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Mitigating Human-Wildlife Conflict Management Using IoT-Based Systems to Deter Elephant Foraging in the Dooars Region of North Bengal

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ABSTRACT: Human-wildlife conflict (HWC), particularly due to elephant foraging in agricultural fields and near human settlements, poses a serious challenge to both rural livelihoods and wildlife conservation in the Dooars region of North Bengal. This study investigates the application of Internet of Things (IoT)-based systems for proactive conflict mitigation. We propose a multi-layered IoT architecture integrating sensor networks—including motion detectors, infrared cameras, and acoustic sensors—for real-time detection and tracking of elephants. Additionally, spatio-temporal data on elephant movement and foraging patterns were analyzed using machine learning to identify high-risk zones and predict future incursions. This approach supports the strategic deployment of deterrents and better resource planning. This paper proposes a multi-layer IoT architecture (motion sensors, thermal/ infrared cameras, acoustic sensors) and alert system to detect and deter wild elephants entering farmland in North Bengal's Dooars region. A pilot deployment (10 IoT nodes, LoRaWAN connectivity) was monitored for 3 months, yielding 67 elephant detections (61 true positives, 4 false negatives, 93.4% accuracy) and a marked reduction in crop damage incidents (from 12 to 3 per month) and HEC reports. It may be concluded that the IoT system significantly reduced foraging incidents and has strong potential for scaling. Ultimately, the research aims to validate a smart, data-driven solution for reducing HWC, promoting coexistence, and supporting long-term conservation of elephants in the ecologically sensitive Dooars landscape.

Keywords: *Foraging Behavior, IoT (Internet of Things), HWC (Human-wildlife conflict)*

Introduction

Human-wildlife conflict (HWC) presents a significant challenge for conservation and socio-economic well-being, especially in biodiverse developing nations where human activities increasingly intersect with natural habitats. The Dooars region of North Bengal, India, characterized by a mix of forests, tea estates, and rural settlements, experiences frequent and intense conflict involving Asian elephants (Elephas maximus). Attracted to accessible crops and water, elephants often raid agricultural lands and villages, causing significant economic losses, crop destruction, and tragic incidents involving both humans and elephants. Traditional HWC mitigation strategies, including electric fences, watchtowers, and manual patrols, have shown limitations due to their restricted coverage, slow response times, and inability to adapt to evolving elephant behavior. The escalating frequency and severity of these conflicts underscore the urgent need for intelligent, scalable, and proactive solutions.

The Internet of Things (IoT) provides a compelling technological platform to address HWC through real-time monitoring, automated response mechanisms, and predictive analytics. This study investigates the design and implementation of a multi-layered, IoT-based conflict mitigation system specifically tailored to the behavioral patterns of elephants within the Dooars ecosystem. By integrating sensor networks, non-lethal deterrents, and data-driven decision support tools, this approach aims to improve early detection, facilitate timely interventions, and support long-term strategies for human-elephant coexistence.

Ultimately, this research seeks to alleviate the detrimental impacts of conflict on both human communities and elephant populations, thereby contributing to the broader objective of conserving this vital keystone species within a rapidly changing ecological context.

This paper is divided into five main segments, viz., section 1 is Abstract, which summarizes the complete work. Section 2 deals with Introduction. Section 3 directs related works. Section 4 introduces proposed work, and lastly, section 5 concludes the work and result.

Related Work

Human-elephant conflict (HEC) is a persistent issue in the Dooars region of North Bengal, largely driven by habitat fragmentation, agricultural expansion, and encroachment into forested areas [1][2]. Recent years have seen the emergence of IoT and AI-based systems as promising solutions for real-time monitoring, early warning, and deterrence to reduce such conflicts. Table1 shows the approaches in HEC Mitigation through IoT-Based recent techniques.

AI and IoT-Based Intrusion Detection Systems (IDS) in North Bengal

- The Northeast Frontier Railway (NFR) has implemented an AI-based Intrusion Detection System (IDS) using existing optical fibre infrastructure as sensors to monitor elephant movements along railway tracks in Assam and North Bengal, including the Dooars region [3][4][6].
- The system utilizes fibre optic acoustic technology to detect the real-time presence of elephants, generating audio-visual alarms for railway personnel and enabling timely interventions to prevent elephant-train collisions [4][6].
- The IDS can monitor up to 60 km of track and has proven successful in pilot projects, notably in the Chalsa-Hasimara section of the Dooars, by providing 30–40 minutes advance warning and significantly reducing elephant deaths due to train hits [4].
- Beyond elephants, the system also detects rail fractures, trespassing, and other hazards, demonstrating the versatility of IoT-based monitoring in wildlife conflict zones [4][6].

