© APR 2026 | IRE Journals | Volume 9 Issue 10 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I10-1717029

Vehicle Based Elephant Detection and Alert System

M. RAGHUL[1], A. RICHIE JOEN[2], S. MONISHKUMAR[3], P. RAMACHANDAR[4]
[1, 2, 3, 4]*Department of Computer Science and Engineering, PSNA College of Engineering and Technology, Tamil Nadu, India*

Abstract- A Vehicle-Based Elephant Detection and Alert System is designed to detect elephant intrusions in areas where villages and forests intersect. The roaming vehicle is equipped with a RADAR, Camera, PIR Sensor, Thermal Sensor, GPS Sensor, and GSM Module. Images of elephants are detected and alerts are transmitted to forest officers and villagers in real time. The thermal sensor enables detection even in complete darkness and foggy environments. The vehicle is powered by solar energy (renewable resources), and the alert message includes the GPS coordinates of the vehicle for precise and easy elephant localization. This system significantly reduces human-elephant conflicts by providing an early warning mechanism through continuous patrolling of forest-village boundary zones.

Index Terms- Radar-based detection, Thermal sensor, Elephant detection vehicle, PIR sensor, ESP32- CAM, GSM alert system, GPS tracking, Human-elephant conflict, Wildlife surveillance, AI/ML classification.

I. INTRODUCTION

Human-elephant conflict is one of the most pressing challenges in wildlife management in South Asia and Africa. In India, elephants frequently stray from forest zones into adjacent human-inhabited areas, causing crop damage, destruction of property, injury, and fatalities on both sides. The situation demands an automated, intelligent system capable of early detection and rapid notification.

This paper presents a Vehicle-Based Elephant Detection and Alert System that addresses the limitations of existing static surveillance methods. The proposed system incorporates a self-propelled autonomous vehicle fitted with a multi-sensor array including a RADAR (implemented via ultrasonic sensors and servo mechanisms), a camera module (ESP32-CAM), a Passive Infrared (PIR) sensor, a thermal sensor, a GPS sensor, and a GSM communication module.

The system traverses the boundary zones autonomously, continuously scanning for elephant presence using sensor fusion and AI/ML-based classification. Upon detection, an alert with GPS coordinates is immediately dispatched via SMS to the relevant authorities. The vehicle is solar-powered, making it environmentally friendly and operationally self-sufficient.

Section II presents the background and motivation. Section III reviews the state of the art. Section IV details the proposed system architecture. Section V discusses the hardware components. Section VI explains the working mechanism. Section VII presents the software implementation. Section VIII provides the results and performance analysis. Section IX concludes the paper.

II. BACKGROUND OF THE INVENTION

Incidents involving elephants venturing outside forest boundaries into human-occupied zones have resulted in severe accidents, electrocutions, property damage, and loss of animal and human lives. News reports frequently document such incidents across Tamil Nadu, Karnataka, Assam, and other Indian states.

A notable case involved a 25-year-old elephant that knocked down an electric pole and died of shock in Coimbatore. The elephant was believed to have wandered out of the forest late at night and entered farmland near Kuppepalayam. Such tragedies underscore the urgent need for proactive detection systems.

Traditional mitigation methods include trenches, electric fences, and guard patrols. However, these are static, expensive to maintain, and often ineffective in rugged terrain. The coverage area is typically limited and does not adapt to elephant movement patterns. Furthermore, guard patrols are subject to human error and fatigue.

The integration of autonomous vehicles with sensors and AI offers a scalable, cost-effective, and reliable solution that can cover large areas, operate in adverse weather, and function around the clock without human supervision.

Table 1 below summarizes documented human-elephant conflict incidents that motivated this research:

Table I: Documented Human-Elephant Conflict Incidents

Location	Incident Description
Coimbatore, Tamil Nadu	Elephant electrocuted after uprooting electric pole near farmland
Kuppepalayam	Elephant strayed from forest into farmland overnight
Assam, NE India	Multiple crop destruction events over one monsoon season
Karnataka, Western Ghats	Three human fatalities in forest-border villages
Kerala, Wayanad	Herd of five elephants entered residential area

III. STATE OF THE ART

A thorough review of existing wildlife surveillance literature and patent landscape reveals several approaches that have been explored to address human-animal conflict.

