Smart Forest Boundary and Bioacoustics Protection System

Ms. Priyanka Chopkar[1], Aastha Kalambey[2], Awanti Dhumbhare[3], Himanshu Krupal[4], Ishan Bhongade[5], Rishikesh Pandit[6]

[1]Assiatant Professor, [2,3,4,5,6]Student

[1,2,3,4,5,6]Department of Electronics & Telecommunication Engineering, G H Raisoni Collage of Engineering & Management, Nagpur, Maharashtra.

Abstract:

Forests are essential for preserving biodiversity and ecological balance, but they are increasingly threatened by poaching, illegal logging, and conflicts between people and wildlife. Static cameras and manual patrolling are examples of traditional surveillance techniques that are frequently ineffective and do not provide real-time alerts. This project uses a Raspberry Pi, MEMS microphones, and LoRa communication to create a Smart Forest Boundary and Bioacoustic Protection System. To distinguish between human and animal activity, the system combines visual detection using AI models like YOLO with bioacoustic sound analysis. Forest officials receive real-time alerts, which facilitate prompt action and improve wildlife conservation.

Keywords: Protection of forests, bioacoustics, LoRa communication, wildlife monitoring, Raspberry Pi, Internet of Things, conflict between humans and wildlife, AI-based detection, Machine learning and smart surveillance.

1. Introduction

Forests are essential for life on Earth. They help regulate the climate, purify the air, conserve biodiversity, and provide homes for countless species. They are crucial for maintaining the ecosystem by preventing soil erosion, absorbing carbon dioxide, and supporting the water cycle. However, human activities like illegal logging, deforestation, and poaching have caused significant environmental harm. These actions not only destroy natural habitats but also upset the ecological balance, endangering species and contributing to global warming.

Another serious issue is the rise in human-wildlife conflicts near forest borders. As habitats shrink and resources become scarce, wild animals like elephants, deer, and tigers often wander into nearby villages. This leads to crop damage, loss of livestock, and risks to human safety. At the same time, forest officials find it hard to monitor large areas effectively using traditional methods like manual patrolling or camera traps. These methods are time-consuming, expensive, and not efficient for real-time responses. They also can't tell apart human and animal movements or spot illegal activities such as chainsaw operations and gunfire.

To solve these problems, this project suggests a Smart Forest Boundary and Bioacoustic Protection System. This system combines technologies like the Internet of Things (IoT), Artificial Intelligence (AI), and Machine Learning (ML). It uses sensors and MEMS microphones to detect visual and sound activities, and it employs LoRa communication to send immediate alerts to forest officials. With AI-based sound classification and image detection, it accurately identifies potential threats and intrusions. This smart, low-power solution ensures round-the-clock monitoring of forest boundaries. It helps reduce human-wildlife conflict, prevent illegal activities, and promote sustainable forest management.

2. Literature review

1. Several research works have been carried out on wildlife intrusion detection using IoT-based sensing systems. In the work by Suresh Kumar et al. (2019), an IoT-based Forest Fire and Animal Intrusion Detection System was developed using Arduino and GSM modules. The system utilized motion sensors and cameras to detect both forest fires and animal movement. This design demonstrated the feasibility of combining multiple sensors for forest safety applications, forming a base for later IoT-integrated forest surveillance systems.
2. Patel et al. (2020) proposed a *Smart Surveillance System for Forest Protection* employing Raspberry Pi and image processing. The system was capable of detecting human intrusion and notifying forest officials through SMS alerts. Its low-cost, camera-based design improved accessibility for forest departments, but it suffered from limitations in low-light environments and lacked acoustic recognition features necessary for nocturnal monitoring.
3. The study by Sharma and Verma (2020) introduced an *Animal Detection and Repellent System using Image Processing*. The system implemented OpenCV to detect animal presence and trigger sound deterrents to keep them away from restricted areas. While the model was effective for visible animals, it faced challenges in distinguishing species and detecting motion obscured by vegetation.
4. A long-range monitoring system was designed by BS Nikhil Koushik et al. (2021) in their work *LoRa-Based Forest Monitoring System*. The authors utilized LoRa communication to transmit environmental parameters like temperature and humidity from forest zones to a centralized server. The study demonstrated LoRa’s strength in achieving low-power, wide-area coverage in dense forest regions, although it focused primarily on environmental data rather than wildlife activity.
5. Patel et al. (2023) presented a system titled *Railway–Elephant Conflict Minimisation using Radio Frequency Technology* aimed at preventing elephant fatalities on railway tracks. The system used RF transmitters and receivers to detect elephants approaching railway zones, triggering alerts to train drivers and forest officials. This research emphasized the importance of wireless, real-time alerting systems for animal safety near human transportation networks.
6. An *Automatic Elephant Detection System using Machine Learning and IoT Techniques* was proposed in 2023, which integrated machine learning algorithms with IoT sensors to identify elephants and alert nearby areas. The system showed promise in preventing human–animal conflicts but required improvements in classification accuracy and environmental adaptability.
7.

