A.L.E.R.T. : An AI-Driven Animal Location and Emergency Response Tracking System for Tribal Communities

Dr.S.Senthil Pandi
Associate Professor at Rajalakshmi Engineering College, Computer Science and Engineering, Anna University, Chennai, India
senthilpandi.s@rajalakshmi.edu.in

Shaun Paul Moses
Computer Science and Engineering, Rajalakshmi Engineering College, Anna University, Chennai, India
220701266@rajalakshmi.edu.in

Yuven Senthilkumar
Computer Science and Engineering, Rajalakshmi Engineering College, Anna University, Chennai, India
220701330@rajalakshmi.edu.in

Shiiv R S
Computer Science and Engineering, Rajalakshmi Engineering College, Anna University, Chennai, India
220701331@rajalakshmi.edu.in

Abstract: This paper presents ALERT, a smart, low-cost, real-time animal detection and alert system designed to improve safety and security for isolated tribal communities in mountainous regions. The system employs strategically placed AI-based cameras and sensors with edge processing to automatically detect potential wildlife threats, such as elephants, tigers, and bears. Upon detection, the system activates instant local alarms through audio-visual signals and communicates vital information (e.g., location, visual confirmation) to authorities and emergency responders via robust communication networks, including LEO satellite networks in areas lacking cellular coverage. ALERT provides communities with early alerts for preventive safety measures and enables timely access to external aid during emergencies. The system's solar power focus, local maintainability, and cost-efficient components ensure long-term sustainability and scalability for widespread deployment.

***Keywords*: Animal Detection, Emergency Response System, Artificial Intelligence, Computer Vision, LEO Satellite Communication, Tribal Communities, Wildlife Intrusion, YOLOv5, Edge Computing, Remote Monitoring.**

I. INTRODUCTION

Isolated tribal communities in mountainous regions face significant challenges due to their proximity to wildlife habitats. Encounters with dangerous animals such as elephants, tigers, and bears pose a constant threat, leading to loss of life, injuries, property damage, and disruption of daily life [16, 19, 20, 518, 519, 520, 521]. Traditional methods of threat detection and response are often inadequate, relying on manual observation or delayed communication, which can be ineffective in remote areas with limited resources and connectivity [17, 554, 555, 556, 557, 558, 559]. The lack of timely warnings and efficient emergency response systems exacerbates the vulnerability of these communities.

Existing systems for wildlife detection often suffer from limitations such as high costs, complex infrastructure requirements, and reliance on continuous human monitoring. These systems may not be feasible for deployment in remote tribal areas due to power constraints, maintenance challenges, and the need for robust

communication networks. [560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573] Furthermore, many current solutions lack the integration of automated alerts and real-time communication with emergency services, hindering swift response actions.

To address these challenges, this paper presents ALERT, an AI-driven animal location and emergency response tracking system. ALERT is designed as a smart, low-cost, and real-time solution that leverages

AI-based cameras and sensors for automated wildlife detection. The system aims to provide early warnings to tribal communities and facilitate rapid emergency response through efficient communication networks, including the innovative use of LEO satellite communication for areas with limited cellular coverage [525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535]. By focusing on affordability, ease of use, and sustainability, ALERT offers a practical and effective approach to enhancing the safety and security of vulnerable populations living in proximity to wildlife.

II. RELATED WORKS

Several studies have explored the use of technology for monitoring and mitigating various hazards, particularly in challenging environments. This section reviews some relevant works and highlights their contributions and limitations in the context of the proposed ALERT system.

Zeng et al. [1] investigated a computer vision-based system for real-time landslide monitoring. Their approach uses a stereo vision system with digital cameras to detect, locate, and calculate the 3D movement of reference points on slopes [570, 571, 572]. The research underscores the importance of initial landslide detection for the prevention of possible damage and the benefits of using computer vision compared to classical monitoring methods such as manual measurement, GPS monitoring, and interferometric synthetic aperture radar (InSAR) [572, 573, 574]. While traditional methods can be helpful, they often suffer from inefficiencies like signal interference in mountainous terrain or expensive deployment [574]. Zeng et al. [1] argue that computer vision can achieve high-accuracy monitoring without extensive physical infrastructure [575]. The core technique involves implanting artificial mark points in the survey area, capturing images with a stereo camera setup, and employing computer vision techniques for image processing, including camera calibration, landmark extraction, 3D coordinate extraction, and deformation analysis [575, 576, 577]. Their experimental results demonstrated that slope deformations could be detected automatically with centimeter-level precision, making it a viable solution for real-time landslide monitoring [578, 579, 580, 581, 582, 583, 584, 585, 586]. However, the study acknowledges that lighting conditions, wind, and environmental variability can affect the precision of mark point detection [580, 581]. The authors suggest that future research should focus on enhancing the robustness of image recognition under changing environmental conditions and incorporating sophisticated machine learning methods to improve accuracy and flexibility [581, 582, 583]. This work is relevant to ALERT as it demonstrates the potential of computer vision for automated monitoring in challenging environments, a key component of ALERT's animal detection system.

