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AI-ASSISTED INTRUSION DETECTION AND WILDLIFE CONSERVATION: ADDRESSING THE ASSAM TRAIN COLLISION CRISIS

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Abstract:

In India, where infrastructure meets biodiversity-rich environments, railway-wildlife collisions are a significant conservation and safety problem. Seven elephants were killed when a high-speed train in Assam collided with a group of wild Asiatic elephants on December 20, 2025. This case-based study incorporated operational, technological and environmental factors. The collision site was outside the area of AI-based Intrusion Detection Systems (IDS), and the results showed that fog, nighttime operations, and forest cover greatly decreased visibility. The IDS relies on human interaction and operates below Level 4 autonomy, causing significant delays. Elephant movements were not captured by static corridor mapping. To align technology and animal conservation with India's sustainable development goals, multimodal sensing, increased coverage, adaptive speed control, and improved autonomy must be blended with human oversight.

Keywords: *AI-based Intrusion Detection System; Train–Elephant Collision; Wildlife Conservation; System Autonomy; Human–Nature–Technology Integration; Sustainable Development; Forested Railway Corridors.*

Introduction:

India is finding it more and more challenging to balance between biodiversity preservation and rapid technological advancement. Railway expansion intersects vital habitats for more than 7.6% of the world's species, including endangered elephants, resulting in conflicts between humans and wildlife [1,2]. The train-elephant incident in Assam in 2025 revealed deficiencies in ecological monitoring, operational planning, and AI deployment. Although some corridors have AI-based intrusion detection systems installed, these systems function below Level 4 autonomy, sending alarms to human operators instead of automated emergency responses [3,4]. Elephant movement is not captured by static corridor mapping, especially when it is misty or at night. In keeping with India's objective of sustainable development, this study investigates how AI technology, human interaction, and ecological measures can work collaboratively to promote railway safety and minimise wildlife casualties [5].

Railway-wildlife collisions pose a significant threat to conservation and public safety, especially in areas where railway infrastructure crosses areas rich in biodiversity. Even with the advent of Artificial Intelligence-based Intrusion Detection Systems (IDS), large mammal-related fatalities still happen. Seven Asiatic elephants were killed in a train-elephant collision in Assam on December 20, 2025, which highlights the shortcomings of current mitigating strategies.

The limited spatial coverage, reliance on human intervention, and lesser levels of autonomy of current IDS deployments cause delayed reactions in adverse conditions like fog, nighttime operations, and dense forest cover. Also, dynamic animal migration patterns are not captured by static wildlife corridor mapping. The efficacy of conservation-oriented railway safety systems is constrained by the lack of an integrated framework that incorporates sophisticated AI autonomy, real-time multimodal sensing, adaptive train control, and efficient human oversight. To assist wildlife protection and India's sustainable development goals, these gaps must be filled.

Literature Review:

AI-Based Obstacle Detection Techniques for Unfavourable Environments

AI-based obstacle detection in railway corridors has evolved from single-sensor approaches to robust multi-modal sensing architectures capable of operating in complex ecological and environmental conditions. These systems are particularly relevant in forested, hilly, fog-prone, and low-visibility regions such as Northeast India.

1. **Image-Based Vision Systems**

   Image-based detection systems employ high-resolution RGB cameras combined with deep learning models such as Convolutional Neural Networks (CNNs) and object-detection frameworks (e.g., YOLO, Faster R-CNN) to identify wildlife on or near railway tracks. These systems are effective under normal lighting conditions and provide contextual scene understanding, enabling classification of animals, humans, and vehicles [4,12].

   However, their performance degrades significantly in adverse conditions such as fog, heavy rain, nighttime operations, and dense vegetation, where contrast and visibility are reduced. In forested corridors, occlusion by trees and uneven terrain further limits reliable detection.

2. **Infrared and Thermal Imaging Sensors**

   Infrared (IR) and thermal imaging sensors detect heat signatures rather than visible light, making them particularly effective for nocturnal wildlife detection and low-visibility environments. Thermal cameras can identify large mammals such as elephants even through partial vegetation cover and fog, where optical cameras fail [9,10].

   In railway applications, thermal imaging has demonstrated improved detection accuracy during nighttime and early morning hours, which coincide with peak elephant movement. Nevertheless, thermal sensors may struggle to distinguish between species of similar thermal profiles and can be affected by ambient temperature variations and dense canopy cover.

3. **Multi-Modal Sensor Fusion**

   Multi-modal sensor fusion integrates data from multiple sensor types—optical cameras, thermal imaging, infrared sensors, acoustic sensors, LiDAR, and radar—into a unified AI framework. By combining complementary sensor inputs, these systems significantly enhance detection robustness and reduce false positives under adverse environmental conditions [9,12].

   Sensor fusion algorithms leverage probabilistic models, deep neural networks, and temporal data correlation to maintain situational awareness even when one sensor modality is compromised. For example, thermal sensors can confirm detections during fog, while acoustic sensors capture elephant vocalisations and movement sounds in dense forests.

   In hilly, forested railway corridors, multi-modal fusion has proven effective in maintaining detection accuracy despite terrain variation, occlusion, and weather disturbances, making it a critical component of next-generation AI-based Intrusion Detection Systems.

4. **Relevance to Indian Railway Corridors**

   Given India’s diverse terrain and climatic

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conditions, reliance on a single sensing modality is inadequate for preventing wildlife collisions. AI-based obstacle detection systems must be designed to handle fog, rain, steep gradients, dense vegetation, and nocturnal wildlife movement. Multi-modal sensor fusion, combined with adaptive learning and real-time data processing, offers a scalable solution aligned with India's biodiversity conservation and railway safety objectives.

