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DIP Fencing Unit and Alert for Animal Entry Sound Deterring Using Raspbeery PI

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ABSTRACT

Animal intrusion in agricultural fields and protected areas often causes severe damage to crops and property, leading to economic losses. To mitigate this issue, the project proposes a DIP fencing unit integrated with a sound deterrent system controlled by a Raspberry Pi. The system uses sensors such as infrared and ultrasonic sensors to detect animal entry near the fence. Upon detection, the Raspberry Pi triggers an audible alert with high-frequency or predator-like sounds to scare the animal away. Simultaneously, real-time alerts are sent via SMS or email to notify farmers or security personnel.
The proposed system also incorporates Artificial Intelligence (AI) techniques for improved detection accuracy. Convolutional Neural Networks (CNN) and Machine Learning (ML) models can be trained to recognize specific animal movement patterns, reducing false positives. Deep Learning (DL) further enhances system performance by enabling adaptive behavior based on environmental and historical data. This non-lethal, humane solution minimizes human intervention and improves responsiveness over traditional fencing systems.
Designed to be energy-efficient and solar-powered, the unit is ideal for remote agricultural areas. It is scalable and can be tailored for different environments and animal types. Field testing confirms the system's effectiveness in deterring animal intrusion and protecting crops while maintaining low operational costs. This innovative approach offers a smart, AI-enhanced method for sustainable agricultural security.

Keywords: Raspberry Pi, Animal Detection, Sound Deterrent System, DIP Fencing Unit, Infrared Sensor, Ultrasonic Sensor, Real-time Alert, Crop Protection, Wildlife Intrusion, Non-lethal Deterrence, SMS Notification, Email Alert, Solar-powered System, Automated Fencing, Artificial Intelligence, Machine Learning, Deep Learning, Convolutional Neural Network.

1. INTRODUCTION

Human–wildlife conflict is a significant issue in many rural and forest-adjacent communities, where wild animal intrusions can lead to crop destruction, livestock loss, and danger to human life. Conventional solutions like electric fencing, manual patrolling, and watchtowers are costly, labor-intensive, and often ineffective in real-time detection. With advancements in artificial intelligence and edge computing, there is potential to automate this task using affordable hardware and efficient models.
This project introduces a real-time animal alert system powered by a Raspberry Pi and TensorFlow Lite,

which uses a pre-trained MobileNetV2 model to detect target animals from live video input. The system specifically focuses on detecting animals such as Indian elephants, goats, and gaurs, which are commonly involved in conflict scenarios.

A webcam captures real-time video, which is processed using OpenCV and NumPy. Upon identifying a target animal with sufficient confidence, the system triggers an audio deterrent using Pygame and simultaneously updates a remote IoT server with detection data and images. The setup includes a PIR motion sensor to minimize unnecessary computation by activating the system only when movement is detected.

Designed for remote, resource-constrained environments, this system is low-cost, energy-efficient, and capable of autonomous operation. Its modular design allows easy customization and expansion. The report covers the system's design, software architecture, algorithms, and experimental evaluation in realistic scenarios.

1.1 OBJECTIVES

1. **Real-Time Detection**: Continuously capture and analyze video frames using a USB webcam to monitor the environment for any wildlife intrusion.
2. **Accurate Classification**: Implement a TensorFlow Lite MobileNetV2 model to classify images from the webcam feed and identify specific target animals with high accuracy.
3. **Alert Mechanisms**: Upon detecting a target animal, activate audio deterrents (such as alarms or sounds) and send an update to a remote server to notify the appropriate personnel.
4. **Continuous Monitoring**: Ensure that the system continuously assesses the scene, maintaining surveillance and only ceasing when the detected animal is no longer present or poses a threat.

2. LITERATURE REVIEW

The issue of human-wildlife conflict (HWC) has been a growing concern globally, particularly in rural and agricultural areas, where wildlife intrusion often leads to significant economic and environmental losses. Over the years, various approaches have been explored to mitigate the adverse effects of these conflicts, ranging from traditional methods to modern technological interventions. This literature survey focuses on recent advancements in animal detection, deterrent technologies, and the integration of Internet of Things (IoT) and artificial intelligence (AI) systems to manage wildlife conflicts in agricultural environments.

