International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

VANRAKSHAK – A MACHINE LEARNING BASED REAL-TIME AUDIO ANALYSIS AND ALERT SYSTEM

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ABSTRACT-

Vanrakshak is an innovative, IoT-based intelligent system designed for real-time monitoring of forest environments through sound analysis. The project focuses on preventing illegal activities such as tree cutting, gunshots, and other human-induced disturbances in restricted zones by using audio-based anomaly detection. The system employs a microphone module that continuously captures audio from the environment and sends it to a microcontroller using LoRaWAN technology. The audio signals are then processed using a Convolutional Neural Network (CNN) model to detect anomalies. If any illegal activity is identified, an alert containing the type of event and its location is immediately generated and displayed on an admin dashboard. This project integrates edge computing, wireless communication, and artificial intelligence to provide a low-cost, energy-efficient, and effective forest monitoring solution.

Index terms- IoT, LoRaWAN, CNN, Forest Monitoring, Real-Time Detection, Audio Processing, Anomaly Detection.

1. Introduction :

Forests play an essential role in maintaining ecological balance. However, illegal activities like deforestation, poaching, and unauthorized logging pose serious threats to the environment. Manual monitoring methods are time-consuming, costly, and inefficient for covering large forest areas. To overcome these challenges, an automated and intelligent system is required that can monitor environmental changes continuously and send instant alerts when suspicious activities are detected.

The proposed system, "Vanrakshak," aims to provide an intelligent solution for real-time forest surveillance using sound-based event detection. The system's primary objective is to listen to the environmental sounds using a microphone sensor, process the audio using a CNN-based neural network model, and send alerts when an abnormal sound is detected. LoRaWAN technology is used for wireless data transmission, as it supports long-range communication with minimal power consumption, making it suitable for deployment in remote forest regions. The project ensures faster responses to illegal activities, improved security, and greater efficiency in forest management.

Literature Review :

Many research studies have explored the use of artificial intelligence and IoT for environmental monitoring. Previous systems have used camera-based image detection or vibration sensors for identifying illegal logging, but these methods are often limited by visibility or physical proximity. Audio-based detection provides an effective alternative as sound travels farther than light and can be captured even when the event is not directly visible.

Existing studies show that machine learning models such as Convolutional Neural Networks (CNNs) perform effectively in recognizing patterns from audio spectrograms. Works like the "Environmental Sound Classification using CNN" and "Acoustic Event Detection using Deep Learning" have proven that sound classification can achieve accuracy levels above 90% when trained with properly labeled datasets.

However, most research focuses on urban or laboratory conditions and not on remote forest areas where power and connectivity are limited. Vanrakshak bridges this gap by combining CNN-based sound recognition with LoRaWAN-based data transmission for wide-range, low-power operation.

Review of Related Literature

2.1. Early Sound Detection Systems

Initial sound-based monitoring systems used simple threshold-based approaches where certain frequencies or sound levels triggered alarms. While these systems were useful for basic noise detection, they failed to differentiate between similar sound types (e.g., thunder vs. gunshot). Researchers like Salamon et al. (2017) introduced machine learning algorithms capable of classifying environmental sounds using feature extraction techniques such as Mel-Frequency Cepstral Coefficients (MFCC). Their work proved that environmental sound classification could achieve high accuracy with proper training datasets.

2.2. Deep Learning-Based Audio Event Detection

With the advancement of artificial intelligence, CNNs became a popular choice for audio classification. CNNs can extract spatial and temporal features from spectrogram images of audio signals. Studies by Hershey et al. (2019) and Piczak (2015) demonstrated the effectiveness of CNNs in classifying sounds such as chainsaws, gunshots, and vehicle noises. These models showed improved accuracy over traditional classifiers like Support Vector Machines (SVM) and Random Forest.
Further research by Drossos et al. (2020) emphasized real-time sound event detection (SED) systems that run efficiently on low-power edge devices. This aligns with Vanrakshak's design goal of deploying CNNs on microcontrollers with limited computation capacity.

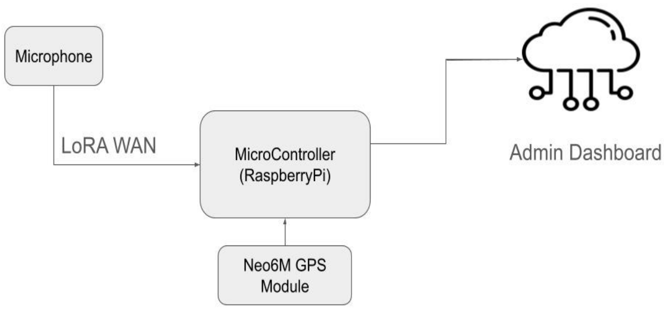
2.3. IoT and LoRaWAN-Based Monitoring Systems

Internet of Things (IoT) networks have revolutionized environmental monitoring by enabling remote data transmission. LoRaWAN (Long Range Wide Area Network) is particularly suitable for forest environments due to its long communication range, low power usage, and low cost. Previous studies such as Lopez et al. (2020) demonstrated the deployment of LoRa-based sensor networks for forest fire detection and air quality monitoring. However, these systems were primarily focused on temperature or gas sensors. Vanrakshak extends this concept to include **audio sensors** combined with **ML-based decision-making**, which enhances the system's capability to identify illegal human activities.