The literature describes significant developments in AI-based obstacle identification for railroad safety using multi-modal sensor fusion, thermal imaging, and image-based vision systems. Under ideal circumstances, vision-based techniques provide accurate object classification, but in low visibility, fog, and thick vegetation, their performance declines. Thermal and infrared sensors enhance low-visibility and nighttime detection, but they have issues with ambient interference and species separation. By combining complementary sensor data and mitigating the limitations of individual sensors, multimodal sensor fusion provides the most reliable detection. operational limitations such as dynamic wildlife migration, human-in-the-loop delays, and limited deployment coverage. The necessity for integrated, context-aware AI systems to support sustainable railway operations and wildlife conservation in India is further highlighted by the paucity of studies that address the biological and climatic complexity of Indian railway corridors.

Methodology:

This study uses a case-based mixed-methods approach to investigate operational, technological, and environmental aspects that contribute to collisions between railroads and wildlife. The train-elephant incident in Assam in December 2025 was chosen because it is relevant to AI-based railway safety systems and has ecological significance. The analysis evaluates incident circumstances using policy documents, reliable media sources, and railway records. To determine detection restrictions, environmental parameters such as wildlife corridor mapping, visibility conditions (fog and nighttime operations), and forest cover were assessed. Using the SAE J3016 framework to contextualise operational constraints, a technological evaluation of AI-based Intrusion Detection Systems (IDS) looked at their coverage, sensor modalities, and autonomy.

To find effective strategies like multi-modal sensing and continuous monitoring, a comparative analysis of successful AI deployments in southern Indian railway corridors was carried out.

Ultimately, an integration analysis combined operational procedures, AI capabilities, and ecological insights to create practical suggestions that complemented the goals of wildlife conservation and railway safety.

Results:

- Environmental Findings: Fog, nighttime operations, and dense forests reduced detection.
- Technological Findings: The IDS coverage did not include the accident site, and reliance on human operators resulted in critical delays.
- Ecological Findings: Collisions occurred outside static corridors, highlighting dynamic elephant movement.
- Comparative insights: Multimodal sensing, adaptive speed control, and continuous monitoring have reduced collisions in other regions [9,10].

Key Findings:

1. Fog and low visibility limit both AI and human detection. [4], [9], [6].
2. IDS systems do not operate autonomously; instead, they generate alerts for human operators. [13], [11].
3. Static corridors do not capture elephant dynamics. [6], [8], [10].
4. The integration of AI, human intervention, and ecological planning is necessary. [12], [3], [5].

Discussion:

Dense fog, nighttime operations, and forested terrain significantly compromised both human visibility and AI-based detection capabilities at the collision site. Optical sensor performance deteriorated under low-visibility conditions, while limited sensor diversity restricted reliable obstacle detection. These environmental constraints highlight the vulnerability of single-modality intrusion detection systems in ecologically complex railway corridors.

The absence of IDS coverage at the accident location and the reliance on human-mediated alert systems further delayed operational responses. Existing AI-based IDS deployed on Indian Railways functions below **SAE Level 4 autonomy**, where systems primarily assist by detecting obstacles and issuing alerts rather than executing safety-critical actions independently. In such configurations, human decision-making remains central, introducing reaction-time delays that are critical during high-speed train operations. While fully automated (Level 4) railway autonomy represents a future objective, current deployments lack the capability for autonomous braking or real-time speed regulation.

Ecological findings reveal that elephant movement patterns are dynamic, seasonal, and often extend beyond historically demarcated corridors. Static corridor mapping, therefore, fails to capture real-time wildlife behaviour, particularly during nocturnal hours and adverse weather conditions. This underscores the necessity for adaptive and continuous monitoring approaches that integrate ecological data with technological systems.

Overall, the findings demonstrate that technology alone cannot prevent wildlife–train collisions unless it is embedded within a broader framework that integrates environmental intelligence, operational controls, and human oversight.

Recommendations:

1. Expand IDS coverage in ecologically sensitive zones by integrating real-time ecological and environmental data rather than relying solely on static corridor maps.
2. Implement multi-modal sensing architectures, combining thermal imaging, infrared, optical, and acoustic sensors to ensure reliable detection under fog, rain, nighttime, and dense forest conditions.
3. Progressively enhance system autonomy, moving toward higher automation levels capable of executing safety-critical functions such as automated alerts, speed reduction advisories, and, in the long term, autonomous braking—while retaining human supervision.
4. Adopt adaptive speed management strategies in high-risk zones, particularly during periods of low visibility, nighttime operations, and known wildlife movement seasons.
5. Establish data-driven monitoring frameworks to continuously refine AI algorithms, update wildlife movement models, and dynamically redefine high-risk corridors.

By integrating AI-based detection technologies with ecological understanding, operational adaptability, and human oversight, Indian Railways can advance toward a sustainable model that balances infrastructure development with biodiversity conservation. Such an approach supports India's broader sustainable development goals by fostering a resilient human–nature–technology coexistence framework.

Conclusion:

The incident in Assam highlights the need for conservation, human intervention, and integrated AI strategies. Low autonomy, insufficient coverage, and environmental constraints limit the capabilities of current IDS. Multimodal sensing, increased autonomy, adaptive speed control, and ongoing ecological monitoring are required for dynamic elephant movement. By using these tactics, India can achieve its sustainable development objectives and guarantee a future where technology advancement and wildlife preservation coexist in harmony.

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