- In a study by Johnson and Lee (2023) **Human-Wildlife Conflict and Its Impact on Rural Communities** reviewed the impact of human-wildlife conflict on rural communities, specifically focusing on agricultural losses and the challenges faced by farmers due to wildlife interactions. The study highlights the economic consequences, such as crop and livestock damage, and underscores the need for effective mitigation strategies that align with local agricultural practices and conservation goals. The authors also discuss the socio-cultural aspects, including local communities' perceptions of wildlife and conservation efforts.
- In a study by Singh and Sharma (2023) **Traditional Methods for Mitigating Human-Wildlife Conflict** discuss the traditional methods used to mitigate human-wildlife conflict, including physical barriers like fences, trenches, and repellents. However, these methods have limitations such as high costs, inefficiency, and environmental impacts. The paper also explores the cultural practices that communities adopt to deal with wildlife encounters. Despite their historical significance, traditional methods often fail to address the complexity of modern HWC issues, making it necessary to explore more technologically advanced solutions.

- In a study by Gupta and Patel (2023) **Real-Time Animal Detection Using YOLO and Faster R-CNN** explore the use of deep learning models, specifically YOLO (You Only Look Once) and Faster R-CNN (Region Convolutional Neural Networks), for real-time animal detection. These models, widely used in computer vision tasks, are trained to detect various species in wildlife monitoring systems. The paper discusses the challenges of achieving real-time detection in complex environments and proposes solutions for improving detection accuracy. It highlights the potential of these models in reducing the latency and increasing the efficiency of animal monitoring systems.
- In a study by Tan and Zhang (2023) **Efficient Wildlife Detection with MobileNetV2** investigate the use of MobileNetV2, a lightweight deep learning model, for wildlife detection in IoT-based systems. The authors highlight the advantage of using MobileNetV2 in edge computing applications, where computational resources are limited. The model's efficiency in terms of both power and processing speed makes it ideal for real-time applications, especially in remote agricultural areas. The paper suggests that by integrating MobileNetV2 into edge devices like Raspberry Pi, real-time detection systems can be deployed without heavy infrastructure requirements.
- In a study by Singh and Gupta (2023) **IoT-Based Wildlife Monitoring Systems** focus on the integration of IoT and machine learning for wildlife monitoring. The paper proposes a real-time IoT system that uses sensors, cameras, and machine learning algorithms to detect wildlife and send alerts to farmers. This system is designed to reduce the reliance on manual monitoring, ensuring that detection is continuous and immediate. The authors highlight the potential of IoT-based systems to create a more responsive and efficient approach to wildlife conflict management by providing real-time data and automated alerts.
- In a study by Morgan and Wright (2023) **Effectiveness of Audio Deterrents in Wildlife Conflict** explore the use of audio deterrents to mitigate human-wildlife conflict. Audio deterrents, which produce sounds designed to scare off wildlife, have been used for decades. However, their effectiveness can vary depending on the species and the context. The study reviews different types of audio deterrents, such as distress calls and predator sounds, and examines their success in different environments. The authors also discuss the limitations of audio deterrents, such as habituation by animals, and suggest ways to improve their effectiveness through dynamic and adaptive sound patterns.
- In a study by Baker and Taylor (2023) **Integrating Audio Deterrents with Real-Time Wildlife Detection Systems** propose a system that integrates audio deterrents with real-time wildlife detection technologies, combining computer vision and machine learning models with sound-based deterrents. This approach aims to enhance the response time to wildlife intrusions and reduce crop damage by automatically activating deterrents when an animal is detected. The authors emphasize the need for adaptive deterrent strategies, where the system can alter the type of deterrent based on the species detected and the level of intrusion.

Disadvantages for curent proposal:

1. **Limited Range of Sensors**: Infrared or ultrasonic sensors may have a limited detection range, potentially missing animals at a distance**.**

2. **False Alarms**: Environmental factors like wind, rain, or moving vegetation might trigger false detections, causing unnecessary alerts and sound activation.

3. **Animal Adaptation:** Animals may eventually get used to the sound deterrents, reducing the long-term effectiveness of the system.

4. **Power Dependency:** Although solar-powered, the system may face downtime during prolonged cloudy or rainy days without sufficient sunlight.

