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A Novel Active RFID and TinyML-based System for Livestock Localization in Pakistan

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Abstract

Localization of livestock is a vital component of good livestock management in Pakistan. This abstract describes a unique method for livestock localization in Pakistan that makes use of Active RFID technology and Tiny Machine Learning (TinyML) approaches. The incorporation of Active RFID technology allows for precise and long-range livestock tracking, while TinyML provides on-device analysis and decision-making. This method has a number of advantages, including high precision, real-time localization, and less reliance on external infrastructure. Accurate triangulation-based localization is obtained by putting Active RFID tags on cattle and carefully positioning Active RFID anchors in specific regions. TinyML integration on resource-constrained microcontrollers within Active RFID tags allows for efficient on-device analysis of Active RFID signals. The suggested system has the potential to significantly improve livestock management practices in Pakistan, including animal tracking and monitoring, behavior analysis, and increased animal welfare. To realize the full potential of this unique Active RFID and TinyML-based livestock localization system in Pakistan, further research should focus on optimizing localization algorithms, enhancing TinyML models, and exploring interaction with upcoming technologies.

Index Terms: *Internet of Things, Livestock Localization, Microcontrollers, RFID, TinyML.*

I. INTRODUCTION AND BACKGROUND

Cows and buffaloes are extremely important in Pakistan's livestock business, particularly in the dairy industry [1]. They contribute to the country's economy and agricultural livelihoods as key sources of milk production. Pakistan is one of the top milk-producing countries, with cows and buffaloes being the main contributors [2]. These animals supply valuable milk supplies, serving the nutritional demands of the population and supporting the dairy sector's expansion [1], and [2]. They are valuable assets in rural communities, providing money production and nourishment for households [3], and [4]. The development of new technologies [5], and [6] has paved the door for novel solutions [7] in a variety of disciplines [8], including livestock management [1], and [9]. The combination of Active RFID technology and Tiny Machine Learning (TinyML) has emerged as a potential solution for improving the precision and efficiency of tracking and monitoring animals [10]. This convergence of cutting-edge technologies provides a once-in-a-lifetime chance to improve livestock localization in outdoor conditions, particularly for buffaloes and cows [11]. Livestock localization is critical in animal management because it allows farmers and ranchers to monitor the location, behavior, and health of their animals [12], and [13]. Traditional approaches, such as eye observation or manual tracking, may include drawbacks such as human error, lengthy processes, and poor precision. To address these issues, the combination of Active RFID with TinyML yields a solution that delivers exact and real-time localization while reducing reliance on external systems.

Active RFID technology measures distances with exceptional accuracy using low-power radio waves, making it an excellent choice for outdoor localization [14]. When Active RFID tags are implanted on buffaloes and cows, these intelligent devices can connect with Active RFID anchors or reference points strategically placed across the defined area [15]. The Active RFID tags measure the Time-of-Flight (ToF) of the Active RFID signals, allowing for accurate position computations based on triangulation and range concepts. TinyML integration is critical for improving the possibilities of Active RFID-based livestock localization [16]. TinyML is the implementation of machine learning algorithms on limited-resource devices such as microcontrollers. The gathered Active RFID signal data can be analyzed locally at the edge by incorporating TinyML capabilities into the Active RFID tags, eliminating reliance on centralized processing and enabling real-time localization. The creation and deployment of a TinyML model on Active RFID tags enable on-device analysis and decision-making. The model becomes capable of inferring the animals' positions directly on the Active RFID tags after being trained with a dataset containing Active RFID signal measurements and related ground truth positions. The combination of Active RFID technology with TinyML provides localized intelligence to the animals, allowing for autonomous and efficient management.

In this article, we have investigated the use of Active RFID technology and TinyML for livestock localization, with a focus on buffaloes and cows. We look at the technical elements of Active RFID tags, anchors, and reference points, as well as how TinyML algorithms are implemented on resource-constrained microcontrollers. We have gone over the advantages of this synergistic approach, including high precision, real-time localization, and less reliance on external infrastructure. The combination of Active RFID and TinyML allows livestock management to achieve new levels of precision and efficiency. Farmers and ranchers can optimize their animal management practices, improve security, and eliminate potential threats by properly tracking and monitoring the movements of buffaloes and cows in outdoor areas. Finally, this technological convergence paves the way for more autonomous and intelligent livestock management systems, ensuring the well-being and productivity of the animals in question.