A. Existing Fixed Camera Systems

Current wildlife surveillance systems predominantly use fixed AI-enabled cameras for monitoring. These setups have limited directional coverage and cannot reposition themselves to track animal movement outside their static field of view. They require extensive infrastructure to cover large boundary regions and are susceptible to vandalism and power outages.

B. PIR Sensor-Based Alerts

Some deployed systems use Passive Infrared (PIR) sensors placed along forest boundaries. These generate alerts when body heat is detected. While simple and low-cost, they cannot identify the species causing the trigger, leading to high false alarm rates from other animals or passing humans. PIR sensors also have limited range and angular coverage.

C. Drone-Based Surveillance

Unmanned Aerial Vehicles (UAVs) have been deployed for wildlife monitoring. Drones offer high mobility and broad area coverage but have significant limitations: limited flight endurance (typically 20- 40 minutes), high cost, noise disturbance to animals, weather dependency, and requirement for skilled operators. They cannot operate continuously without frequent battery replacement.

D. Acoustic Monitoring

Research has explored using microphone arrays to detect characteristic sounds made by elephants (infrasound and audible rumbles). While promising for long-range detection in open areas, acoustic systems struggle with background noise from traffic, rain, and wind in real-world boundary environments.

E. Gap in Existing Solutions

No existing deployed system combines ground-level mobility, multi-sensor fusion (radar + thermal + optical + PIR), AI-based species classification, GPS-tagged alerts, and autonomous navigation in a single integrated unit. The proposed system fills this critical gap.

Table II: Comparison of Existing Systems

System Type	Advantages	Limitations/Gap
Fixed Cameras	Static, limited FoV	No mobility or thermal
PIR Arrays	Low cost	High false alarm rate
Drones/UAVs	Wide coverage	Short endurance, high cost
Acoustic Systems	Long-range passive	Weather/noise sensitive
Proposed System	Multi-sensor, mobile, AI	Comprehensive solution

IV. PRIOR ART SEARCH REPORT

A comprehensive search of published patents and academic literature was conducted to identify prior art relevant to the proposed invention. The search was performed across databases including Google Patents, Espacenet, USPTO, and IEEE Xplore.

Search Keywords Used:

- Elephant detection sensor vehicle
- Wildlife intrusion alert system
- Autonomous wildlife surveillance robot
- Radar-based animal detection
- PIR thermal camera elephant monitoring
- ESP32 wildlife camera trap
- Human-elephant conflict prevention technology

Key Prior Art References:

1. IN Patent 201841027xxx - Describes a fixed fence-based vibration sensor system for elephant detection. No mobility, no multi-sensor fusion, no AI classification.
2. US Patent 10,117,xx - Covers drone-based wildlife monitoring with thermal imaging. Does not include ground vehicle, GPS-tagged SMS alerts, or ultrasonic radar.
3. JP Patent 2018-xxx - Proposes infrared barrier systems in forest boundaries. Limited to static installations without autonomous navigation.
4. Research Paper (IEEE ICCCNT 2022) - AI-camera-based elephant classification using deep learning. Fixed deployment, no vehicle integration or real-time alert via SMS.

Novelty Established:
Based on the prior art search, the proposed system is novel in its combination of: (a) autonomous ground vehicle platform, (b) 360-degree radar scanning, (c) thermal sensor for night-time detection, (d) AI/ML-based elephant classification, and (e) GPS-tagged GSM SMS alert system, integrated into a single solar-powered unit.

V. PROPOSED INVENTION

The proposed invention is a solar-powered autonomous ground vehicle that continuously patrols forest- village boundary areas to detect and report elephant presence. The system integrates five sensing modalities into a unified detection platform.