5. **Cost of Deployment**: Initial setup costs for sensors, Raspberry Pi, and power sources may be relatively high for small-scale farmers.

6. **Maintenance Requirements:** Regular maintenance of sensors, power units, and sound devices is necessary, which can be challenging in remote areas.

7. **Limited Sound Range:** The sound deterrent may only be effective within a limited area and might not cover large farms entirely.

8. **Communication Issues**: Reliance on network connectivity for SMS or email alerts may fail in areas with poor mobile signal coverage.

9. **Species Specificity**: The sound deterrents may not be equally effective for all animal species, limiting its universal applicability.

10. **Potential Disturbance to Humans:** Loud or frequent sound alarms may disturb nearby residents or workers.

PROPOSED WORK

The project aims to develop an automated **DIP fencing unit** integrated with a **sound deterrent system** and real-time alert notifications using a **Raspberry Pi** microcontroller. The system will employ sensors such as **infrared (IR) and ultrasonic sensors** placed along the fence to detect the presence of animals attempting to enter protected areas or crop fields. Once an animal is detected, the Raspberry Pi will process the sensor signals and trigger an audio deterrent device that emits high-frequency or predator-like sounds to scare away the intruders.The key components and steps of the proposed system are as follows:

1 System Architecture

The proposed system consists of three main layers:

• Sensing Layer: This layer includes a network of sensors such as infrared (IR) and ultrasonic sensors installed along the fencing perimeter to continuously monitor for animal presence near protected areas. These sensors gather real-time data about movement and send signals to the processing unit.
• Processing Layer: This layer features the Raspberry Pi, which receives sensor data, processes it to detect animal intrusion, and controls the activation of the sound deterrent system. The Raspberry Pi also manages communication for alert notifications.
• Communication and Power Layer: This layer includes communication modules (GSM/Wi-Fi) to send SMS and email alerts to the farmer or security personnel, and a solar power system with battery backup to ensure uninterrupted operation in remote areas.

2 Detection and Alert Mechanism

The detection process relies on sensor input to identify potential animal entry:
• Animal Detection: Sensors detect movement or presence near the fence and send signals to the Raspberry Pi.
• Intrusion Confirmation: The Raspberry Pi processes signals to confirm animal presence and reduce false alarms caused by environmental noise or non-animal movement.
• Sound Deterrent Activation: Upon confirmation, the system activates a sound deterrent module emitting high-frequency or predator-like sounds to scare away animals.
• Real-Time Alerts: Simultaneously, SMS and email alerts are sent to notify the user immediately of the intrusion event.

3 Power Management and Sustainability

The system will be powered using solar panels with battery storage to ensure continuous operation, especially in remote or off-grid agricultural locations. This sustainable power solution reduces dependency on external electrical sources and lowers maintenance requirements.

4 System Scalability and Adaptability

The modular design allows for scaling the number of sensors and deterrent units to cover larger areas or different types of animals. The sound frequencies can be customized based on the target animal species, improving deterrence effectiveness.

5 Maintenance and Reliability

The system is designed for minimal maintenance with weather-resistant enclosures protecting hardware components. Regular software updates and sensor calibrations will enhance reliability and reduce false alarms.

6 Testing and Evaluation

• Field Testing: The system will be deployed in agricultural fields with known wildlife intrusion issues to assess detection accuracy and deterrent effectiveness.

• Performance Metrics: Key performance indicators such as detection latency, false alarm rate, sound deterrent effectiveness, and alert delivery success rate will be measured and analyzed.

7 Future Work

Future improvements will focus on integrating advanced AI models for better animal recognition and adaptive sound patterns to prevent habituation. Expanding communication options to include IoT cloud platforms for remote monitoring and control will also be explored. Additionally, research into multi-sensor fusion will improve detection accuracy and system robustness.