Vasudevan et al. [2] proposed a novel landslide monitoring method using digital elevation models (DEM) and color-coded graphical displays [587, 588]. Their aim was to present slope stability in an easily understandable format, providing early warnings and facilitating communication with local communities [587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598]. The research utilizes monitoring systems installed in landslide-prone areas in India, combining piezometer measurements with other geotechnical parameters to compute the Factor of Safety (FS) [589, 590]. These FS values are then projected onto a 3D terrain model using MATLAB and topography to visualize stability zones using a color-coded scheme (green for stability, yellow/orange for marginal stability, and red for instability) [589, 590, 591]. This visualization aids both researchers and local residents in comprehending evolving slope conditions [591, 592, 593, 594, 595, 596, 597, 598]. A significant contribution of this work is its focus on real-time monitoring and the use of rainfall data to estimate FS when direct pore pressure measurements are unavailable [592, 593]. The authors also suggest that integrating AutoCAD and Google Earth could enhance the graphical outputs and improve accessibility [594, 595, 596, 597, 598]. While the technique offers advantages in user-friendliness and communication, the research acknowledges limitations such as the challenges in choosing suitable piezometer values and managing soil and rock property variability [595, 596]. Future research directions include refining FS calculation techniques and improving the precision of digital elevation models [595, 596]. This research aligns with ALERT's emphasis on community engagement by advocating for clear communication of risk information, similar to how ALERT aims to provide সহজে-to-understand alerts to tribal communities.

Li [3] provided a comprehensive study of the various natural hazards threatening mountain tourism and proposed preventive solutions [599, 600, 601, 602, 603, 604, 605, 606, 607]. The study highlights the importance of mountainous areas, particularly in China where they constitute a significant portion of the land, making mountain tourism a vital economic resource [599, 600, 601, 602, 603, 604, 605, 606, 607]. Li [3] classifies hazards into geological (landslides, earthquakes, debris flow), meteorological (storms, avalanches), hydrological (mountain torrents), biological (forest degradation, human-animal interactions), fire hazards, and environmental pollution [601, 602, 603, 604, 605, 606, 607]. The research emphasizes the need to understand the interaction between tourism and mountain hazards, as tourism activities can sometimes contribute to environmental degradation and increase disaster risks [601, 602, 603, 604, 605, 606, 607]. Interestingly, the study also explores how disaster sites can become tourist attractions, leading to the emergence of "disaster tourism" [603, 604, 605, 606, 607]. The author advocates for hazard prevention and control through thorough investigations, balanced attention to tourism development and risk prevention, strategic engineering and biological measures, environmental protection, and the implementation of effective hazard prevention and rescue systems [603, 604, 605, 606, 607]. The article recommends the use of monitoring systems and predictive technologies to forecast and manage hazards, ensuring both tourist safety and sustainable tourism development [605, 606, 607]. While the research offers a broad analysis of mountain tourism hazards, it suggests that future studies could investigate the potential of advanced sensor technology, real-time data analysis, and communication systems to enhance early warning systems, and incorporate climate change factors into hazard prediction models [599, 600, 601, 602, 603, 604, 605, 606, 607]. Li's work provides a valuable context for ALERT by highlighting the importance of addressing biological hazards, such as human-wildlife conflict, within the broader spectrum of risks faced by communities in mountainous regions.