A. Novelties of the Invention

- Integration of multi-sensor fusion (ultrasonic/RADAR, PIR, ESP32-CAM, GPS, GSM, thermal sensor)
- Real-time elephant detection using a machine learning model deployed on ESP32-CAM
- Automatic SMS alert system transmitting GPS coordinates to forest officers and village authorities
- Vehicle self-adaptation: automatic direction-changing based on obstacle and terrain sensing
- Solar-powered operation for continuous autonomous functioning without human intervention
- Thermal imaging integration enabling detection in complete darkness and fog

B. Inventive Steps

1. RADAR-style ultrasonic scanning: A servo motor rotates the ultrasonic sensor through 180 to 360 degrees to scan the surrounding area, generating a real-time distance map analogous to a RADAR sweep.
2. AI/ML-based classification: The ESP32-CAM module captures images of detected objects and applies a trained convolutional neural network (CNN) model to distinguish elephants from other animals, vehicles, or humans.
3. Thermal sensor integration: The thermal camera operates in the infrared spectrum, detecting body heat signatures invisible to standard optical cameras, enabling reliable detection in night conditions and adverse weather.
4. GPS-tagged alerts: Upon positive elephant identification, the system reads the current GPS coordinates and composes an SMS message including location data, which is transmitted via the GSM module.
5. Autonomous navigation: The vehicle uses ultrasonic sensors for obstacle avoidance and follows pre-programmed patrol routes along the forest boundary.

C. Applications

i. Reducing human-elephant conflict in forest-fringe communities

ii. Monitoring animal movement patterns to understand seasonal migration routes
iii. Preventing crop raiding incidents by providing early warnings to farmers
iv. Assisting forest department patrol teams with data on elephant locations
v. Research and ecological studies on elephant behavioral patterns
vi. Applicable to other large animal detection (tigers, leopards, bison)

VI. HARDWARE COMPONENTS AND SPECIFICATIONS

The vehicle integrates the following hardware components, each selected for its specific contribution to the detection and communication functions:

Table III: Hardware Components and Specifications

Component	Function	Key Specification
ESP32-CAM Module	Image capture and AI inference	OV2640 camera, Wi-Fi/BT, 240MHz dual-core
Ultrasonic Sensor (HC-SR04)	Distance measurement / RADAR	Range: 2cm-400cm, ±3mm accuracy
Servo Motor (SG90)	Rotate ultrasonic for 360° scan	0-180° rotation, 4.8-6V operating
PIR Sensor (HC-SR501)	Passive infrared motion detection	7m range, 120° detection angle
Thermal Sensor (MLX90614)	Infrared body heat detection	-70°C to +380°C range, night capable
GPS Module (NEO-6M)	Real-time location tracking	Accuracy: 2.5m CEP, 9600 baud
LORA Module (SIM800L)	SMS alert transmission	Quad-band 850/900/1800/1900 MHz
Solar Panel + Battery	Power supply	6V/2W panel, 3.7V Li-ion backup
L298N Motor Driver	Vehicle locomotion control	Dual H-bridge, 2A per channel

A. ESP32-CAM Module

The ESP32-CAM is a compact, low-cost microcontroller module with an integrated OV2640 camera sensor. It runs a quantized TensorFlow Lite (TFLite) model for on-device elephant classification. The dual-core Xtensa LX6 processor at 240 MHz provides sufficient computational power for real-time inference.

B. Ultrasonic Radar System

Two HC-SR04 ultrasonic sensors are mounted on an SG90 servo motor. The servo sweeps through 180 degrees (extendable to 360 degrees with dual sensors) at 2-degree increments. At each angular position, the ultrasonic sensor emits a 40 kHz pulse and measures the echo time to compute distance. The resulting data array constitutes a polar distance map displayed as a RADAR visualization.

C. Thermal Sensor

The MLX90614 non-contact infrared thermometer detects body heat from warm-blooded animals. It has a field of view of 90 degrees and can measure temperature from a distance of approximately 3 to 5 meters. Unlike standard cameras, thermal detection is unaffected by darkness, fog, or camouflage.

D. GPS and GSM Integration

The NEO-6M GPS module continuously provides geographic coordinates. When the AI model or thermal sensor triggers a detection event, the system reads the GPS coordinates and formats an SMS message: 'ELEPHANT DETECTED at Lat: XX.XXX, Lon: YY.YYY. Alert Level: HIGH.' This message is transmitted via the SIM800L GSM module to pre-registered phone numbers of forest officers and village watch committees.

VII. SYSTEM ARCHITECTURE AND CIRCUIT DESIGN

The system architecture follows a layered design: (1) Sensing Layer, (2) Processing Layer, (3) Communication Layer, and (4) Actuation Layer.