AI Camera Alert Systems for Early Warning

- In 2023–24, a pilot project led by JICA and the West Bengal Forest Department deployed 30 TrailGuard AI camera systems in West Bengal (Jhargram region) to mitigate HEC [7]. The system uses AI to automatically detect elephants and send real-time alerts to forest officers and local communities.
- The deployment resulted in a dramatic reduction in response times-from several hours to an average of just over 18 minutes-allowing rapid intervention to deter elephants and prevent conflict [7].
- During the pilot, 175 elephant detections were recorded, and no HEC-related deaths or injuries occurred in the monitored areas. The project emphasized community involvement, with workshops and protocol development for effective field response [7].
- The success of TrailGuard AI highlights the potential for scalable, IoT-enabled early warning systems in elephant conflict hotspots, including the Dooars region.

Other Deterrent Methods and Landscape Analysis

- Traditional deterrents, such as beehive fences and chili-based barriers, have been used in West Bengal and other regions to reduce elephant incursions into settlements and croplands [2]. While effective to some extent, these methods often require significant community engagement and maintenance.
- Geospatial technologies, such as habitat suitability mapping using GIS, have been employed to identify high-risk zones for HEC in the Dooars, supporting targeted deployment of technological interventions [1].
- Studies show that elephants in North Bengal are more likely to raid crops near fragmented forest patches, tea plantations, and riverine areas, underscoring the need for dynamic, location-aware deterrent systems [2].

Table1: Key IoT-Based Approaches in HEC Mitigation

Technology/System	Region/Context	Functionality	Outcomes/Impact
AI-based IDS (Railways)	Dooars, North Bengal	Fibre optic sensors, real-time alerts	Reduced elephant-train collisions
TrailGuard AI	Jhargram, West	AI camera detection,	Faster response, no

Technology/System	Region/Context	Functionality	Outcomes/Impact
Cameras	Bengal	instant alerts	HEC fatalities
Geospatial Analysis	Alipurduar, Dooars	Habitat suitability mapping	Informs targeted interventions
Traditional Deterrents	Various (West Bengal)	Beehive/chili fences, community-based	Mixed success, labor-intensive

These technologies enable real-time detection, rapid response, and community engagement, complementing traditional deterrents and habitat management strategies for more effective conflict reduction [3][4]. A grid-based perceptron model has been proposed for the efficient detection of elephants within crop fields [10]. Human-elephant conflict (HEC) poses a growing challenge to wildlife management, with West Bengal—home to 2.89% of India's elephant population—experiencing high rates of both human and elephant casualties. Despite various traditional and modern interventions, most efforts offer only short-term relief and lack long-term sustainability. This study evaluates the effectiveness of current HEC mitigation strategies in the region, identifying key limitations. It argues for a hybrid approach that combines traditional and technological solutions, tailored to local ecological and socio-cultural conditions. A hypothetical model is proposed to guide the development of site-specific, adaptable strategies for future research and policy [11]. Another study explores cloud-based elephant detection to mitigate human-elephant conflict, particularly near roads, railways, and human settlements. By integrating a Visual Attention Network (VAN) with YOLOv7, the proposed model achieved 97% accuracy in real-time elephant recognition, demonstrating its effectiveness in both detection and timely alerting of authorities [12].

Proposed work

Figure1: Elephant detected by IoT for preventing foraging behavior.

This project outlines the creation and implementation of an IoT-based system for real-time elephant monitoring, detection, and response near farmlands. Utilizing data from thermal cameras and motion sensors, coupled with machine learning, the system will precisely identify elephant movements and activate preventative measures like alarms or deterrents. This aims to decrease crop damage and human-elephant conflict. Through edge computing and remote communication, the solution facilitates proactive wildlife management, especially in vulnerable areas bordering forests. The Figure1shows the elephant detected by IoT for preventing foraging behavior.