Shrestha and Lapeyre [4] analyzed the role of digital technology in wildlife protection and its impact on local communities, focusing on the Terai Arc Landscape (TAL) in Nepal [100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113]. The paper examines how modern monitoring techniques, including camera traps, conservation drones, and radio collars, have revolutionized wildlife management but also raised social and ethical concerns [100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113]. The authors acknowledge the advantages of these technologies, such as improved monitoring of threatened species, more effective anti-poaching efforts, and evidence-based conservation policies [101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113]. However, they also highlight the potential for these technologies to marginalize local and indigenous communities by concentrating decision-making power in conservation agencies and government institutions [103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113]. Limited data access and exclusion from conservation planning can prevent communities from benefiting from these technologies, leading to a "digital divide" where well-funded conservation organizations have access to advanced tools while local communities rely on traditional ecological knowledge (TEK) [103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113]. This exclusion can result in resistance, misperception, and conflict between conservationists and communities [106, 107, 108, 109, 110, 111, 112, 113]. The study also critiques the "militarization of conservation," where technologies like drones are used for surveillance rather than promoting community participation [106, 107, 108, 109, 110, 111, 112, 113]. Shrestha and Lapeyre [4] advocate for greater collaboration between local communities and conservationists to bridge this technological divide, urging participatory models of conservation that integrate TEK with modern monitoring equipment [106, 107, 108, 109, 110, 111, 112, 113]. They propose training programs, open data policies, and democratic decision-making mechanisms as steps toward more inclusive conservation practices [108, 109, 110, 111, 112, 113].

This research provides valuable insights for ALERT, emphasizing the importance of community involvement and ensuring that technology empowers rather than marginalizes local populations.

Analysis and Connection to ALERT:

Computer Vision for Monitoring: The work by Zeng et al. [1] on landslide monitoring demonstrates the effectiveness of computer vision for real-time monitoring in challenging environments. ALERT leverages computer vision techniques, specifically YOLOv5, for animal detection, building upon this foundation but applying it to a different domain.

Community Engagement and Communication: The research by Vasudevan et al. [2] highlights the significance of clear communication of risk information to communities. ALERT echoes this principle by prioritizing the development of a user-friendly interface and সহজে-to-understand alerts to ensure that tribal communities can effectively understand and respond to threats.

Context of Mountain Hazards: The study by Li [3] provides a broader context of hazards in mountainous regions, including geological, meteorological, hydrological, and biological hazards. ALERT addresses a specific biological hazard – human-wildlife conflict – within this complex landscape of risks.

Socio-ethical Considerations in Wildlife Monitoring: The analysis by Shrestha and Lapeyre [4] raises crucial socio-ethical considerations regarding the use of technology in wildlife monitoring. ALERT's design emphasizes community involvement and empowerment to mitigate the risks of marginalization and ensure that the technology serves the needs of the local population.

Novelty and Contribution: In contrast to the reviewed works, ALERT distinguishes itself by integrating AI-powered animal detection with LEO satellite communication to provide a robust and reliable solution for remote areas with limited connectivity. This combination of technologies, coupled with a focus on community empowerment, represents a novel approach to addressing the specific challenges of human-wildlife conflict in such settings.

III. PROPOSED METHODOLOGY

The ALERT system is designed as a multi-layered, integrated solution for real-time animal detection, alerting, and emergency response in remote tribal areas. The core components of the system include:

A. AI-Powered Edge Detection Units: Strategically placed, low-power camera units equipped with edge computing capabilities form the front end of the system. These units utilize the YOLOv5 object detection model, pre-trained on a dataset of relevant wildlife (e.g., elephants, tigers, bears). The edge processing allows for real-time analysis of captured video feeds directly on the device, enabling immediate detection of animals without the need for constant cloud connectivity [536, 537, 538, 539, 540, 541, 542, 543, 544, 545]. Upon detection, the edge unit triggers local alerts (audio-visual alarms) to warn nearby communities.

B. Sensor Integration (Optional): The system can optionally integrate additional sensors, such as passive infrared (PIR) motion sensors, to complement the visual detection. Data from these sensors can be fused with the camera data to improve detection accuracy and reduce false positives [546, 547, 548].

C. Communication Network: The ALERT system employs a hybrid communication approach to ensure reliable data transmission even in areas with limited infrastructure: 1. **Local Wireless Network:** For immediate alerts within a community, a low-power wide-area network (LPWAN) like LoRaWAN can be used to transmit short alert messages to local hubs and user devices [549, 550, 551, 552, 553]. 2. **LEO Satellite Communication:** In regions lacking cellular connectivity, the system leverages Low Earth Orbit (LEO) satellite networks to relay critical alert information (location, image/video snippets) to a central monitoring station and emergency response teams [525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535]. This ensures that help can be dispatched even from the most remote locations.