A. Sensing Layer

The sensing layer comprises the ultrasonic sensors (radar sweep), PIR sensor (motion trigger), ESP32-CAM (visual detection), thermal sensor (heat detection), and GPS module (location). All sensors feed data to the central ESP32 processing unit. The multi-modal approach ensures robustness: even if the optical camera is occluded by fog or darkness, the thermal and PIR sensors continue to function.

B. Processing Layer

The ESP32 microcontroller serves as the central processing unit. It runs the following concurrent tasks:
(i) servo sweep control for radar scanning, (ii) distance measurement and polar map construction, (iii) PIR

interrupt monitoring, (iv) ESP32-CAM image capture and inference, (v) thermal sensor polling, and (vi) GPS data parsing.

C. Decision Logic

The detection decision follows a hierarchical fusion logic:

6. If PIR detects motion AND thermal detects elevated temperature (>35°C) -> trigger ESP32-CAM capture.
7. ESP32-CAM runs CNN inference on captured frame.
8. If confidence score >85% for 'elephant' class -> flag detection event.
9. System reads GPS coordinates.
10. GSM module sends SMS alert with coordinates.
11. Vehicle adjusts patrol direction away from elephant to avoid provocation.

D. Communication Layer

The SIM800L GSM module communicates with the ESP32 via UART at 9600 baud. AT commands are used to initialize the module, set SMS mode, and transmit messages. The system supports multiple recipients and can also send alerts via HTTP POST to a web server or cloud platform for dashboard monitoring.

E. Actuation Layer

The vehicle is driven by DC motors controlled via the L298N H-bridge motor driver. Obstacle detection by the front-facing ultrasonic sensors triggers automatic steering corrections. The solar panel and Li-ion battery management system ensures continuous operation during daytime and extended nighttime missions.

VIII. WORKING MECHANISM

The working mechanism of the Vehicle-Based Elephant Detection and Alert System proceeds through the following operational phases:

Phase 1: Deployment and Initialization

The vehicle is deployed at a predetermined starting point along the forest-village boundary. Upon power-on, the system initializes all sensors, establishes GPS lock, and registers the GSM module with the cellular network. The patrol path is pre-programmed into the microcontroller or can be guided by GPS waypoints.

Phase 2: Continuous Radar Patrol Sweep

The servo motor rotates the ultrasonic sensor through 180 to 360 degrees continuously. At each 2-degree increment, a distance measurement is taken. The resulting array of (angle, distance) pairs forms a real-time polar map of the surroundings. Objects within 400 cm are flagged on the radar display. Large objects (consistent with elephant dimensions of 2-3 meters height, 4-6 meters length) trigger the next phase.

Phase 3: Multi-Sensor Confirmation

When the radar detects a large object, the PIR sensor checks for motion and the thermal sensor checks for a heat signature characteristic of a large mammal (body temperature 36-38°C). Simultaneous positive readings from both sensors significantly reduce false positives. The system waits for 3 consecutive positive readings within 5 seconds before proceeding to image-based classification.

Phase 4: AI-Based Elephant Classification

The ESP32-CAM captures a high-resolution image (1600x1200 pixels) of the detected object. The image is resized to 96x96 pixels for the TFLite model. The CNN model, trained on a dataset of 5,000 labeled images (elephants, other animals, humans, vehicles), outputs a confidence score for each class. If the 'elephant' class achieves a confidence score above the 85% threshold, the event is classified as an elephant detection.

Phase 5: Alert Generation and Transmission

Upon confirmed detection, the system reads the current GPS coordinates from the NEO-6M module. An SMS message is formatted and transmitted via the SIM800L GSM module to the pre-configured recipient list. The message includes the detection timestamp, GPS coordinates (latitude and longitude), and alert severity level. A secondary LED and buzzer alert is also activated on the vehicle for direct notification.

Phase 6: Vehicle Response

Following alert transmission, the vehicle modifies its patrol behavior to avoid approaching the elephant further, preventing provocation. It retreats 5 meters, re-scans to confirm the elephant's position, and then routes around the area while continuing its boundary patrol on the unaffected segment.

Phase 7: Data Logging

All detection events, GPS tracks, sensor readings, and alert logs are stored in EEPROM/flash memory. This data is uploaded to a cloud server via GSM when connectivity permits, enabling forest department personnel to access historical patrol data and elephant movement records through a web dashboard.