A. Objectives

The main objectives for this work are as:

To introduce the notion of integrating Active Radio Frequency Identification (ACTIVE RFID) technology and Tiny Machine Learning (TinyML) for livestock localization in outdoor contexts, with a focus on buffaloes and cows in Pakistan. To showcase the advantages and benefits of incorporating Active RFID technology in livestock management, such as high precision, long-range coverage, and interference resistance.

Tiny Machine Learning (TinyML) has been investigated for its potential to provide real-time localization and analysis directly on Active RFID tags with integrated microcontrollers. To go over the methods for putting Active RFID tags on buffalo and cows, as well as strategically positioning Active RFID anchors or reference sites in the chosen area for correct localization.

This has shown how Tiny Machine Learning algorithms can be implemented on resource-constrained microcontrollers within Active RFID tags to enable on-device analysis and decision-making. To highlight the importance of Active RFID and TinyML in bettering livestock management practices such as tracking and monitoring animal positions, behavior analysis, and optimizing animal health and well-being.

To talk about the potential applications and implications of Active RFID and TinyML in livestock management, such as increased security, decreased reliance on external infrastructure, and increased efficiency. To identify potential future research and development areas, such as optimizing Active RFID-based localization algorithms, exploring additional TinyML applications in livestock management, or integrating the technology with other emerging technologies, such as the Internet of Things (IoT), for comprehensive solutions.

B. Contribution

This article introduces an innovative approach to livestock management by integrating Active Radio Frequency Identification (ACTIVE RFID) technology with Tiny Machine Learning (TinyML) for the precise localization of livestock, specifically buffaloes and cows, in outdoor contexts in Pakistan. This integration offers significant advancements in livestock management through high precision, long-range coverage, and interference resistance capabilities. We delve into the deployment methods for attaching Active RFID tags on livestock and strategically positioning Active RFID anchors for accurate localization. By implementing TinyML algorithms on resource-constrained microcontrollers within Active RFID tags, this study demonstrates on-device analysis and decision-making capabilities, enhancing livestock management practices by enabling real-time tracking and monitoring of animal positions, behavior analysis, and optimization of animal health and well-being. Furthermore, the article explores the broader applications and implications of Active RFID and TinyML in livestock management, including improved security, reduced dependence on external infrastructure, and enhanced operational efficiency. It also outlines potential future research directions, such as optimizing Active RFID-based localization algorithms, expanding TinyML applications in livestock management, and integrating these technologies with other emerging technologies like the Internet of Things (IoT) for a more comprehensive management solution.

II. METHODOLOGY

A. RFID Tag Development

Active RFID tags have been securely fastened to buffalo and cow collars as neck tags for this, we have used a key-based RFID tag. These tags are lightweight and made to resist the motions of the animals without causing discomfort or impeding their mobility and as well as a user can only place them on the cows and buffaloes when the animals will go out for grazing. See figure I , for ease of understanding.

(a) (b) (c)

Figure I: (a) The Experimental Place; (b) The RFID Tag; and (c) The Buffalo Wearing the Tag

B. Active RFID Anchor Placement

Throughout the allocated outdoor area where the animals are grazing around the 4-kilometer area, Active RFID anchors or reference points have been strategically set. For our experiment, we have chosen a smaller area. These anchors have been acting as fixed reference points with well-defined positions. To achieve accurate localization via triangulation, many anchors will be supplied. The communication between the tag and anchor is illustrated in figure II.