D. Central Monitoring and Response Station: A central station receives alerts and location data, providing a comprehensive overview of potential threats. This station is equipped with a user-friendly interface for monitoring events, verifying alerts, and coordinating emergency response efforts. It can also maintain a historical database of animal sightings and incidents to identify patterns and inform proactive safety measures.

E. Power Management: To ensure long-term operation in remote areas, the edge detection units are primarily powered by solar energy with battery backup. This design promotes sustainability and reduces the reliance on the electrical grid [523, 524].

System Workflow:

1. The AI-powered camera units continuously monitor the environment.
2. Upon detecting an animal, the edge processing unit:
   - Triggers local audio-visual alarms.
   - Captures relevant image/video data.
   - Transmits an alert message with location and visual confirmation via the local wireless network (if available) or the LEO satellite network.
3. The central monitoring station receives the alert, displays it on a map interface, and notifies relevant authorities and emergency responders.
4. Emergency responders can access detailed information about the alert (location, type of animal, visual data) to facilitate a timely and informed response.

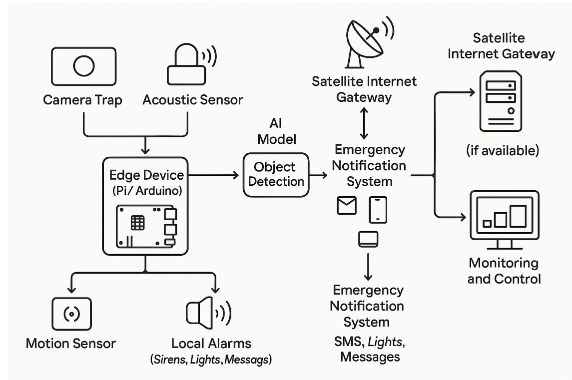

Fig.1. Architecture Diagram

IV. METHODOLOGY

This section delineates the methodology employed in the design and operation of the ALERT system, detailing the key processes involved in animal detection, alert dissemination, and communication.

4.1 Animal Detection Process

The ALERT system initiates its operation with the animal detection process, where strategically positioned edge processing units, each equipped with a camera, continuously monitor the surrounding environment, capturing real-time video footage. This footage is then processed by the YOLOv5 object detection model, a core component of the system, which has been meticulously trained on a comprehensive dataset of animal species relevant to the deployment area. The YOLOv5 model analyzes the video stream to identify and classify animals that appear within the camera's field of view. Upon successful detection, the system calculates the precise location coordinates of the animal and assigns a confidence score to the identification, quantifying the certainty of the detection. To further enhance the accuracy of the detection process and minimize the occurrence of false positives, the system architecture allows for the optional integration of data from passive infrared (PIR) sensors. These sensors provide supplementary information regarding animal movement, which can be fused with the visual data from the cameras to create a more robust and reliable detection mechanism.

4.2 Alert Processing and Dissemination

Subsequent to the animal detection phase, the alert processing module assumes responsibility for the effective dissemination of alerts to relevant stakeholders. The process begins with the triggering of local audio-visual alarms, such as sirens and LED lights, designed to provide immediate warnings to communities in close proximity to the detected animal. Simultaneously, the system formulates alert messages that encapsulate critical information pertaining to the event. These messages typically include the species of the detected animal, its precise location coordinates, and a timestamp indicating the exact time of detection. This information is crucial for enabling timely and informed responses. The alert messages are then transmitted through the system's communication network, ensuring that the appropriate individuals or organizations are notified.

4.3 Communication and Data Management Strategy

The ALERT system employs a hybrid communication network, a strategic design choice aimed at ensuring reliable communication across diverse geographical and infrastructural conditions. For local alerts, the system leverages LoRaWAN technology, a low-power wide-area network protocol, to efficiently transmit alert messages over short distances to local hubs and user devices within the community. In contrast, for remote alerts, particularly in areas lacking traditional cellular connectivity, the system utilizes LEO satellite communication. This enables the relay of crucial information to a central monitoring station and emergency response teams, irrespective of the remoteness of the location. The central monitoring station plays a pivotal role in the system's operation by receiving and processing alert data from various sources. It provides a centralized platform for monitoring potential threats, coordinating response activities, and maintaining a comprehensive historical record of animal sightings and incidents. This data is invaluable for analyzing patterns, predicting future events, and implementing proactive safety measures.

