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GPS Smart Location Tracking Mobile Application for Train Transportation

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***Abstract* - This research project introduces an innovative train tracking system aimed at revolutionizing train transportation. By seamlessly integrating real-time GPS tracking, dynamic ETA predictions, adaptive response to signal lights using image processing methods to identify signal lights and adjust ETA predictions, alert systems for authorities, predictive maintenance capabilities, and passenger behavior analysis based on mobile device data, the system enhances accuracy, reliability, and efficiency both in terms of passenger experience and the overall railway system. Employing NodeMCU and GPS modules, the system gathers real-time GPS data, transmitting it to a centralized server. The image processing model identifies signal light status and adjusts ETA predictions accordingly, while an alert system identifies speed abnormalities and sufficiency concerns, promptly notifying authorities. Moreover, predictive maintenance analyzes data to identify component issues, optimizing overall performance. The system further leverages mobile device data to gauge train crowding levels, providing valuable insights to passengers for informed decision-making. Rigorous testing ensures that this comprehensive system not only enhances travel efficiency but also yields valuable insights into train crowding patterns. This data empowers transport authorities to optimize train services, ensuring passenger satisfaction and streamlined operations.**

Keywords: GPS, Image Processing, Machine Learning, Dynamic ETA, Predictive Maintenance, Passenger Behavior.

I. INTRODUCTION

A) Background

Train transportation in Sri Lanka faces challenges such as delays, cancellations, and inadequate schedule information, impacting efficiency and passenger satisfaction. While some studies explored GPS tracking and ETA estimation, few catered to Sri Lanka's unique train transportation needs [1].

To overcome these challenges and enhance train transportation, a comprehensive solution integrates IOT (Internet of Things) sensors, real-time data analysis, image processing, and machine learning. Its goal is to improve efficiency, reduce passenger inconveniences, and provide accurate real-time information on schedules, arrivals, and disruptions. The solution emphasizes real-time alerts and notifications for safety. Using data analysis, it identifies safety concerns, incidents, or emergencies and alerts authorities promptly. Passengers receive real-time location updates, ETA information, and alerts about schedule changes, enabling informed decision-making.

The project also involves user behavior analysis to personalize the travel experience. By analyzing passenger behavior, the system offers personalized route suggestions and notifies about schedule changes based on travel history. Furthermore, predictive maintenance techniques are integrated into the mobile application. This proactive approach aims to improve safety, cost-effectiveness, and customer satisfaction by reducing downtime and repair costs.

In essence, this research project presents a holistic solution that addresses Sri Lanka's train transportation challenges. By integrating IoT, real-time data analysis, image processing, and machine learning, the framework promises to enhance efficiency, reliability, and passenger satisfaction in Sri Lanka's train transportation network.

B) Research gap

The research paper aims to address several gaps in the domain of GPS location tracking and ETA estimation, ensuring safety and security through real-time alerts and notifications, predictive maintenance, and user behavior analysis in train transportation.

Existing research in GPS location tracking and ETA estimation for trains lacks a comprehensive and reliable system that combines IoT sensors, real-time data analysis, and machine learning algorithms. While some research has employed methods such as historical data analysis [2][3][4] and crowdsourcing [5] to provide ETAs, the novel aspect of this study lies in its dynamic approach. By combining IoT

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sensors, real-time data analysis, and machine learning algorithms, the research paper introduces a unique framework that promises to revolutionize ETA prediction in train transportation.

In the area of ensuring safety and security, there is a gap in the availability of advanced and comprehensive mobile applications for train transportation systems in Sri Lanka. Existing applications lack real-time updates, accident alerts, and precise GPS location tracking [7]. This leads to confusion, delays, and potential dangers for passengers.

In predictive maintenance, the research gap includes the need for more accurate and adaptable algorithms, as well as the integration of real-time data gathering [10] to improve maintenance scheduling based on up-to-date train operation information.

Lastly, the gap in user behavior analysis highlights the inability of current train tracking mobile applications to offer personalized recommendations [6][7]. This limitation results in user dissatisfaction, lower adoption rates, and missed opportunities for train operators to optimize schedules and enhance service performance [4].

