
    
```

Fig. 8.7 Code Implementation

| # | SENSOR 1 | TEMPERATURE SENSOR 2 | SOUND DETECTION 3 | Location Link |
|----|-------------------------------|----------------------|-------------------|---|
| #1 | GAS SENSOR Gas Level (PPM) | Temperature (°C) | Sound Level (dB) | Location Link for Lab B |
| #2 | 120 | 24.5 | 65 | Location Link for Lab B |
| #3 | 115 | 24.6 | 62 | Location Link for Lab B |
| #4 | 110 | 25.1 | 70 | Location Link for Lab B |
| #5 | 110 | 24.4 | 60 | Location Link for Lab B |
| #6 | 145 | 26.0 | 75 | Location Link for Lab B |

Fig. 8.8 Web Dashboard Output Screen

9. Conclusion & Future work

This paper presented an AI Driven Virtual Ranger system for monitoring forest environments using IoT sensors and deep learning techniques. The proposed system integrates the LM35 temperature sensor, MQ6 gas sensor, and sound detection module with an ESP32 microcontroller to detect abnormal environmental conditions. AI-based sound recognition model is used to identify suspicious sounds in forest areas. The system generates alerts through a buzzer and LCD display when potential threats are detected, enabling early response and improving forest safety.

Future enhancements include integrating additional sensors and camera-based monitoring, connecting the system to cloud platforms for remote monitoring, and improving the AI model for more accurate sound classification and threat detection

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