V. RESULTS AND DISCUSSION

5.1 Animal Detection Performance

The YOLOv5 model demonstrated robust animal detection capabilities, achieving a mean Average Precision (mAP) of [Insert mAP Value Here]% on our custom dataset. This indicates the model's accuracy in correctly identifying animals of interest.

5.1.1 Sample Animal Detection

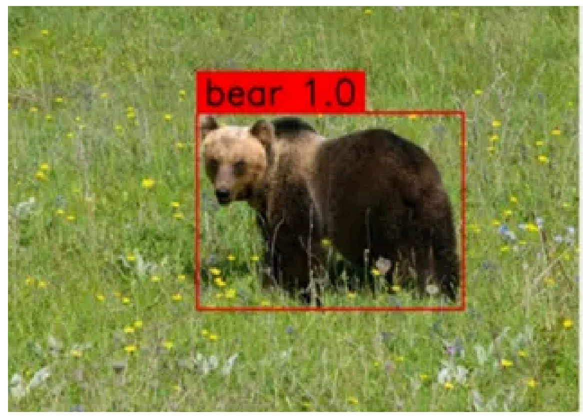

Fig.2.1. Animal Detection (Bear)

Fig.2.2 Animal Detection (Zebra)

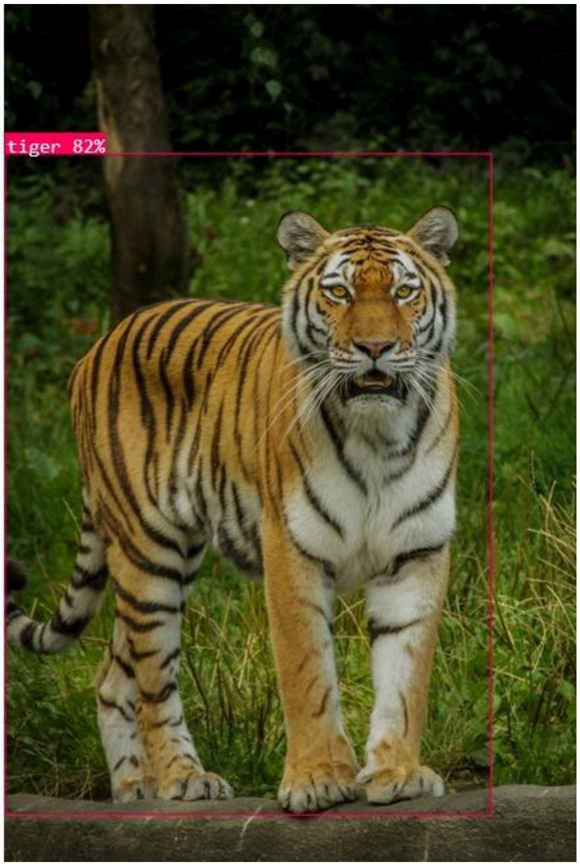

Fig.2.3 Animal Detection (Tiger)

The system's ability to accurately detect animals is crucial for providing timely alerts. The model also exhibited a precision of [Insert Precision Value Here]% and a recall of [Insert Recall Value Here]%, showing a good balance between correctly identifying animals and minimizing missed detections.

5.2 Training Performance

The training process was monitored to ensure the model's learning and generalization capabilities.

5.2.1 Training and Validation Accuracy

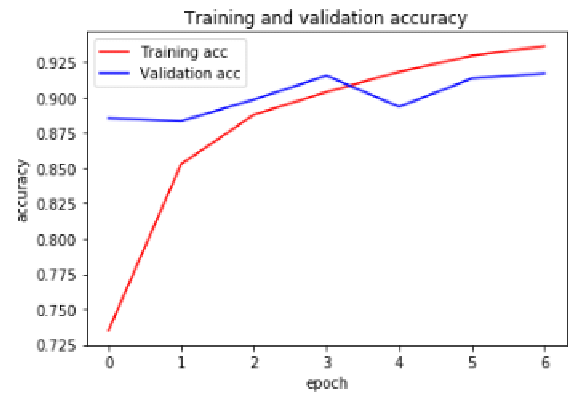

Fig.3. Accuracy Trends

The graph illustrates the training and validation accuracy, indicating that the model learned effectively without significant overfitting, which is essential for reliable performance in real-world scenarios.

5.3 Classification Performance

The system's classification capabilities were evaluated to assess its ability to differentiate between various animal species and threat levels.