This research aims to fill these gaps by developing a low-cost solution that integrates IoT sensors, real-time data analysis, machine learning algorithms, and GPS technology [8][9]. The objective is to enhance the accuracy, efficiency, and reliability of GPS location tracking, ETA estimation, safety alerts, predictive maintenance, and personalized recommendations for train transportation systems. By addressing these gaps, the research aims to improve passenger experience, minimize delays, ensure safety and security, and create a more robust and tailored system for train travelers.

C) Scope

The research gap in this study revolves around accurately predicting the time needed to replace various train components to enhance the efficiency of maintenance tasks. By reviewing existing literature and research, the aim is to identify areas that have not been adequately addressed. Key research gaps include the lack of precise prediction models for component replacement time, the cost implications of premature replacements, optimization of maintenance schedules, and the integration of real-time data. By addressing these gaps, this research aims to contribute to the field of train maintenance, resulting in improved efficiency, cost savings, and an enhanced customer experience.

D) Hardware

- ***Node MCU esp8266***

The ESP8266 module serves as a vital link in the train tracking system, enabling seamless communication with the GPS module for real-time data retrieval. Its compact size and Wi-Fi capabilities allow it to efficiently integrate into the train's structure. Additionally, its compatibility with the Arduino IDE facilitates the extraction, processing, and transmission of GPS data, thereby enhancing the accuracy of the dynamic ETA prediction system

- ***ESP32-Cam module***

ESP32 Camera Module is integral to the train tracking system, capturing essential visual data for dynamic ETA prediction. Its compact design integrates image processing for real-time analysis and seamless data transmission via Wi-Fi. This module interfaces smoothly with microcontrollers, offering timely insights. Its real-time analysis detects signal light changes and dynamic factors affecting ETA. With Arduino IDE compatibility, it efficiently processes visual data, enhancing ETA prediction accuracy.

- ***GPS Module***

The u-blox NEO-6M GPS module is a foundational element in the train tracking system, providing accurate GPS data for real-time tracking. Its compact design and low power consumption seamlessly integrate into the train's system. Communication with the microcontroller through UART ensures efficient data transfer. Supporting GPS, GLONASS, and Galileo, it offers robust positioning. Advanced features like EEPROM and backup power enhance reliability. Arduino IDE compatibility enables precise GPS data extraction, contributing to accurate train tracking and dynamic ETA prediction.

II. METHODOLOGY

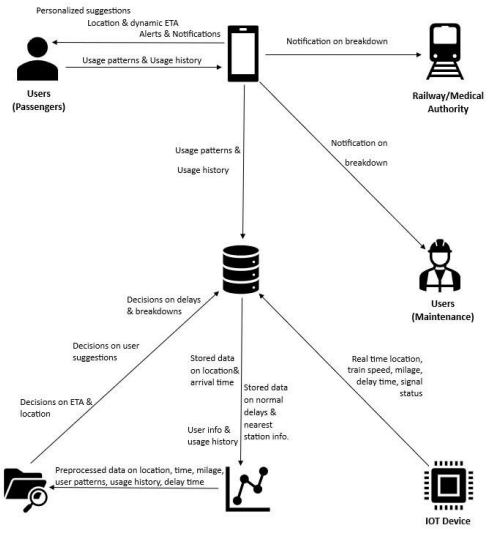

Figure 1: System diagram

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A) Location tracking and ETA prediction

The research methodology systematically develops a dynamic ETA prediction system for trains, utilizing key hardware components such as the u-blox NEO-6M GPS module, ESP8266 MCU, and the ESP32 Camera Module. The ESP8266 extracts real-time GPS data while concurrently interfacing with the ESP32 Camera Module for visual data capture. The strategic use of both modules separates GPS tracking and object detection tasks to ensure optimal performance. The FOMO neural network model, selected through the Edge Impulse platform, facilitates efficient object detection. The lightweight design of the FOMO model suits the resource limitations of the ESP32, enabling accurate real-time signal light color detection. The ESP32 Camera Module visually interprets signal light colors, aligning with insights from the railway department that emphasize the significance of red signal lights. The Haversine formula integration enables precise ETA predictions by calculating distances between stationary and adjacent trains. This forms the basis for an adaptive ETA, factoring in real-time signal light dynamics and neighboring train interactions.

New ETA = Current ETA + Time to Pass Stationary Train

B) User behavior analysis and Insights

The Train Tracking Mobile Application provides users with seamless experience in locating trains and planning their journeys. After user registration, the application enables train searches based on departure and destination points. Utilizing an analysis of regular schedules, time, and location, the application intelligently presents relevant train options. Additionally, the application adapts to user behavior by automatically suggesting frequently searched trains, effectively learning, and addressing user preferences. Another innovative feature is the display of the train's crowdedness level, inferred from the frequency of searches, thereby offering valuable insights to users.