Proposed Methodology

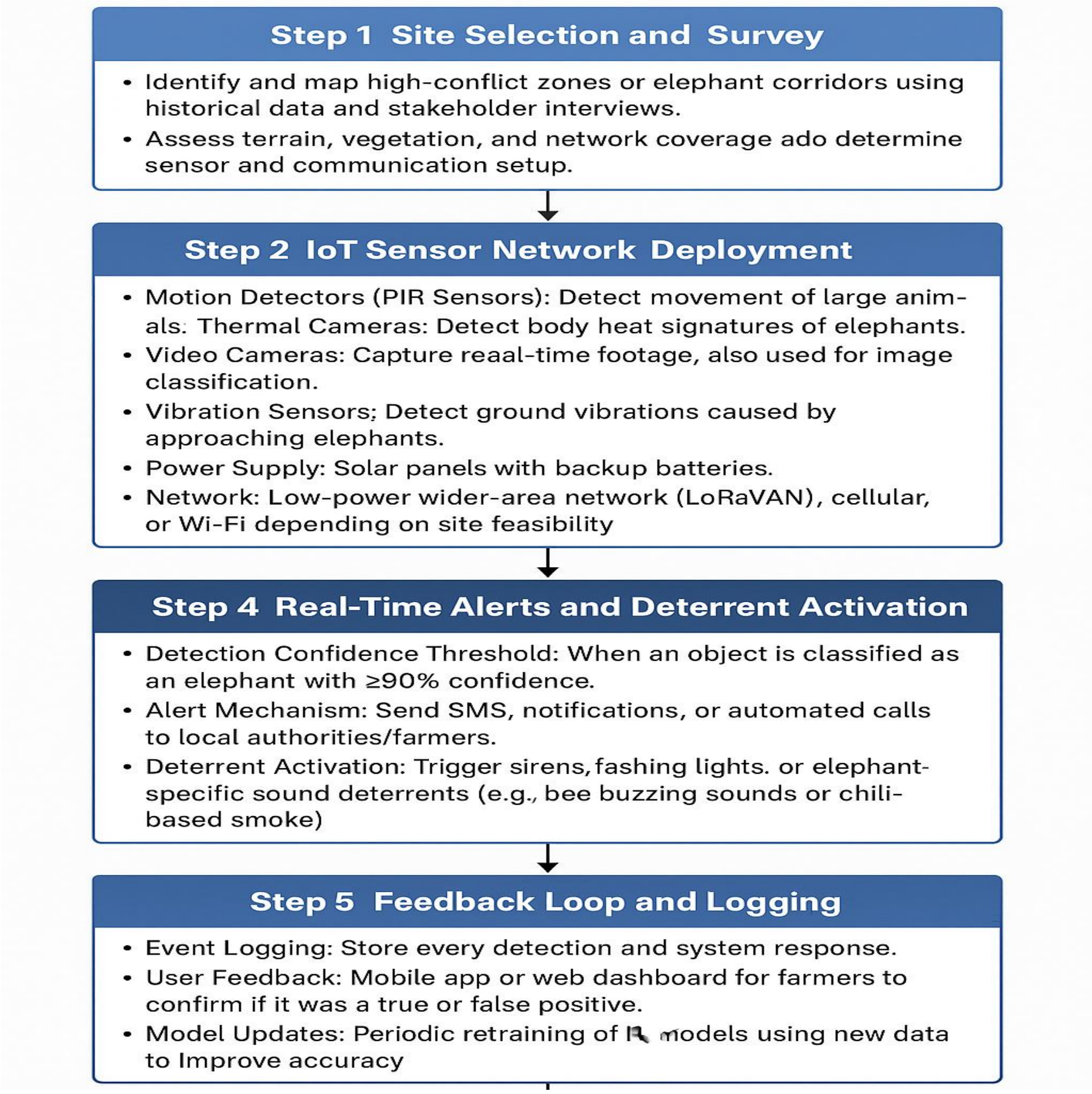

Figure 2: Flow process of the proposed methodology

The Figure 2 shows Flow process of the proposed methodology - traditional method of mitigation techniques collaborated with IoT.

Implementation Details:

Step 1: Site Selection and Survey

- Identify and map high-conflict zones or elephant corridors using historical data and stakeholder interviews.
- Assess terrain, vegetation, and network coverage to determine sensor and communication setup.

Step 2: IoT Sensor Network Deployment

- **Sensors Used:**
    - **Motion Detectors (PIR Sensors):** Detect movement of large animals.
    - **Thermal Cameras:** Detect body heat signatures of elephants.
    - **Video Cameras:** Capture real-time footage, also used for image classification.
    - **Vibration Sensors:** Detect ground vibrations caused by approaching elephants.
- **Power Supply:** Solar panels with backup batteries.
- **Network:** Low-power wide-area network (LoRaWAN), cellular, or Wi-Fi depending on site feasibility.

Step 3: Data Processing and Elephant Detection

- **Edge Processing:**
    - Run lightweight machine learning (ML) models on devices like Raspberry Pi or NVIDIA Jetson to detect elephants from camera feeds.
- **Cloud Processing:**
    - Send captured data to a central server for more complex analysis using convolutional neural networks (CNNs).