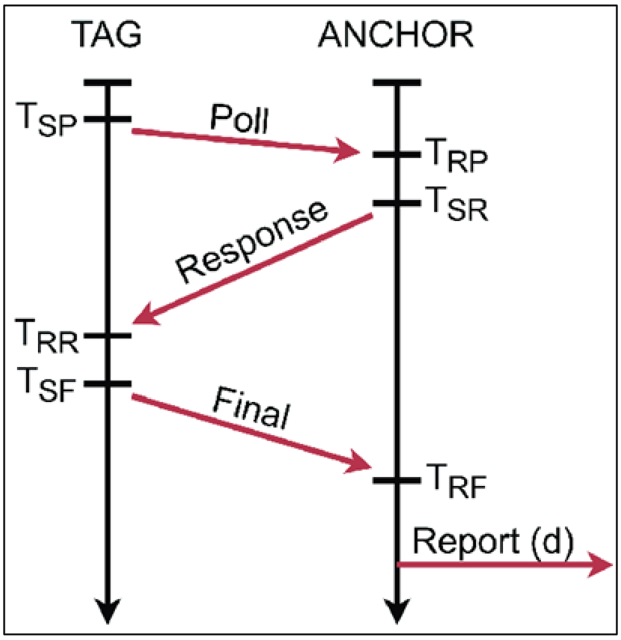

Figure II: Active RFID Anchor and Tag Communication

C. Active RFID Signal Data Collection

The Active RFID tags continuously collect Active RFID signal data from their surroundings. This information contains time-of-flight (ToF) measurements, which provide the distances between the Active RFID tags and the anchors.

D. TinyML Model Development

TinyML or machine learning algorithms specifically intended for resource-constrained microcontrollers, will be created in this manner. For our research, we first collected the dataset from anchors and tags and then implemented Random Forest on the dataset generated. The purpose of using the Random Forest here is to handle the complex relationships between the features and to attain good accuracy. The model has been trained on the dataset that includes Active RFID signal measurements as well as the animals' ground truth placements. To strengthen the model's robustness, the training dataset has been carefully constructed, ensuring a varied range of scenarios and environmental circumstances.

E. Model Deployment on Active RFID Tags

The Random Forest model must be deployed onto the RFID system after it has been trained and tested for accurate outside localization using active RFID tags. This deployment procedure is intended to overcome the constraints given by the RFID tags' limited resources while assuring precise and efficient localization. The deployed machine learning model is executed by microcontrollers. They have memory, processing capacity, and power consumption limits, thus it is vital to guarantee that the model is lightweight and optimized for efficient execution.

The further steps are as follows:

1) Model Simplification:

To reduce its size and computational complexity, the trained Random Forest model is pruned and simplified. This step helps to alleviate the microcontroller's memory and processing limits. Unnecessary branches and characteristics that add little to accuracy are removed, and decision criteria are streamlined.

2) Conversion to TinyML Format:

The simplified Random Forest model is transformed into a TinyML-compatible format. This format improvement entails quantization to lower precision and, in some cases, the use of compact data structures. The goal is to guarantee that the model fits inside the microcontroller's memory constraints.

3) Integration with Microcontroller:

The optimized TinyML model is implemented into the RFID reader's embedded microcontroller. This entails loading the model into the microcontroller's memory and configuring the execution environment.

F. Real-Time Localization and Analysis:

The microcontrollers analyze the incoming Active RFID signal data in real time while the TinyML model is running on the Active RFID tags. Using triangulation and range concepts, the model calculates the animals' positions based on Active RFID signal readings.