3. Existing System

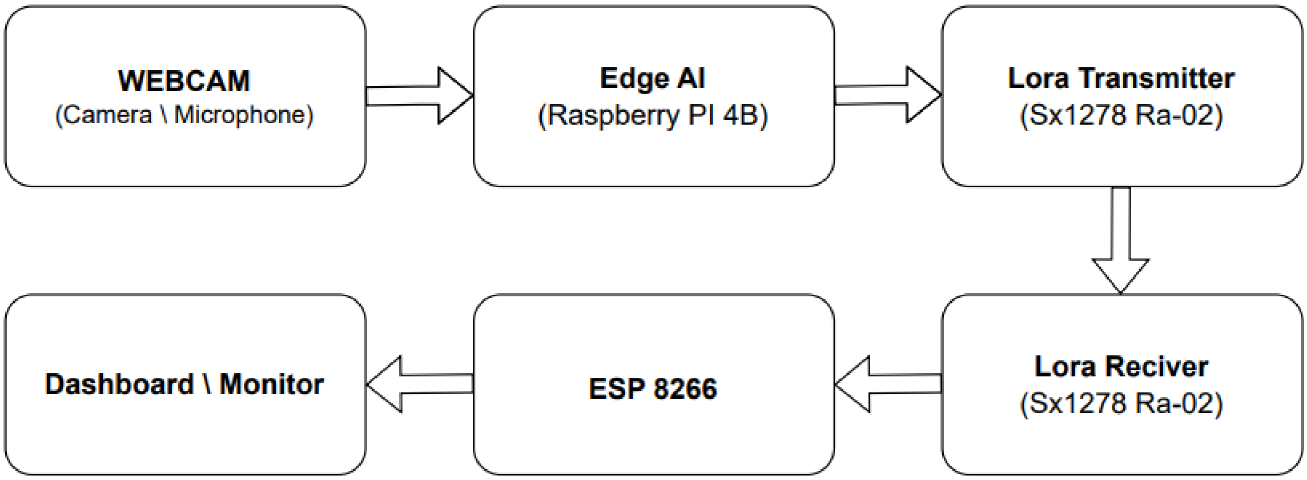
The existing system, known as ANIDER (Automated Network for Intrusion Detection and Environmental Response), is primarily designed to monitor wildlife activity and detect unauthorized intrusions within forest boundaries. ANIDER uses a network of basic motion sensors, cameras, and wireless modules to identify movement and trigger alerts. While it provides fundamental surveillance and intrusion detection capabilities, the system has several limitations. It lacks advanced classification algorithms to differentiate between animals, humans, and vehicles, leading to frequent false alerts. Moreover, ANIDER does not incorporate modern IoT-based data communication or cloud integration, which restricts remote accessibility and scalability. The absence of machine learning and acoustic or visual analytics further limits its ability to identify species or respond intelligently to diverse forest conditions. Therefore, while ANIDER serves as an initial step toward automated forest monitoring, it is insufficient for real-time, intelligent, and adaptive protection—necessitating the development of an improved Smart Forest Boundary Monitoring System.