IX.SOFTWARE IMPLEMENTATION

A. Machine Learning Model

The elephant classification model is a MobileNetV2-based Convolutional Neural Network, fine-tuned using transfer learning on a custom dataset of 5,000 images. The dataset includes 1,250 images each of elephants, other wildlife, humans, and vehicles. The model achieves a classification accuracy of 92.3% on the validation set. The trained model is converted to TensorFlow Lite format for deployment on the ESP32-CAM.

B. Radar Visualization Software

The ultrasonic radar data is transmitted via serial communication to a connected laptop or can be displayed on an OLED screen mounted on the vehicle. The visualization uses a Processing IDE sketch that plots each (angle, distance) reading as a green line on a black polar grid, mimicking a classical RADAR display. Detected objects appear as bright green artifacts on the sweep.

C. GPS Parsing and Alert Formatting

The NMEA sentences from the NEO-6M GPS module are parsed by a custom Arduino library routine. The GPRMC sentence provides real-time latitude, longitude, speed, and time. The ESP32 firmware extracts latitude and longitude values and formats them into the SMS alert string.

D. Obstacle Avoidance Algorithm

The vehicle employs a simple reactive navigation algorithm. The forward-facing ultrasonic sensor continuously measures distance. If a obstacle is detected within 30 cm, the vehicle stops, reverses 10 cm, and rotates to find a clear path. The algorithm prioritizes staying on the boundary patrol line by comparing compass bearing (from a digital magnetometer) with the desired heading.

Table IV: Software Modules and Their Functions

Module	Description
Sensor Fusion Controller	Coordinates PIR, thermal, ultrasonic, and camera inputs
CNN Inference Engine	TFLite model for elephant classification on ESP32-CAM
Radar Sweep Manager	Servo control + distance array + polar map generation
GPS Parser	NMEA sentence parsing, coordinate extraction
GSM Alert Sender	AT command sequencing, SMS composition and dispatch
Motor Driver Controller	PWM-based speed control, obstacle avoidance logic
Data Logger	EEPROM write, detection event timestamping, cloud upload

X. RESULTS AND PERFORMANCE ANALYSIS

The prototype was tested over a period of 30 days along the boundary of Anamalai Tiger Reserve in Coimbatore district, Tamil Nadu. A total of 45 patrol sessions were conducted, each lasting 2-4 hours. The following performance metrics were recorded:

Table V: System Performance Metrics

Parameter	Value
Detection Accuracy (Day)	94.7%
Detection Accuracy (Night - Thermal)	89.3%
False Positive Rate	6.8%
SMS Alert Delivery Time	< 8 seconds
GPS Location Accuracy	±2.8 meters
Radar Scan Coverage	360 degrees / 4-meter radius
Battery Life per Charge Cycle	6-8 hours (with solar assist)

Vehicle Patrol Speed	0.5-1.2 km/h

a. Detection Accuracy

The system achieved 94.7% detection accuracy under daytime conditions. Nighttime accuracy was 89.3%, relying primarily on thermal and PIR sensors with the ESP32-CAM operating in low-light mode. The primary source of false positives was large cattle, which have similar thermal signatures and size profiles to juvenile elephants.

b. Alert Response Time

From the moment the elephant detection confidence threshold was crossed, the average time to SMS alert delivery was 7.4 seconds. This includes the GPS fix time (2.1 seconds average), SMS composition (0.3 seconds), and GSM network transmission latency (approximately 5 seconds on the tested 2G/4G network).

c. Comparison with Existing Systems

Compared to static PIR fence systems, the proposed system demonstrated a 34% reduction in false alarm rate due to multi-sensor confirmation and AI classification. Compared to fixed camera systems, coverage area was 3.8x greater per unit due to vehicle mobility. Energy consumption was 2.1 watts average, enabling continuous solar-powered operation.

XI. CLAIMS

The inventors claim the following novel features and aspects of the invention:

Claim 1: A vehicle-based animal detection system comprising: a mobile autonomous ground vehicle; an ultrasonic sensor mounted on a servo motor configured to perform 360-degree sweep scanning to generate a real-time radar map of surrounding objects; an ESP32-CAM module configured to capture images and perform on-device AI-based elephant classification using a deployed TensorFlow Lite model; wherein detection results from the ultrasonic radar and the AI model are fused to reduce false positives.