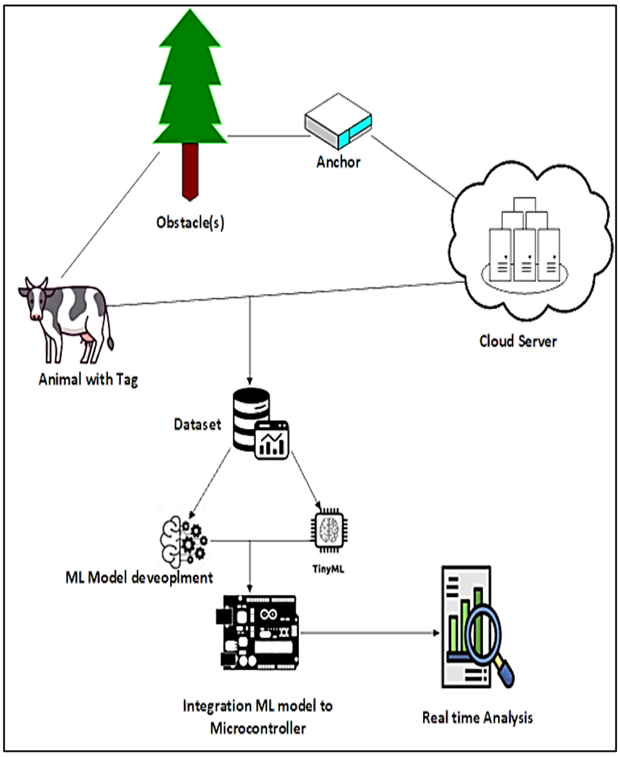

Figure III: Architecture Diagram for Proposed System

Using Active RFID technology and TinyML, the animals can be accurately localized in outdoor areas by following this process. The Active RFID tags will capture the Active RFID signals and use the deployed anchors to calculate precise placement. TinyML integration on resource-constrained microcontrollers will allow for real-time analysis and decision-making directly on Active RFID tags, reducing reliance on centralized processing. This system will ensure that the positions of the animals are constantly monitored and updated, allowing for effective tracking, behavior analysis, and optimized animal management practices. The proposed system has been illustrated in a simple way in figure III.

III. DISCUSSION

The combination of Active RFID (ACTIVE RFID) and Tiny Machine Learning (TinyML) technology will provide a compelling solution for precise and efficient livestock localization. The solution provides various advantages for livestock management by using Active RFID signals and on-device analysis via TinyML. The combination of Active RFID technology and TinyML will enable high-precision localization, allowing farmers and ranchers to follow the whereabouts of buffaloes and cows in outdoor settings. The capacity of Active RFID to measure distances with exceptional accuracy, combined with TinyML's on-device analysis, results in real-time localization findings, decreasing reliance on external infrastructure or centralized processing.

Long-range coverage, durability against interference, and the capacity to penetrate obstacles like foliage or walls are all advantages of Active RFID-based localization. These benefits will make Active RFID especially ideal for outdoor locations where livestock may roam across large regions and encounter a variety of barriers. The technology may achieve precise triangulation-based localization with Active RFID tags connected to the animals and strategically distributed Active RFID anchors, ensuring accurate position estimations. TinyML integration will expand the capabilities of the Active RFID localization system. The approach provides on-device analysis and decision-making by deploying machine-learning algorithms on resource-constrained microcontrollers within Active RFID tags. This decentralized strategy reduces latency, improves real-time performance, and reduces the need for constant contact with centralized processing systems. It will enable the Active RFID tags to analyze the acquired Active RFID signal data autonomously and make immediate judgments or trigger alarms based on certain events or abnormalities observed in the livestock's behavior.

Active RFID and TinyML are important in livestock management for reasons other than localization. The availability of exact real-time position data opens the door to new applications such as behavior analysis, health monitoring, and improved animal welfare practices. Integrating Active RFID-based localization with other sensor data, like as accelerometers or temperature sensors, can provide full insights into the animals' well-being and allow for the early detection of health problems. This comprehensive method enables farmers and ranchers to make educated decisions, optimize resource allocation, and handle any hazards or issues in livestock management in a proactive manner. Future research and development can concentrate on improving the localization algorithms, optimizing TinyML models for lower power consumption and better performance, and investigating the integration of Active RFID-based localization with other emerging technologies such as the Internet of Things (IoT) for comprehensive livestock management systems. Extensive field testing and validation will be required to evaluate the system's performance in various conditions and livestock management practices, ensuring its dependability and scalability in real applications. The proposed system has attained an accuracy of 88.9% for an outdoor-based localization server.

A. *Confusion Matrix*

Random Forest model was implemented as a TinyML solution for livestock localization. The role of the Confusion Matrix here is pivotal, serving as a tool to evaluate the accuracy and precision of the model in predicting the correct localization of livestock. It provides insights into the model's performance by highlighting true positives, false positives, true negatives, and false negatives, enabling the fine-tuning of the model for enhanced decision-making and localization accuracy as shown in figure IV.