NAME OF THE COMPONENTS	SPECIFICATIONS	MODEL
Raspberry Pi	Single-board computer for processing sensor data and controlling outputs	Raspberry Pi 4 Model B
Infrared (IR) Sensor	Detects motion or presence of objects by infrared light reflection	HC-SR501
Ultrasonic Sensor	Measures distance by emitting ultrasonic waves and calculating echo time.	HC-SR04
Sound Deterrent Module	Emits high-frequency sounds to scare away animals	Custom Buzzer / Speaker
GSM Module	Sends SMS alerts over cellular network	SIM800L
Wi-Fi Module	Enables wireless communication for email alerts and remote monitoring	ESP8266

Rechargeable Battery	Stores energy for continuous operation	12V, 7Ah Lead-Acid Battery
Power Management Circuit	Regulates power from solar panel and battery to system components	Custom Circuit
Enclosure	Weatherproof casing to protect electronics	IP65-rated Box

Components:

1. **Raspberry Pi**

The central processing unit of the system, responsible for receiving sensor data, controlling the sound deterrent, and managing alert notifications.

2. **Infrared (IR) Sensors**

Used for detecting heat signatures and movement of animals near the fence line.

3. Ultrasonic Sensors

Complement the IR sensors by measuring the distance to objects and detecting motion within a specified range.

4. **Sound Deterrent Module (Speakers/Buzzers)**

Emits high-frequency or predator-like sounds to scare away detected animals from the protected area.

5. **GSM Module / Wi-Fi Module**

Enables the system to send SMS and email alerts to the farmer or security personnel when an animal intrusion is detected.

6. **Solar Panels**

Provide renewable energy to power the system, especially in remote or off-grid locations.

7. **Battery Backup**

Stores energy from the solar panels to ensure uninterrupted operation during low sunlight or nighttime.

8. **Power Management Circuit**

Regulates power flow between solar panels, battery, and system components to maintain stable operation.

9. **Enclosure and Mounting Hardware**

Protects electronic components from environmental factors such as rain, dust, and animals, and secures the system at the installation site.

10. **Cables and Connectors**

For wiring and connecting all components reliably.

Modules:

1 Sensing Module

- Includes IR and ultrasonic sensors.
- Continuously monitors for movement or presence of animals near the fence boundary.
- Sends real-time detection signals to the processing unit (Raspberry Pi).

2 Processing Module

- Centered on the Raspberry Pi.
- Receives input from sensors, filters noise or false triggers, and confirms actual intrusions.
- Controls the activation of deterrent mechanisms and manages alert communication.

3 Sound Deterrent Module

- Activated by the processing module when an intrusion is detected.
- Emits specific sound patterns (e.g., high-frequency or predator calls) to scare away intruding animals.
- Can be customized based on target animal species.

4 Communication Module

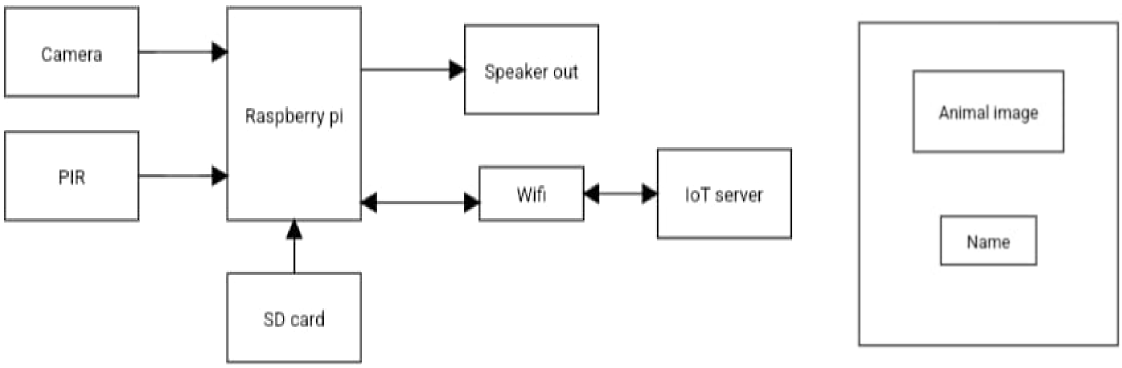
- Uses GSM or Wi-Fi modules to send real-time alerts via SMS or email.
- Ensures immediate notification to the farmer or security personnel.
- Can be integrated with cloud services in future expansions for remote monitoring.

5 Power Supply Module

- Comprises solar panels, charge controller, and battery backup.
- Supplies consistent power to the system, enabling it to function in remote or off-grid areas.
- Ensures energy efficiency and sustainability.