Claim 2: The system of Claim 1, further comprising: a Passive Infrared (PIR) sensor for detecting thermal motion of warm-blooded animals; a thermal infrared sensor for non-contact body temperature measurement; wherein positive outputs from both the PIR sensor and the thermal sensor are required to trigger image capture by the ESP32-CAM module.

Claim 3: The system of Claims 1 and 2, further comprising: a NEO-6M GPS module for real-time geographic coordinate tracking; a SIM800L GSM module for cellular SMS communication; wherein upon confirmed elephant detection, the system automatically transmits an SMS alert containing the GPS coordinates of the vehicle to pre-registered recipients within 10 seconds of detection.

Claim 4: The system of Claims 1-3, wherein the mobile vehicle is powered by a solar photovoltaic panel and rechargeable lithium-ion battery, enabling autonomous continuous operation for a minimum of 6 hours without external charging.

Claim 5: The system of Claims 1-4, wherein the vehicle is equipped with an obstacle avoidance algorithm using front-facing ultrasonic sensors and an L298N H-bridge motor driver, enabling autonomous navigation along forest-village boundary patrol routes without human intervention.

Claim 6: A method for wildlife intrusion detection comprising the steps of: (a) continuously sweeping an ultrasonic sensor through 360 degrees to construct a real-time polar distance map; (b) triggering image capture when PIR motion detection and thermal heat signature are simultaneously positive; (c) classifying the captured image using an on-device CNN with >85% confidence threshold for elephant detection; (d) upon positive classification, reading GPS coordinates and transmitting an SMS alert via GSM module to authorities.

Claim 7: The method of Claim 6, wherein the SMS alert includes latitude and longitude coordinates with an accuracy of less than 3 meters, enabling responding personnel to locate the detection site within a radius of 5 meters.

Claim 8: The system of Claims 1-5, wherein the AI/ML classification model is a MobileNetV2-based Convolutional Neural Network trained on a dataset comprising at least 5,000 labeled images of elephants, other wildlife species, humans, and vehicles, achieving a minimum classification accuracy of 90% on a held-out validation set.

XII.CONCLUSION

This paper has presented a Vehicle-Based Elephant Detection and Alert System designed to address the critical problem of human-elephant conflict in forest-fringe communities. The proposed system integrates an autonomous mobile ground vehicle with a comprehensive sensor suite including ultrasonic radar, ESP32-CAM with AI inference, PIR sensor, thermal sensor, GPS module, and GSM communication.

The system successfully demonstrates the effectiveness of multi-sensor fusion and on-device AI classification for reliable elephant detection in both daytime and nighttime conditions. Field testing over 45 patrol sessions yielded a detection accuracy of 94.7% in daylight and 89.3% at night, with alert delivery within 8 seconds.

Key contributions of this work include: (1) a novel integration of RADAR-style ground scanning with AI visual classification on a low-cost embedded platform; (2) solar-powered autonomous operation enabling continuous boundary patrol without human supervision; (3) GPS-tagged SMS alerts providing precise location information to first responders; and (4) thermal sensing capability overcoming the limitations of optical cameras in adverse environmental conditions.

Future work will focus on improving the AI model to handle a wider variety of wildlife species, integrating LoRaWAN communication for areas without cellular coverage, and deploying a fleet of coordinated vehicles for larger-scale boundary coverage. Additionally, an edge computing upgrade to a Raspberry Pi 4 will enable real-time video streaming and more complex behavioral analysis.

The Vehicle-Based Elephant Detection and Alert System represents a significant advancement over existing static surveillance methods and holds strong potential for deployment across forest departments in India and other regions facing similar human-wildlife conflict challenges.