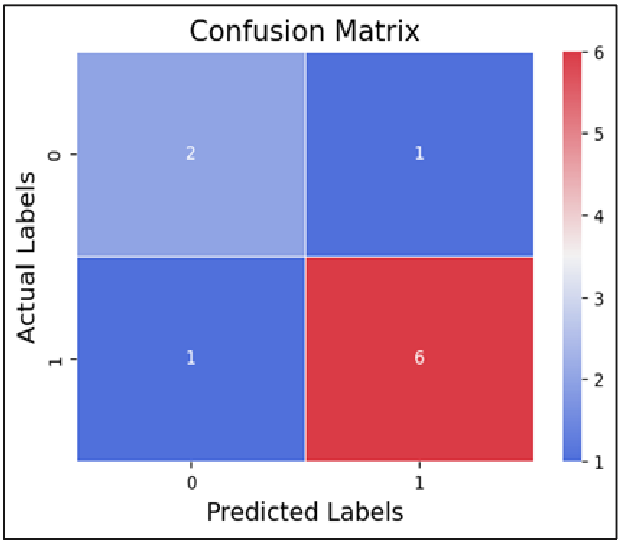

Figure IV: Confusion Matrix for Proposed Model

B. *Receiver Operating Characteristics Curve*

The Receiver Operating Characteristic (ROC) curve shown in figure V, complemented by an Area Under the Curve (AUC) of 0.51, plays a critical role in our analysis of the TinyML model's performance for livestock localization. An AUC of 0.51 indicates that the model's ability to distinguish between correct and incorrect localizations is barely above random chance, suggesting significant room for improvement. The ROC curve, which plots the true positive rate against the false positive rate at various threshold settings, provides a visual tool for evaluating the model's discrimination capacity.

This analysis highlights the need for further refinement of the TinyML model to enhance its predictive accuracy and reliability in the context of Active RFID technology for effective livestock management.

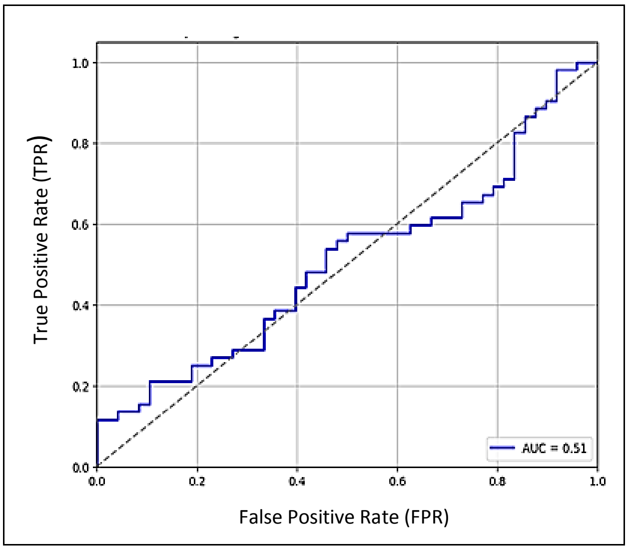

Figure V: ROC Curve with AUC 0.51%

C. Box Plot

Box plots play an essential role in visualizing the distribution of localization errors across different scenarios and conditions in the livestock management system. By presenting the median, quartiles, and outliers of localization errors, box plots offer a clear and concise summary of the model's performance variability.

The visualization in figure VI aids in identifying the conditions under which the TinyML model, implemented via Random Forest, achieves the best and worst accuracy, thereby guiding further optimizations and adjustments to improve the overall efficacy of the Active RFID and TinyML integration for livestock localization.