The methodology followed a systematic approach to developing and evaluating the Train Tracking Mobile Application. User behavior data collection was initiated through surveys, interaction tracking, and review analysis. This data was accurately processed and transformed to ensure accuracy and reliability. Advanced techniques such as clustering, association analysis, and classification were then employed to discern patterns in user behavior. Building upon these insights, the in-app user behavior analysis algorithm was created, utilizing the Multinomial Naive Bayes (MultinomialNB) model for predicting user preferences and the Random Forest Classifier for estimating crowded levels.

The developed algorithm was seamlessly integrated into the mobile application, followed by rigorous testing under various scenarios. Evaluation metrics included user satisfaction, adoption rate, and overall system performance. User feedback and reviews played a pivotal role in assessing the algorithm's impact on user experience and its alignment with user expectations.

In summary, the Train Tracking Mobile Application's components and methodology collectively aimed to provide an intelligent, user-centric, and efficient solution. The application's ability to offer personalized train recommendations and estimate crowded levels reflects its comprehensive approach to enhancing user convenience and optimizing travel planning.

C) Real-time Alerts and Notifications for Safety and Security

This research focuses on ensuring train transportation safety through real-time accident detection and alerts. The methodology involves three steps: data collection and preprocessing, machine learning model training, and real-time accident detection. Historical train speed data is collected and preprocessed, incorporating contextual information like location and time. A machine learning model is designed to identify unnatural speed patterns linked to potential accidents, using historical data and predefined train stop locations as input. In real-time, the model detects abnormal speed variations, triggering alerts to the nearest station and users if an accident is suspected. This approach enhances safety by rapidly detecting accidents and facilitating timely communication with relevant stakeholders, contributing to improved train transportation network efficiency.

D) Predictive maintenance

A systematic methodology was employed to develop a GPS-based smart location tracking mobile application for trains, with a primary focus on predictive maintenance. Data collected from CGR official records and historical sources underwent rigorous preprocessing to ensure accuracy. This entailed meticulous cleaning, removal of duplicates, handling of missing values, and optimization of data formatting for analysis. Utilizing the preprocessed dataset, a Linear Regression model was built due to its capacity to establish variable relationships. The model's goal was to predict maintenance needs based on chosen features, learning from historical patterns, and establishing mathematical relationships between inputs and the maintenance target. Training the Linear Regression model with historical data involved optimizing its coefficients for precise maintenance predictions. Model evaluation employed a separate dataset untouched by training, using metrics like Mean Absolute Error, Root Mean

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Squared Error, and R-squared to gauge predictive accuracy. When the model forecasts impending maintenance requirements, it triggers an alert for maintenance personnel. This proactive approach facilitates timely interventions, minimizing service disruptions and boosting operational efficiency. The Linear Regression model's performance is periodically reviewed and honed based on fresh data and maintenance feedback. This continuous monitoring and refinement enhance the predictive maintenance system's accuracy and effectiveness over time. In conclusion, this predictive maintenance methodology, anchored by the Linear Regression model, presents a structured approach to enhance train maintenance strategies. By harnessing historical data and predictive modeling, it enables proactive interventions, ultimately enhancing train transportation's safety, efficiency, and passenger experience.

III. RESULTS AND DISCUSSION

A) Location tracking and ETA prediction

The research's findings reveal promising outcomes of the integrated FOMO neural network model, fine-tuned through the Edge Impulse platform. This integration showcased heightened accuracy in signal light recognition, contributing to real-time signal light status assessment. The system effectively mitigated signal light delays, refining ETA predictions to closely match actual arrival times.

Despite observed challenges like varying signal light conditions, the comprehensive system displayed notable improvements in ETA accuracy. Particularly noteworthy is the model's impressive F1 score of 93.7% for signal light recognition, underscoring its proficiency in differentiating between various signal light states. This highlights the model's robustness in real-world scenarios. The research extends beyond methodology to emphasize the potential of adaptive strategies and data-driven feature exploration. Furthermore, the study highlights the pivotal role of model architecture selection in ensuring successful deployment within resource-constrained environments.