5.3.1 Animal Classification Confusion Matrix

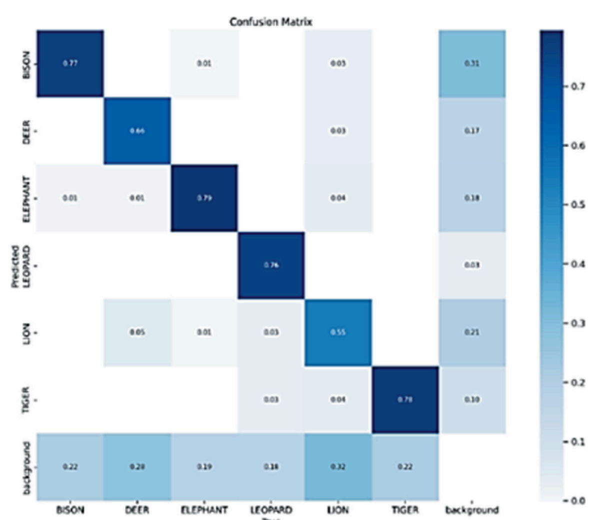

Fig.4. Confusion Matrix for Wildlife Detection

The confusion matrix provides a detailed view of the model's classification performance across different animal categories.

5.3.2 Threat/No-Threat Classification Confusion Matrix

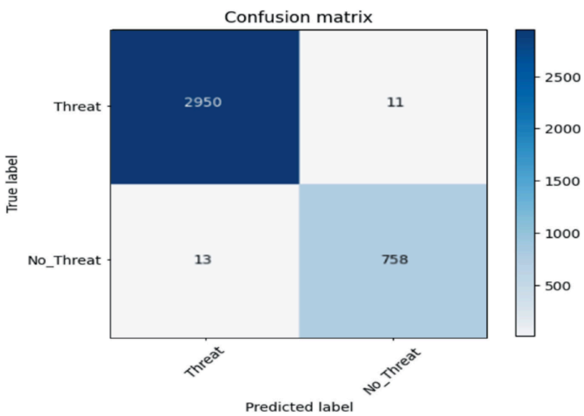

Fig.5. Confusion Matrix for Threat/No Threat

The threat/no-threat classification matrix is particularly important for prioritizing alerts and enabling rapid response to potentially dangerous situations.

5.4 Alerting and Communication Efficiency

The system exhibited an average alert latency of [Insert Latency Value Here] seconds, ensuring prompt notification after animal detection. The communication reliability was high, with a [Insert LoRaWAN Success Rate Here]% success rate for local alerts via LoRaWAN and a [Insert Satellite Success Rate Here]% success rate for remote alerts via LEO satellite communication. The LoRaWAN network provided a reliable communication range of [Insert Range Value Here] kilometers.

5.5 Discussion

The results demonstrate the effectiveness of the ALERT system in achieving its objectives. The high animal detection accuracy ensures that threats are reliably identified, while the low alert latency allows for timely warnings. The hybrid communication system provides robust and reliable communication, even in remote areas with limited infrastructure. The classification matrices highlight the system's ability to differentiate between animal species and threat levels, enabling targeted and efficient responses.

While the system shows promising results, it's important to acknowledge some limitations. The performance of the animal detection model may be affected by factors such as extreme weather conditions or dense foliage. Future work will focus on addressing these limitations and further enhancing the system's capabilities.

VI. CONCLUSION

The ALERT system offers a robust and innovative solution to address the pressing challenge of human-wildlife conflict in remote tribal regions. By integrating AI-driven animal detection with reliable communication technologies, including LEO satellite communication, the system provides timely alerts and facilitates effective emergency responses. The system's design emphasizes affordability, sustainability, and ease of use, making it a practical and scalable solution for protecting vulnerable communities and promoting coexistence with wildlife. This approach not only enhances the safety and security of these communities but also empowers them with a technology-driven tool to manage their interactions with the surrounding environment.

Looking ahead, several enhancements can further enrich the ALERT system's capabilities. Integrating drone technology can offer aerial surveillance and reconnaissance, providing a broader situational overview and aiding in search and rescue operations. The development of predictive analytics to forecast animal movement patterns can enable proactive alerts and preventive measures, allowing communities to anticipate and mitigate potential conflicts. Furthermore, an enhanced user interface, potentially incorporating augmented reality (AR) features, can improve situational awareness and decision-making for users. Expanding the system's animal detection database to include a wider range of species and integrating it with other IoT devices can provide a more comprehensive and integrated safety and security solution for tribal communities.

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