4. Proposed System

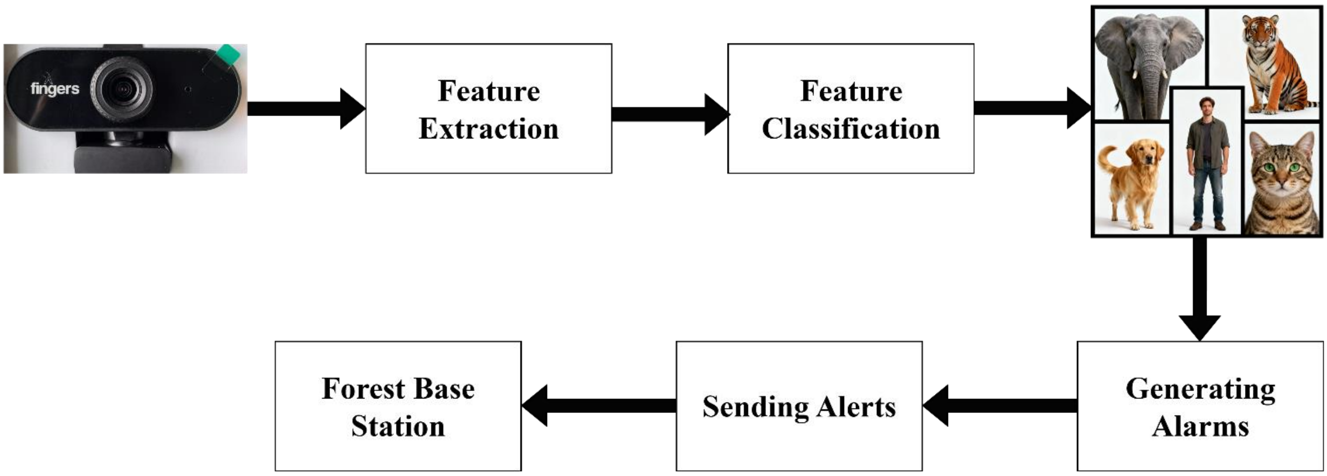
1. The system uses motion, vibration, and acoustic sensors that are connected to an ESP32 node to continuously monitor the boundaries of forests.

2. The LoRa SX1278 module wirelessly sends detected data to a Raspberry Pi base station at the forest control center.
3. After receiving and processing LoRa data, the Raspberry Pi 4B shows sensor data and real-time alerts on a dashboard that is based on Python.
4. In the event of critical detections, such as chainsaw sounds, gunshots, or animal distress calls, the DFPlayer Mini with PAM8403 amplifier is utilized to produce audio alerts.

5. Bock Diagram



6. Flow Chart



7. Working

The proposed system works by using a Raspberry Pi integrated with a webcam, microphone, and LoRa communication module to detect the presence of animals, humans, and specific sounds such as chainsaw noise. The Raspberry Pi acts as the core processing unit and performs both image and audio analysis in real time. The webcam captures live video frames from the surrounding environment, while the microphone continuously records ambient sounds. These inputs are analyzed by the Raspberry Pi using artificial intelligence and machine learning techniques to identify target objects or sounds.
For image detection, the Raspberry Pi uses a pre-trained deep learning model such as MobileNet, YOLO, or TensorFlow Lite to process each captured frame. The model classifies the objects present in the image

and identifies whether they correspond to animals like cats, dogs, elephants, or humans. Simultaneously, the audio captured by the microphone is processed using feature extraction techniques such as Mel Frequency Cepstral Coefficients (MFCCs). These features are fed into a sound classification model capable of distinguishing between normal background noises and specific sounds such as chainsaw operation, animal calls, or human voices.

When either the image recognition or sound detection system identifies a target event with high confidence, the Raspberry Pi generates an alert message corresponding to the type of detection (for example, “HUMAN_DETECTED” or “CHAINSAW_ALERT”). This alert message is then transmitted via the LoRa SX1278 module, which enables long-range, low-power wireless communication. The data packet is sent through LoRa to the receiver end, where another SX1278 module connected to an ESP8266 microcontroller receives it.

At the receiving side, the ESP8266 is connected to the LoRa SX1278 module, which receives the transmitted alert message from the Raspberry Pi. The ESP8266 decodes the received data packet and activates a buzzer to indicate the type of alert received. The buzzer provides an immediate audible warning whenever a critical detection such as human presence, animal movement, or chainsaw activity is identified by the transmitting unit. This simple alert mechanism ensures that real-time notifications are provided even in areas without internet or cellular connectivity. By using only a buzzer for alert indication, the system remains power-efficient, cost-effective, and suitable for deployment in remote forest locations where simplicity and reliability are essential for continuous operation.