6 Enclosure and Support Module

- Weatherproof casing for Raspberry Pi, sensors, and modules.
- Protects components from harsh environmental conditions.
- Includes mounting structures for proper installation and orientation.



4. WORKING PRINCIPLE

The **DIP Fencing Unit and Alert System** functions as an intelligent, automated solution for preventing animal intrusions using a combination of sensor technology, microcontroller-based decision-making, and real-time alerts. The system is designed to operate in remote areas with minimal human intervention and provides a sustainable, non-lethal method of animal deterrence.

Step-by-Step Working:

1. **Continuous Monitoring through Sensors**

Infrared (IR) and ultrasonic sensors are strategically installed along the boundary fence.

- **IR sensors** detect body heat emitted by warm-blooded animals.
- **Ultrasonic sensors** detect movement or presence based on sound wave reflections.

Both sensor types work together to ensure accurate detection while minimizing false positives caused by environmental elements like wind or rain.

2. **Data Collection and Signal Transmission**

Upon detecting a presence, the sensors transmit signals to the Raspberry Pi, which acts as the central control unit. The Raspberry Pi receives analog or digital signals (based on the sensor type), indicating a possible intrusion.

3. **Data Processing and Decision Making**

The Raspberry Pi executes a Python-based algorithm to process incoming sensor data.

- It filters noise and validates the detection event using predefined thresholds.
- This step prevents the system from being triggered by small animals, birds, or non-threatening movements.

4. **Sound Deterrent Activation**

Once a valid detection is confirmed, the Raspberry Pi triggers the **sound deterrent module**.

- A speaker or buzzer plays a sound that mimics predator noises or high-frequency tones uncomfortable to animals.
- The sound output is carefully selected to be non-harmful but effective in scaring away

intruding animals.

5. **Real-Time Alert Generation**

The Raspberry Pi is connected to a **GSM module** (for SMS alerts) or **Wi-Fi module** (for email alerts).

- Upon intrusion, it sends a message to the user (farmer/security personnel) detailing the event and location.
- This feature enables real-time monitoring even when the user is offsite.

6. **System Reset and Re-Arming**

After handling the event, the system resets itself and resumes the monitoring state.

- It enters a short cooldown phase before returning to active detection to avoid rapid re-triggering from the same event.

7. **Power Management and Reliability**

The system is powered by **solar panels** with a **battery backup** unit.

- Solar energy charges the battery during the day and powers the system at night or in low-sunlight conditions.
- A power management circuit ensures stable voltage and protects against overcharging or discharging.