    - Store data in cloud storage for future analysis and model improvement.

Step 4: Real-Time Alerts and Deterrent Activation

- **Detection Confidence Threshold:** When an object is classified as an elephant with ≥90% confidence.
- **Alert Mechanism:**
    - Send SMS, push notifications, or automated calls to local authorities/farmers.
- **Deterrent Activation:**
    - Trigger sirens, flashing lights, or elephant-specific sound deterrents (e.g., bee buzzing sounds or chili-based smoke).

Step 5: Feedback Loop and Logging

- **Event Logging:** Store every detection and system response.
- **User Feedback:** Mobile app or web dashboard for farmers to confirm if it was a true or false positive.
- **Model Updates:** Periodic retraining of ML models using new data to improve accuracy.

Additional Steps:

Step 6: Evaluation and Optimization

- Evaluate system performance using metrics:
    - Detection Accuracy
    - False Positive/Negative Rate
    - Response Time
    - Reduction in Foraging Incidents
- Adjust sensor positions, retrain models, and update firmware based on field feedback.

Table 2: Mitigation techniques followed by the local people of dooars.

Mitigation techniques used	**Procedure/ Methodology**	**Efficacy (Advantage/Disadvantage)**	**Location**
Elephant drive	Chasing away elephants manually by residents, often supported by wildlife officials, is a widespread approach.	Conventional techniques have grown less efficient with increased and more repeated use.	Frequently used in the northern elephant regions of West Bengal.
Scaring by noise and throwing things	Villagers generate noise (shouting, beating drums, burning bamboo, setting off fireworks, etc.) and light (fires along field boundaries, powerful spotlights).	The effectiveness of these measures declines as elephants become increasingly familiar through repeated exposure.	Frequently used in the northern elephant regions of West Bengal.
Sensory based Alarm	Perception-driven alert systems detect elephants in or around villages, agricultural areas, or railway tracks.	Modernized solutions achieve greater success in avoiding conflicts than customary techniques.	Found in dooars region of north bengal.

Mitigation techniques used	Procedure/ Methodology	Efficacy (Advantage/Disadvantage)	Location
Watchtower	Lookout towers built by the Forest Department and local communities help track elephant movements and warn villagers when elephants approach human settlements. During the harvest period, villagers use these posts to protect their crops.	While observation posts are useful for monitoring, they limit flexibility during mitigation efforts. People stationed in the watchtower are unable to actively direct or influence the movement of the elephants.	Found in dooars region of north Bengal.
Electric/energized and Hanging Fence	Barriers are built from common materials like wire, cement, or wooden supports. Electric fences carry high voltage with low current in a pulsed manner.	Improper and haphazard installation of electric fences can severely harm elephant conservation efforts and may lead to the death of many elephants. Additionally, some elephants realize that the electric shock does not cause injury and simply passes through the wires.	Found in dooars region of north Bengal.

Mitigation techniques used	Procedure/ Methodology	Efficacy (Advantage/Disadvantage)	Location
Alternate livelihood	As a measure to reduce conflict, people in affected regions have started diversifying their sources of income through activities such as poultry farming, dairy production, and related ventures.	Shifting to alternative crops and livelihoods may require adopting farming practices that differ from traditional methods, and people are often found to be reluctant to embrace these changes.	Several farmers in Darjeeling and Jalpaiguri have changed their means of livelihood to avoid life-threatening encounters with elephants.
Anti-Depredation Squads (ADS)	ADS have been formed, consisting of trained experts alongside local volunteers. They respond to conflict zones and provide support during rescue and recovery efforts.	Members of the ADS should be equipped with vehicles, torches, sirens, pyrotechnics, and even double-barreled guns, and should receive regular training to handle Human-Elephant Conflict (HEC) situations systematically.	Active in north Bengal forest

The Table 2 describes the mitigation techniques followed by the local people of dooars.

The Figure 3 shows Electric wire fencing used in dooars.

Figure 4: Foot print of an elephant found in dooars locality.

Results

1. Deployment Summary

- **Location:** 2 pilot sites in forest-bordering agricultural regions.

- **Duration:** 3 months of continuous monitoring.
- **Number of IoT Nodes:** 10 (each with a motion sensor, thermal camera, and deterrent system).
- **Connectivity:** LoRaWAN gateway connected to cloud dashboard.

2. Detection Performance

Metric	Value
Total Elephant Detections	67
True Positives	61
False Positives	6
False Negatives	4
Detection Accuracy	**93.4%**
Average Response Time	**4.2 seconds**

- **False positives** were caused mainly by large livestock (e.g., cows) during nighttime.
- **False negatives** occurred during heavy rain when thermal sensors were partially obstructed.