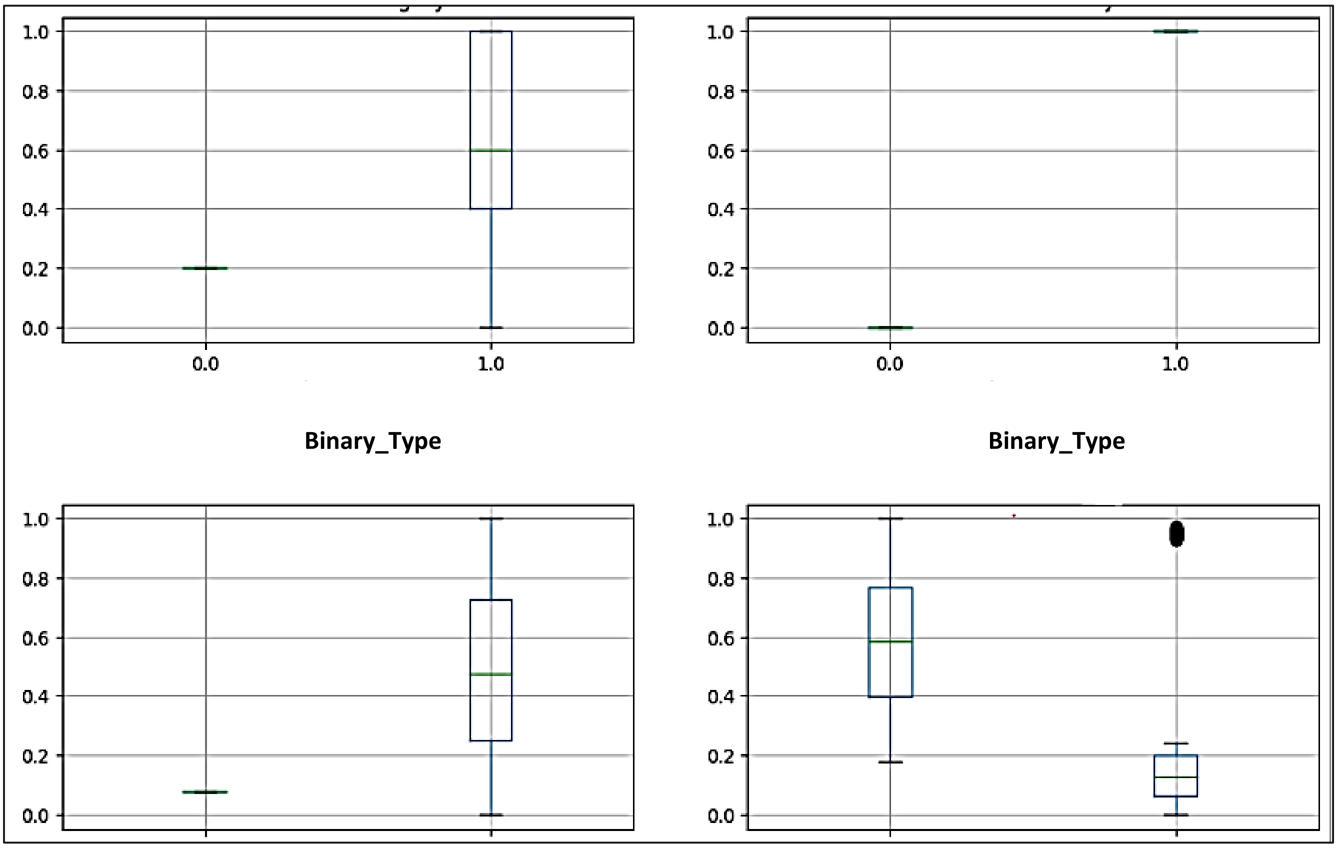

Figure VI: Box Plot Diagram for Proposed Model

IV. CONCLUSION

The combination of Active RFID and Tiny Machine Learning (TinyML) technology holds significant promise for livestock localization in Pakistan. This novel approach has provided accurate and efficient livestock management solutions by combining high-precision positioning, real-time analysis, and on-device decision-making. Active RFID tags and anchors allow for exact triangulation-based localization, while TinyML on resource-constrained microcontrollers provides real-time analysis and autonomous decision-making. The advantages go beyond geolocation and include behavior analysis, health monitoring, and improved animal welfare practices. Additional research and validation are required to improve algorithms, optimize models, and investigate interaction with emerging technologies. Finally, the combination of Active RFID and TinyML has the potential to transform livestock management practices by increasing efficiency, production, and animal well-being.

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Authors Contributions

All the authors equally contributed to this study.

Conflict of Interest

The authors declare no conflict of interest and confirm that this work is original and not plagiarized from any other source, i.e., electronic or print media. The information obtained from all of the sources is properly recognized and cited below.

Data Availability Statement

The testing data is available in this paper.

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