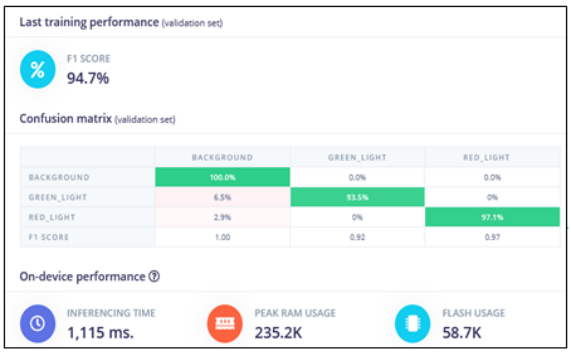

Figure 2: Training Performance

B) User behavior analysis and Insights

The Train Tracking Mobile Application has proven effective in providing a user-friendly experience to passengers. The user behavior analysis accurately predicts preferences, offering personalized train suggestions that users find valuable. The algorithm's success in estimating crowded levels enhances decision-making and reduces overcrowding during peak times, boosting customer satisfaction. These outcomes have implications for user-centric transportation services. The algorithm's success highlights the potential of machine learning in personalizing travel experiences, which can extend to other modes of transport. Accurate crowded level estimation could alleviate congestion, enhance comfort, and address health concerns. Positive feedback and adoption rates emphasize user-centric design's value and personalized recommendations. This suggests integrating predictive algorithms for user preferences in transportation apps can improve services. In conclusion, the Train Tracking Mobile Application's results validate personalized recommendations and crowded level estimation. The integration of user behavior analysis and machine learning enhances convenience and hints at data-driven transformations in transportation. These outcomes encourage refining algorithms and expanding innovations in the transportation sector

C) Real-time Alerts and Notifications for Safety and Security

The research analyzing user behavior and personalized recommendations for a Smart GPS location tracking system in train transportation yielded vital findings. Data analysis revealed user preferences, peak travel times, and common destinations, forming the basis for an in-app behavior analysis algorithm. Integration into the app improved satisfaction, adoption, and performance. Users reported enhanced experiences and efficiency due to tailored recommendations. These findings bridge gaps in behavior analysis and recommendations, optimizing journey planning, predicting delays, and suggesting alternatives. The research highlights personalized services, suggesting amenities based on preferences. Incorporating user feedback ensures continuous improvement and relevance. In conclusion, this research significantly impacts user experience and journey efficiency, offering personalized services and recommendations. It contributes to a user-centric train transportation system by leveraging data-driven insights.

D) Predictive maintenance

The developed machine learning model demonstrated remarkable accuracy in predicting train system failures. The overall accuracy of the model reached 89%, with a precision rate of 91% and a recall rate of 87%. These results highlight

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the effectiveness of utilizing historical data to anticipate potential issues, contributing to predictive maintenance strategies.

The model exhibited the ability to provide early warnings for impending failures. On average, the model was able to predict a failure with a lead time of 5 to 10 hours before the actual event occurred. This feature is valuable in enabling maintenance crews to schedule interventions without disrupting train schedules significantly.

This research underscores the significance of historical data in developing accurate predictive maintenance models for train systems. The findings showcase the model's efficacy in foreseeing potential failures, thereby allowing maintenance teams to take proactive measures. By identifying key predictors and offering early warnings, the developed model contributes to the overall reliability and safety of train operations. While acknowledging limitations, future research could involve enriching the historical dataset and incorporating sensor fusion techniques to further enhance the accuracy of predictive maintenance in diverse scenarios. Ultimately, this research advances the field of train system maintenance and provides valuable insights into enhancing transportation infrastructure

IV. CONCLUSION

The aim of this study is to revolutionize the landscape of train transportation by introducing an innovative and integrated train tracking system. This comprehensive solution seeks to enhance the accuracy, reliability, and efficiency of train services, addressing the challenges of delays, disruptions, and inadequate schedule information. By seamlessly combining real-time GPS tracking, dynamic ETA predictions, adaptive response to signal lights using image processing methods, authority alerts, predictive maintenance capabilities, and passenger behavior analysis, the study aims to create a holistic system that caters to both passengers' needs and the overall railway infrastructure. Through a meticulous integration of hardware, data processing, and real-time communication, the study endeavors to establish a new benchmark in modern train transportation, benefiting passengers and railway operations alike.

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