2.4. Challenges and Research Gaps

Despite significant progress, current research lacks robust implementations that combine LoRaWAN with deep learning for real-time sound analysis. Many models are limited to laboratory environments with stable networks and power sources. Additionally, false alarm rates remain a challenge due to background noise and wildlife sounds. The Vanrakshak project addresses these issues by optimizing CNN inference on edge devices, implementing real-time filtering, and sending only event-triggered alerts to minimize data transmission and power consumption.

Block Diagram :



***Components and Operation**:*

1. Power Supply:
The power supply is the foundation of the entire system. It converts the main AC voltage into a stable DC output (usually 5V or 3.3V) suitable for the microcontroller, LoRa module, and microphone circuit. Since the device is designed for deployment in forest regions where continuous power may not be available, it can also operate on solar panels and rechargeable batteries. Voltage regulators and protection circuits are included to maintain consistent power and protect sensitive components from surges or voltage fluctuations.

2. Microphone Module:
The microphone module serves as the primary sensing device. It continuously captures ambient sounds from the environment and converts them into electrical signals. A high-sensitivity condenser microphone is used to detect a wide frequency range—from low-frequency chainsaw noise to high-frequency gunshots. The captured analog signals are then sent to the microcontroller's ADC (Analog-to-Digital Converter) for digital processing. The system ensures continuous listening even under low signal conditions by using noise filtering algorithms.

3. Microcontroller (ESP32 / Raspberry Pi):
The microcontroller acts as the core processing unit of the system. It receives digital audio input from the microphone, preprocesses it, and performs local computations. The preprocessing includes noise reduction, framing, and transforming the audio into Mel-spectrograms suitable for CNN analysis. The ESP32 or Raspberry Pi is chosen for its balance of processing power and low energy consumption. It can also interface seamlessly with LoRa modules, GPS sensors, and the dashboard server through Wi-Fi or serial communication. The microcontroller makes real-time decisions—if the CNN model detects an anomaly, it triggers the alert system immediately.

4. LoRaWAN Module:
The LoRa (Long Range) module enables low-power, long-distance wireless communication between the edge device (sensor node) and the base station or gateway. It allows data to be transmitted over several kilometers, making it ideal for remote forest environments. LoRaWAN provides secure communication using end-to-end encryption, ensuring that all detected alerts are transmitted reliably without interference. Only small packets such as event type, confidence score, and GPS coordinates are transmitted, reducing bandwidth usage.

5. CNN-Based Neural Network Processor:
The Convolutional Neural Network (CNN) is the "intelligent" component responsible for analyzing the captured audio. Once the microcontroller converts sound data into spectrograms, the CNN model classifies them into categories such as *normal environmental sound*, *chainsaw noise*, *gunshot*, or *fire crackling*. The CNN has been trained using a large dataset of labeled sound samples to improve accuracy and reduce false detections. It extracts spatial and temporal features automatically and makes predictions with high reliability. The model is optimized for edge computing (using TensorFlow Lite or PyTorch Mobile) to ensure fast inference even on small devices.

6. GPS Module:
To ensure that alerts include precise location information, a GPS module is integrated with the system. When an anomaly is detected, the module fetches the latitude and longitude coordinates of the node and attaches them to the alert data. This information helps forest officers identify the exact location of the illegal activity and respond quickly.

7. Admin Dashboard:
The admin dashboard is a graphical interface that receives data from multiple Vanrakshak sensor nodes deployed in different areas. It displays alerts in real time along with details such as the event type, timestamp, and geographical location on a digital map. The dashboard is designed for remote access, allowing administrators to monitor all connected devices from a central location. It also maintains a historical log of past events, enabling trend analysis, performance evaluation, and planning of future forest patrol operations.

8. Buzzer / Alarm System (Optional):
In addition to remote alerts, a local buzzer or siren can be activated immediately when a suspicious sound is detected. This acts as an on-site deterrent and draws attention to the area of disturbance. The buzzer is controlled directly by the microcontroller and is triggered simultaneously with the alert transmission.