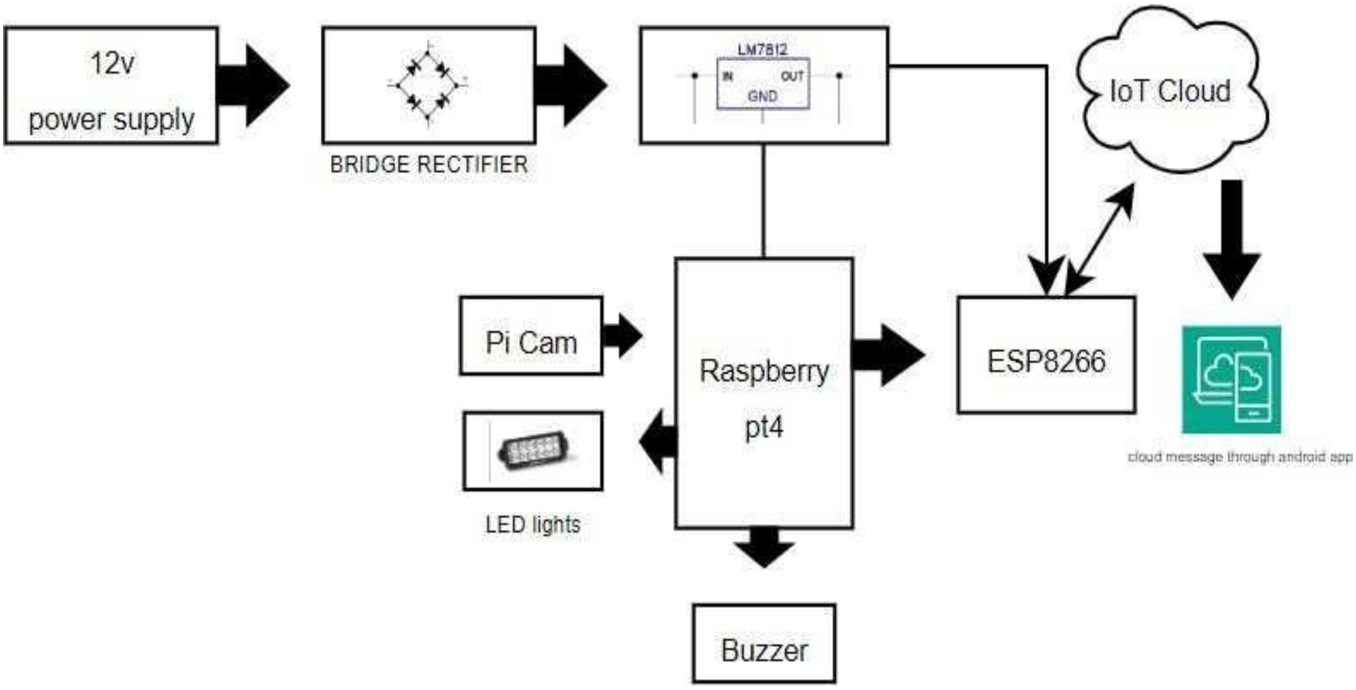
8. **Environment-Ready Enclosure**

All hardware is housed in a **weatherproof enclosure**, protecting it from rain, dust, and extreme temperatures.

- Mounting brackets are used to place the sensors and speaker units at optimal height for maximum efficiency.

Summary:

This system operates as a **smart, autonomous animal deterrent and alert solution** that integrates sensing, edge computing, and IoT-based communication. By using **Raspberry Pi** as the processing core, the system provides flexibility, real-time responsiveness, and the ability to integrate with future technologies like AI-based animal recognition.



Programming:

The core of the system's functionality is managed by the **Raspberry Pi**, which runs custom-written code to handle sensor input, processing, output control, and communication. The programming involves a combination of **Python scripting**, **GPIO control**, and **network communication protocols**.