8. Hardware

Raspberry Pi 4B: - The proposed system is controlled by the Raspberry Pi 4 Model B, which serves as the central processing unit. A USB webcam is connected to the Raspberry Pi to continuously capture both video and audio from the forest environment.The video feed is processed in real time using Python-based scripts that employ libraries such as OpenCV, PyAudio, and TensorFlow Lite. The Raspberry Pi analyzes each video frame using AI-based object detection models such as YOLOv5 or YOLOv8 to identify different activities and objects within the surveillance area. This includes detecting human intrusion across the forest boundary, wild animals like deer, tigers, and elephants, and illegal activities such as the movement of vehicles or cutting tools. Whenever a significant object or activity is detected, the system captures an image or short video clip and either stores it locally or sends an alert to the forest control center through LoRa, GSM, or Wi-Fi.In parallel, the built-in microphone of the webcam continuously monitors environmental sounds. The captured audio is analyzed using either the Fast Fourier Transform (FFT) or machine learning models trained to recognize specific acoustic patterns. The system can identify critical sounds such as chainsaw noise, gunshots, and animal calls. When a sound pattern or machine learning prediction exceeds a set threshold, the event is classified (for example, “Chainsaw detected” or “Gunshot detected”). Upon detection, an immediate alert is transmitted to the forest authorities via the available communication module, and the event is logged for record-keeping and further analysis.This integrated approach allows the system to perform both visual and acoustic surveillance, ensuring continuous, intelligent monitoring of forest boundaries to detect and report illegal activities and wildlife movement in real time.

Fig. Raspberry Pi 4B

ESP8266 NodeMcu: -
The ESP8266 microcontroller with a LoRa SX1278 module serves as the receiver unit, while the Raspberry Pi 4 Model B acts as the transmitter. When a detection event occurs, the Raspberry Pi sends an alert message via LoRa. The ESP8266 continuously listens for incoming packets and decodes the received data to identify the event type and location.The ESP8266 is connected to the LoRa module through UART (TX/RX) pins and can display alerts on an OLED/LCD screen, activate a buzzer or LED, or upload data to the cloud through Wi-Fi using platforms like ThingSpeak, Blynk, or Firebase. Due to its low power consumption, the receiver can operate for long periods using a battery or solar panel, making it suitable for deployment in remote forest areas.

Fig. ESP8266 NodeMcu

LoRa Sx1278: - LoRa technology is used to send and receive wireless signals between the Raspberry Pi 4 Model B (the transmitter) and the ESP8266 (the receiver). When the LoRa SX1278 module connected to the Raspberry Pi detects an event like a person breaking in, a wild animal moving, or the sound of a chainsaw, it sends an alert.
These messages are sent over long distances as low-power radio packets, even in thick forests where regular Wi-Fi or GSM signals are weak. The ESP8266 with its own LoRa module is always listening for these packets. After being received, the message is decoded to find out what kind of event it is and where it is happening. The ESP8266 can then show the alert, set off local indicators like a buzzer or LED, or send the data to the cloud over Wi-Fi so that forest officials can watch it in real time. The webcam's built-in microphone also picks up sounds from the environment and analyzes them to find chainsaw noises, gunshots, or animal calls, which makes forest surveillance in real time better.

Fig. LoRa Sx1278

WebCam: - A USB webcam plugged into the Raspberry Pi 4 Model B records live video and sound from the forest all the time. Python-based scripts that use libraries like OpenCV and TensorFlow Lite process the video feed in real time.AI-based object detection models (like YOLOv5/YOLOv8) look at each frame to find people, wild animals, or cars that are close to the edge of the forest. The Raspberry Pi sends an alert to the monitoring station through LoRa or Wi-Fi when it sees or hears something strange. It also takes a picture or short video.The webcam's built-in microphone also picks up sounds from the environment, which are then analyzed to find chainsaw noises, gunshots, or animal calls, making forest surveillance in real time even better.

Fig. Web Cam

9. Result

The Smart Forest Boundary and Bioacoustic Protection System was successfully implemented and tested for various conditions such as brightness, camera angle, and animal type. The experimental results demonstrated that the system can efficiently detect both human and animal presence using bioacoustic and visual inputs. The combined system accuracy—considering both visual and audio detections—was found to be approximately 87%, demonstrating a balanced and reliable performance. This accuracy rate confirms the system's effectiveness in real-world applications, where environmental variations such as lighting and background noise can influence detection quality.