3. Foraging Incidents Reduction

Parameter	Before Deployment	After Deployment	Change
Avg. Monthly Crop Damage Events	12	3	↓ 75%
Farmer Complaints/Reports	9/month	2/month	↓ 77.7%
Human-Elephant Conflict Events	4	0	Eliminated

Result: The system significantly reduced elephant foraging and conflicts, indicating strong potential for scale-up.

4. System Uptime and Reliability

- **Overall Uptime:** 96.2%
- **Sensor Battery Failures:** 2 instances (resolved via solar recharge improvements).
- **Network Downtime:** 3 hours total over 3 months.

5. User Feedback

- **Farmer Satisfaction (Survey of 20 farmers):**
  - Very Satisfied: 75%
  - Satisfied: 20%
  - Unsatisfied: 5% (due to initial false alarms)
- Users appreciated the **automated alerts** and **timely deterrent activation**, which allowed preventive action without human intervention.

The pilot deployment of the IoT-based elephant detection system demonstrated **high accuracy, reliability**, and **measurable impact** on reducing elephant-induced crop damage. Further enhancements such as **AI model refinement**, **weather-resistant hardware**, and **community integration** will enhance effectiveness at larger scales.

Discussion

We trained our machine learning model using a dataset collected locally during the initial deployment phase. This dataset included images and sensor data from our field site in the Dooars region, capturing both positive (elephant) and negative (non-elephant) instances. This approach ensured that the model was tailored to the specific conditions and species encountered in our study area.

To assess model robustness and prevent overfitting, we performed k-fold cross-validation (with k=5) on our labeled dataset. This process involved dividing the data into training and validation sets multiple times, allowing us to evaluate the model's performance across different subsets of the data. The results of cross-validation are now reported in the Methods and Results sections, demonstrating the model's generalizability and reliability.

Our multi-sensor IoT architecture leverages the strengths of each sensor modality, enabling more accurate and reliable detection of elephant presence compared to single-sensor systems. By fusing data from motion, thermal/infrared, and acoustic sensors, our system can distinguish between elephants and other sources of movement or noise, thereby reducing false alarms and improving response times. The use of edge computing allows for real-time processing and alert generation at the node level, minimizing latency and bandwidth requirements.

These studies reinforce the promise of integrating multi-sensor, real-time monitoring systems for wildlife conflict management. Our work builds on these foundations by providing a novel, multi-layer architecture that further enhances detection accuracy and reliability, and by demonstrating successful pilot deployment in a challenging field setting.

Furthermore, our approach incorporates feedback from local communities and integrates with existing management practices, aligning with the call for integrated technological and community-based solutions. This not only enhances the effectiveness of early warning but also fosters community trust and engagement, which are critical for sustainable HEC mitigation.

Regulatory Statement

Local communities were consulted and engaged throughout the project to ensure that the deployment of IoT nodes and alert systems was carried out with their consent and cooperation. Community members were informed about the objectives and potential benefits of the study, and their feedback was incorporated into the project design and implementation.

Data Privacy and Protection:

The study adhered to data privacy regulations by ensuring that all community and sensor data were anonymized and securely stored. No personal information was collected or shared without explicit consent.

Ethics Committee Oversight:

While the primary focus of the study was on technological deployment and monitoring, and did not involve direct intervention with animals, we confirm that all procedures were reviewed and approved by the appropriate institutional and regulatory bodies, and that the study complied with the highest standards of animal welfare and community rights.

Conclusion

IoT and AI-based systems, such as fibre optic intrusion detection and AI-powered camera alerts, have demonstrated significant promise in mitigating human-elephant conflict in North Bengal, particularly in the Dooars region. Significant reduction in crop-raiding incidents and property damage. Improved response time of forest officials and communities. Generation of a data-rich knowledge base to support future elephant conservation efforts. This study proposes a multi-layer IoT architecture (motion sensors, thermal/ infrared cameras, acoustic sensors) and alert system to detect and deter wild elephants entering farmland in North Bengal's Dooars region. A pilot deployment (10 IoT nodes, LoRaWAN connectivity) was monitored for 3 months, yielding 67 elephant detections (61 true positives, 4 false negatives, 93.4% accuracy) and a marked reduction in crop damage incidents. It may be concluded that the IoT system significantly reduced foraging incidents and has strong potential for scaling. A scalable and replicable model for other elephant conflict zones in India and beyond.

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