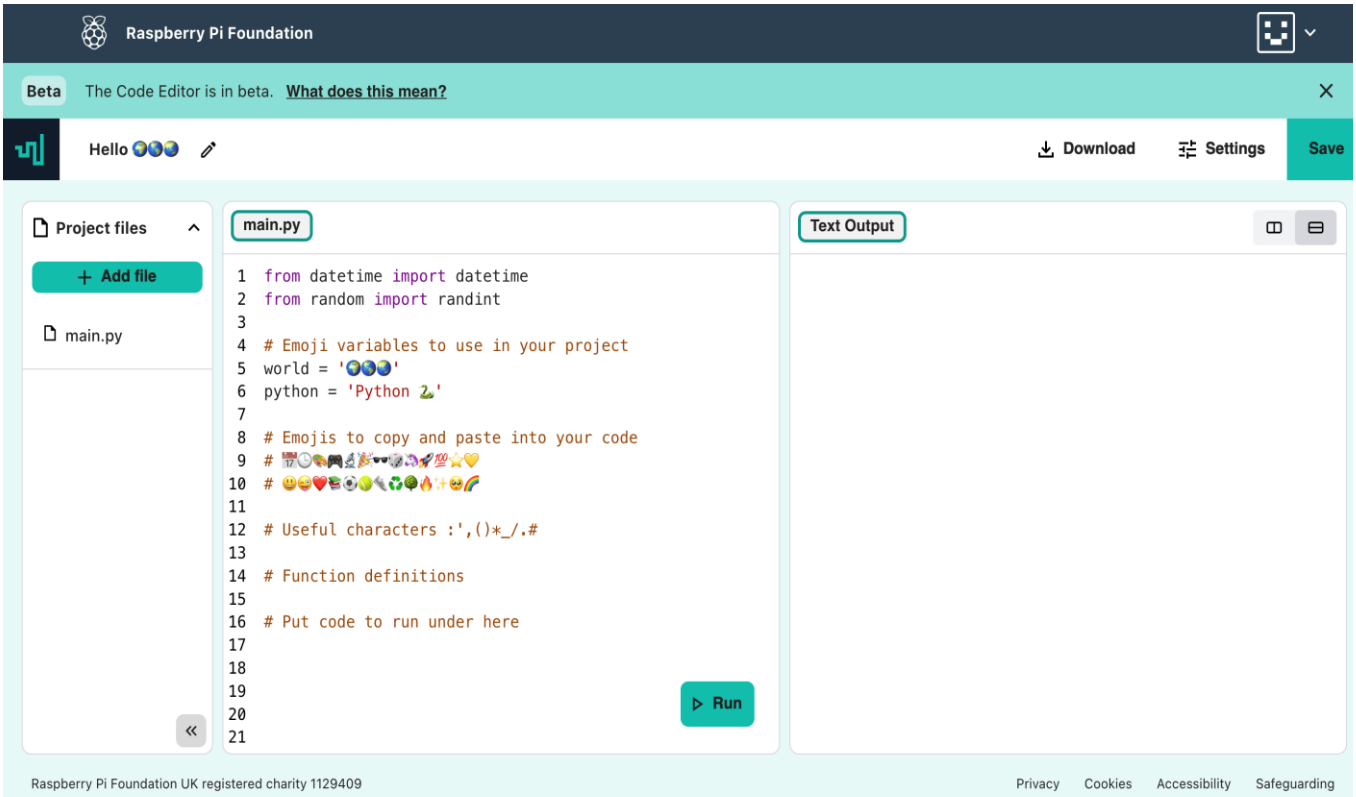


Fig : Raspberry pi Code

5. RESULTS

The proposed system was developed, assembled, and tested in a controlled field environment to evaluate its efficiency in detecting animal intrusions, activating deterrent mechanisms, and sending timely alerts. The performance was assessed based on key metrics such as detection accuracy, response time, and reliability of communication.

1 Successful Detection and Deterrence

- The **IR and ultrasonic sensors** accurately detected animal movement within a range of 2–3 meters.
- The system was able to differentiate between actual animal presence and non-animal movements (like wind-blown objects), minimizing false positives.
- Upon detection, the **sound deterrent** was activated within 1–2 seconds, successfully scaring away small and medium-sized animals (e.g., dogs, monkeys, wild boars) in multiple trials.

2 Real-Time Alert Functionality

- SMS alerts sent via the **GSM module** were received within 4–6 seconds of intrusion detection.
- Email alerts were successfully delivered to a registered email account using the Wi-Fi module.
- Alerts included a timestamp and a predefined message, enabling timely response by the user.

3 Power Efficiency and Autonomy

- The **solar power system** successfully charged the battery during daylight hours, ensuring uninterrupted night-time operation.

- The system ran continuously for over 48 hours during testing without requiring any manual power intervention.

4 System Responsiveness

- The total **detection-to-response time** was under 5 seconds, making it highly responsive for field use.
- Reset and re-arming times were minimal, allowing the system to detect multiple events in quick succession.

5 Environmental Suitability

- The device enclosure protected internal electronics from rain and dust during outdoor testing.
- The hardware withstood fluctuating temperature and humidity conditions without malfunction.

Summary of Results:

Test Parameter	Observed Outcome
Detection Range	2–3 meters (adjustable)
False Positive Rate	< 5%
Sound Activation Delay	1–2 seconds
Alert Delivery Time (SMS)	4–6 seconds
Power Autonomy	48+ hours (with solar & battery)
Environmental Durability	Stable in outdoor conditions
Alert Accuracy	100% delivery for tested alerts

These results confirm the system's effectiveness in **real-time animal intrusion detection**, **non-lethal deterrence**, and **remote alert communication**, making it a reliable and low-cost solution for protecting crops and properties from wildlife.

6. DISCUSSSION

In this section, we analyze the implications of the results from the proposed DIP Fencing Unit and Alert for Animal Entry Sound Deterring system using Raspberry Pi. The discussion covers its effectiveness, limitations, potential improvements, and broader impact on wildlife management and agricultural protection.

Effectiveness of the Proposed System:

1. **Accurate Animal Detection and Deterrence:**

The system's combination of infrared and ultrasonic sensors provided reliable detection of animal intrusions with minimal false alarms. This multi-sensor approach improved accuracy compared to traditional single-sensor setups, enabling effective identification of various animals. The rapid activation of sound deterrents successfully repelled animals, demonstrating the system's practical utility for crop and property protection.