APPENDIX

Appendix A: Pin Configuration Table for ESP32-CAM

ESP32 Pin	Connected Peripheral
GPIO 0	Camera interface (do not use for other purposes)
GPIO 4	LED Flash / PIR sensor input
GPIO 12	Servo Motor PWM control signal
GPIO 13	Ultrasonic ECHO pin
GPIO 14	Ultrasonic TRIG pin
GPIO 16 (U2RXD)	GPS Module TX (UART2)
GPIO 17 (U2TXD)	GPS Module RX (UART2)
GPIO 26	GSM Module TX
GPIO 27	GSM Module RX
GPIO 33	Thermal Sensor SDA (I2C)
GPIO 32	Thermal Sensor SCL (I2C)

Appendix B: CNN Model Training Summary

Parameter	Value
Base Architecture	MobileNetV2 (ImageNet pretrained)
Input Shape	96 x 96 x 3 (RGB)
Training Dataset	5,000 images (4 classes x 1,250 each)
Validation Split	20% (1,000 images)
Training Epochs	30 epochs with early stopping
Optimizer	Adam (lr = 0.0001)

Loss Function	Categorical Cross-Entropy
Validation Accuracy	92.3%
Model Format (Deployed)	TensorFlow Lite (.tflite)
Model Size	1.8 MB (quantized INT8)

ACKNOWLEDGMENT

The authors express their sincere gratitude to the Research and Development Cell of PSNA College of Engineering and Technology, the IPR Cell, and the Department of Electronics and Communication Engineering for their support and guidance throughout this project. Special thanks to the Tamil Nadu Forest Department, Coimbatore Division, for permitting field trials near the Anamalai Tiger Reserve boundary. This research was supported under the institution's project grant for wildlife conservation technology.

REFERENCES

[1] S. Ramasubramanian and K. Vijayakumar, "Human-Elephant Conflict Mitigation Using IoT-Based Sensor Nodes," IEEE Access, vol. 9, pp. 45123–45136, 2021.
[2] A. K. Misra, P. Gupta, and N. Srivastava, "Thermal Imaging for Wildlife Detection at Forest Boundaries," in Proc. Int. Conf. on Wildlife Technology, New Delhi, India, 2020, pp. 112–119.
[3] M. Howard et al., "MobileNets: Efficient Convolutional Neural Networks for Mobile Vision Applications," arXiv:1704.04861 [cs.CV], Apr. 2017.
[4] V. Baskaran, R. Karthik, and T. Suresh, "Autonomous Ground Vehicle for Perimeter Surveillance in Forested Regions," J. Field Robotics, vol. 38, no. 4, pp. 501–518, 2021.
[5] K. P. Selvam and L. Ramachandran, "ESP32-Based Wildlife Camera Trap with Real-Time SMS Alerts," in Proc. IEEE ICSCC, Chennai, 2022, pp. 88–93.
[6] R. Kumar and A. Sharma, "PIR Sensor Network for Large Animal Detection in Agricultural Zones," Sensors and Actuators A: Physical, vol. 315, 112301, 2020.
[7] N. J. Pillay, "Elephant Behavior at Forest-Human Interface: A Review," Biological Conservation, vol. 249, 108739, 2020.
[8] G. Wulder, D. Roy, and M. Herold, "GPS-Based Tracking of Wildlife Incursions for Conservation Management," Remote Sensing of Environment, vol. 214, pp. 250–260, 2018.
[9] M. Raghul, A. Richie Joen, S. Monishkumar, and R. Naganandhini, "Vehicle Based Elephant Detection and Alert System – Prototype Report," PSNA IPR Cell Internal Document, RDC Ref: 2025- ECE-012, Oct. 2025.
[10] S. Krishnan, "Human-Wildlife Conflict in India: Status, Drivers and Solutions," WWF India Technical Report, 2019.
[11] A. Singh and B. Rao, "Ultrasonic Radar System for Short-Range Object Detection Using Arduino," Int. J. Electronics and Communication Engineering, vol. 11, no. 3, pp. 1–6, 2018.
[12] P. Muthukumar and G. Selvaraj, "Solar-Powered Autonomous Patrol Robot for Agricultural Field Monitoring," Applied Mechanics and Materials, vol. 787, pp. 934–938, 2015.
[13] C. Fernando, "Ecology and Behavior of Asian Elephants in Human-Modified Landscapes," Cambridge University Press, 2019, Ch. 7, pp. 183–215.
[14] T. Li, R. Chen, and F. Zhang, "TensorFlow Lite for Microcontrollers: A Practical Guide to Deploying ML Models on Embedded Systems," O'Reilly Media, 2022.
[15] Forest Survey of India, "India State of Forest Report 2021," Ministry of Environment, Forest and Climate Change, Government of India, Dehradun, 2021.