Working Principle

1. **System Start-Up:**
   When powered on, the microcontroller initializes all connected modules like the microphone, GPS, and LoRaWAN, and loads the trained CNN model for continuous operation.

2. **Sound Capture:**
   The microphone senses surrounding audio such as forest ambience, machinery, or human activity and converts it into digital signals through the microcontroller's ADC.

3. **Preprocessing:**
   The audio data is filtered to remove background noise and then converted into Mel-spectrograms for feature extraction.

4. **Sound Classification:**
   The CNN model analyzes these spectrograms and classifies the sound as *normal* or *abnormal* (e.g., gunshot, tree cutting, fire, etc.).

5. **Anomaly Detection:**
   If an abnormal event is detected, the system records its details, including sound type and confidence level.

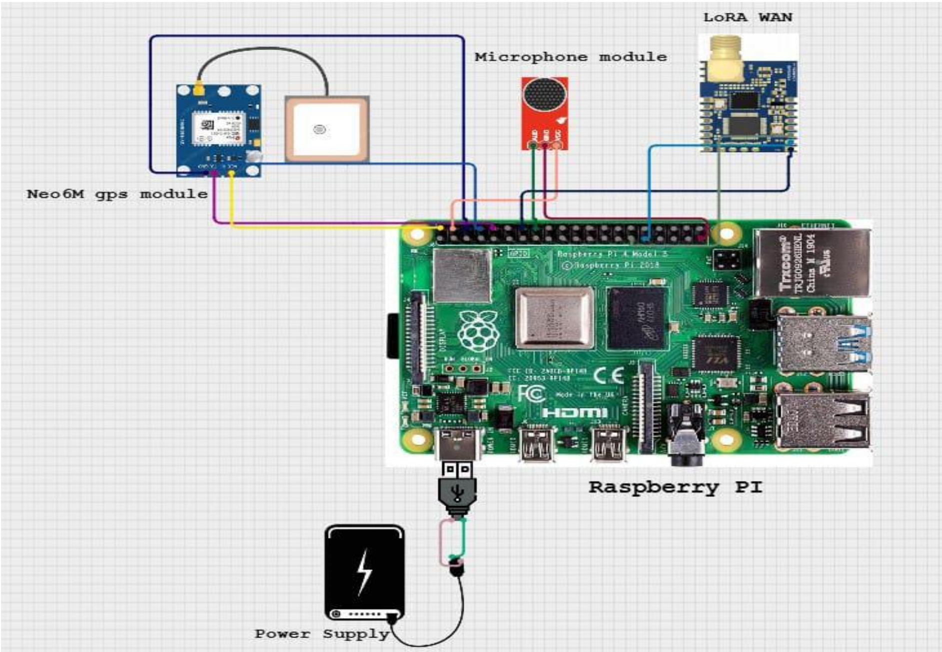
6. **Alert Generation:**
   The GPS module provides the exact location, and an alert message containing the event type, location, and time is created.

7. **Data Transmission:**
   The alert is sent to the admin dashboard through the LoRaWAN module, which supports long-range, low-power communication.

8. **Dashboard Display:**
   The dashboard shows the detected event with its location and timestamp in real time, helping officials respond quickly.

9. **Continuous Monitoring:**
   After sending the alert, the system resumes normal monitoring, maintaining a continuous detection cycle.

Circuit Diagram



Conclusion :

The Vanrakshak system successfully demonstrates how artificial intelligence, IoT communication, and embedded technology can work together to create an effective and intelligent forest monitoring solution. By continuously analyzing environmental audio, the system can identify unusual activities such as tree cutting, gunshots, or fire sounds and instantly send alerts to the concerned authorities. The combination of LoRaWAN for long-range communication and CNN-based sound classification ensures accurate detection even in remote and low-network areas.

This project highlights the importance of edge computing, where the processing of data takes place near the source rather than relying entirely on cloud servers. This reduces latency, saves bandwidth, and allows the system to operate in isolated forest regions with limited connectivity. The low power consumption of LoRaWAN and the compact design of the system make it suitable for long-term, battery-powered deployment.

Through this system, forest officials can gain real-time insights into ground-level activities, enabling faster and more effective decision-making. It reduces dependency on manual patrolling, minimizes human error, and improves the overall efficiency of forest protection measures. Furthermore, the use of machine learning allows the system to be trained for multiple environmental sounds, making it adaptable for different forest conditions and regions.

In the future, Vanrakshak can be expanded with additional sensors like temperature, motion, or smoke detectors to create a multi-sensor monitoring network. Integration with cloud-based dashboards and mobile alert applications can further enhance accessibility and scalability. With continuous improvements in data accuracy and model training, Vanrakshak has the potential to become a vital tool for environmental conservation, wildlife protection, and sustainable ecosystem management.