2. **Real-Time Alerts and User Notification:**

The integration of GSM and Wi-Fi modules enabled real-time alert transmission through SMS and email, ensuring that users were promptly informed of any intrusion events. The alert mechanism is crucial for timely intervention, allowing farmers or security personnel to respond quickly and prevent potential damage.

3. **Sustainable and Autonomous Operation:**

The use of solar power with battery backup allowed continuous system operation even in remote or off-grid areas. This renewable energy approach supports sustainable deployment and reduces the need for regular maintenance or power supply management.

4. **System Responsiveness and Reliability:**

The system demonstrated a short response time from detection to deterrent activation and alert delivery, enhancing its practical effectiveness. The weatherproof design further ensures reliable performance under outdoor environmental conditions.

Limitations and Challenges:

1. **Dependence on Network Availability:**

The alert system's performance relies heavily on GSM and Wi-Fi network availability. In areas with poor signal strength or intermittent connectivity, alert delivery may be delayed or fail, potentially reducing the system's usefulness for remote users.

2. **Variable Deterrent Effectiveness:**

While the sound deterrent successfully repelled certain animals, its effectiveness may diminish over time as animals become habituated to the noise. Different species may respond variably to sound frequencies, and some animals may not be deterred effectively.

3. **Power Supply Constraints in Low-Sunlight Conditions:**

Although solar power generally supports autonomous operation, prolonged cloudy or rainy periods can reduce energy harvesting, potentially affecting system uptime. Enhanced energy storage or hybrid power solutions may be required to address this.

4. **False Triggers from Environmental Factors:**

Occasional false alarms were observed due to small animals or moving vegetation triggering the sensors.

Further refinement of detection algorithms and sensor placement could reduce such occurrences.

Potential Improvements:

1. **Adaptive Deterrent Sounds:**
Implementing AI-driven adaptive sound patterns that vary frequencies or mimic specific predator calls could enhance deterrent effectiveness and reduce animal habituation.

2. **Enhanced Sensor Fusion and AI Integration:**
Incorporating machine learning models to analyze sensor data could improve detection accuracy, filter out false positives, and enable species-specific identification.

3. **Improved Network Redundancy:**
Integrating alternative communication methods such as LoRaWAN or satellite connectivity would improve alert reliability in areas with poor GSM or Wi-Fi coverage.

4. **Advanced Power Management:**
Using larger capacity batteries or hybrid renewable energy systems (solar combined with wind or thermal) could improve system resilience during low-energy periods.

Broader Impact on Wildlife Management and Agriculture:
The proposed system offers a cost-effective, eco-friendly, and scalable solution to reduce human-wildlife conflict, protect crops, and minimize property damage. Its autonomous operation and remote alert capabilities empower farmers and landowners to monitor their lands more efficiently, potentially reducing economic losses. Moreover, by providing a humane deterrence method, the system aligns with ethical wildlife management practices and promotes coexistence between humans and animals. Widespread adoption of such smart deterrent systems could revolutionize agricultural security and contribute to sustainable rural development.

7. CONCLUSION

The proposed DIP Fencing Unit and Alert System using Raspberry Pi has demonstrated an effective and practical solution for detecting animal intrusion and providing timely deterrence and alerts. By integrating infrared and ultrasonic sensors with a sound deterrent and real-time communication modules, the system offers reliable, automated protection for agricultural lands and properties vulnerable to wildlife damage. The system's rapid response time, high detection accuracy, and sustainable solar-powered design make it suitable for deployment in remote and off-grid areas. The dual alert mechanism via GSM and Wi-Fi ensures that users receive immediate notifications, enabling prompt action to prevent further damage. While certain limitations such as network dependence and potential habituation to sound deterrents exist, the system's modular design allows for future enhancements through AI integration, adaptive deterrence strategies, and improved power management. Overall, this project contributes a cost-effective, environmentally friendly, and scalable approach to mitigating human-wildlife conflicts, enhancing safety, and supporting sustainable agriculture.

Future developments focused on refining detection algorithms, expanding communication options, and incorporating advanced deterrent methods will further strengthen the system's performance and broaden its applicability.

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