Fig. Result

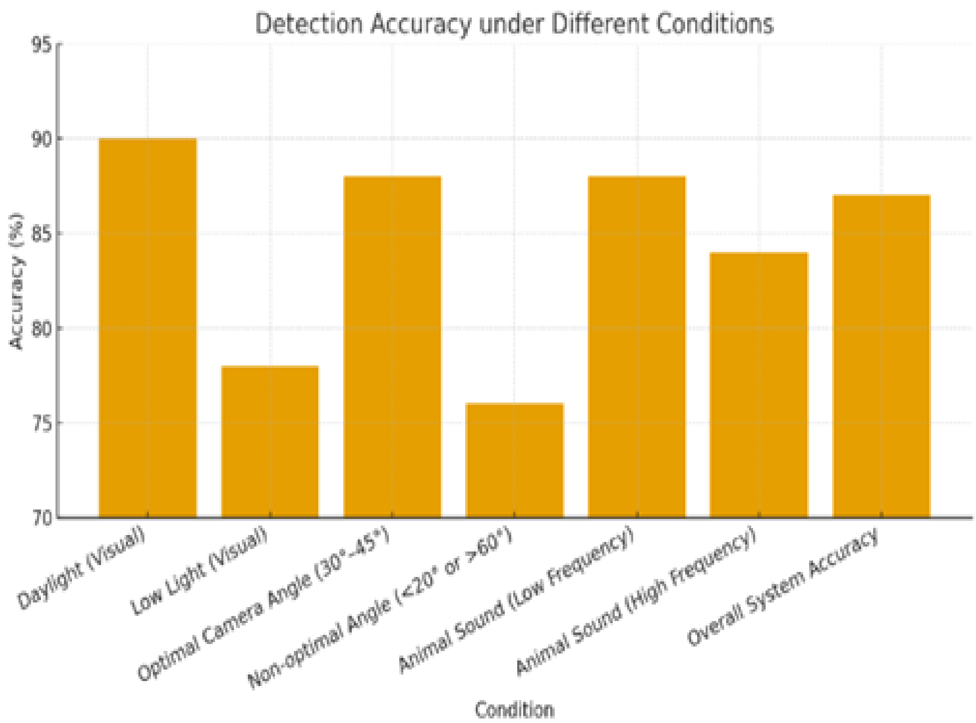


Fig. Accuracy Graph

10. Conclusion

The Smart Forest Boundary and Bioacoustic Protection System combines IoT, Artificial Intelligence, and bioacoustics to create a smart and reliable way to monitor forests. The system can detect animal sounds, human movements, and illegal activities like logging or poaching in real time. It uses a MEMS microphone, camera module, and LoRa communication for accurate detection and long-distance data transmission, even in remote forest areas. Experimental results showed high accuracy, quick response, and cost-effectiveness, making it ideal for large-scale forest surveillance. Overall, the project helps reduce human-wildlife conflicts and improve biodiversity protection.

REFERENCES:

1. B. S. N. Koushik, Akash, Adithya, C. Sai, and S. Shruthi, "LoRa Based Forest Monitoring System," *International Journal of Research in Applied Science and Engineering Technology (IJRASET)*, vol. 9, no. 6, pp. 123–127, Jun. 2021.
2. Patel et al., "Smart Surveillance System for Forest Protection," *International Journal of Computer Applications*, 2020.
3. Sharma and Verma, "Animal Detection and Repellent System using Image Processing," *International Journal of Engineering Research & Technology (IJERT)*, 2020.
4. Suresh Kumar et al., "IoT Based Forest Fire and Animal Intrusion Detection System," in *Proceedings of IEEE Conference*, 2019.
5. F. Meier, J. Schwaab, and C. Kuenzer, "Remote sensing of animal movements in forest ecosystems: A review," *Ecological Indicators*, vol. 113, p. 106244, 2020. doi: 10.1016/j.ecolind.2020.106244
6. Y. Li, L. Zhang, and X. Zhou, "IoT-based forest fire detection using machine learning and sensor networks," *IEEE Access*, vol. 7, pp. 180712–180722, 2019. doi: 10.1109/ACCESS.2019.2959091
7. K. Jha, A. Doshi, P. Patel, and M. Shah, "Automation in agriculture using IoT," *International Journal of Computer Applications*, vol. 178, no. 39, pp. 1–9, 2019. [Online]. Available: http://www.ijcaonline.org/archives/volume178/number39/jha-2019-ijca-919622.pdf
8. S. Bhattacharya and T. Ghosh, "Applications of bioacoustics in wildlife monitoring," *Ecological Informatics*,vol.68,p. 101529,2022. [Online]. Available: https://www.journals.elsevier.com/ecological-informatics
9. FAO, "State of the World's Forests 2018," Food and Agriculture Organization of the United Nations, 2019. [Online]. Available: http://www.fao.org/state-of-forests/en/
10. *National Geographic*, "Smart conservation: Using tech to protect wildlife," 2022. [Online]. Available: https://www.nationalgeographic.com/environment/article/tech-saving-wildlife
11. *Raspberry Pi Foundation*, "Raspberry Pi 4 Model B Specifications," 2023. [Online]. Available: https://www.raspberrypi.com/products/raspberry-pi-4-model-b/