Sri Lanka Intelligent Bus Navigation and Passenger Information System

A.S.C.G. Senarathne
Department of Information Technology
Faculty of Computing
Sri Lanka Institute of Information Technology - Sri Lanka
it21205460@my.sliit.lk

N.V. Kalhara
Department of Information Technology
Faculty of Computing
Sri Lanka Institute of Information Technology - Sri Lanka
it21202490@my.sliit.lk

R.L.H.P. Rajapaksha
Department of Information Technology
Faculty of Computing
Sri Lanka Institute of Information Technology - Sri Lanka
it21192050@my.sliit.lk

M. Thanusan
Department of Information Technology
Faculty of Computing
Sri Lanka Institute of Information Technology - Sri Lanka
it21175848@my.sliit.lk

Sanika Wijayasekara
Department of Computer Systems Engineering
Faculty of Computing
Sri Lanka Institute of Information Technology - Sri Lanka
sanika.w@sliit.lk

Kapila Dissanayaka
Department of Computer Science
Faculty of Computing
Sri Lanka Institute of Information Technology - Sri Lanka
kapila.d@sliit.lk

***Abstract*—The Voice-Enhanced Smart Vehicle Transportation and Alerts Management System aims to transform Sri Lanka's public transportation by addressing several key challenges [1]. Currently, there is no reliable mechanism to track public buses or school vans, resulting in uncertainty about schedules, long waiting times, and safety concerns for children using school transportation. Additionally, passengers often face challenges such as a lack of accurate information regarding bus schedules, inefficient route management, and the inability to monitor vehicle locations in real-time. These issues lead to unnecessary stress and inefficiencies, which discourage people from utilizing public transportation effectively. Furthermore, the existing system lacks accessibility for visually impaired individuals and modern, secure payment solutions, creating barriers for diverse user groups.**

The proposed system provides a comprehensive solution through the integration of advanced technologies, ensuring significant improvements in the public transportation experience. Real-time tracking and notifications ensure that users are consistently informed about vehicle locations and Estimated Time of Arrival (ETA) via a user-friendly mobile application. This functionality reduces waiting times, eliminates the frustration of missing buses, and enhances overall service reliability. Accessibility features, such as voice commands and sound alerts, make the system inclusive for visually impaired users, enabling them to interact seamlessly with the application and receive crucial information without visual dependence.

To modernize fare payments, the system incorporates a reloadable smart card system that integrates with a bitcoin-based payment platform. This ensures secure, contactless transactions, aligning with global trends in cashless transportation systems. Vehicle identification is enhanced through high-resolution camera modules and Optical Character Recognition (OCR) technology. This technology allows users to confirm vehicle identity and receive alerts in cases of unauthorized or unscheduled vehicle movements, thereby enhancing passenger safety and security.

Machine learning algorithms play a critical role in improving the accuracy of ETA predictions. By analyzing traffic conditions, historical data, and route patterns, the system ensures reliable and timely updates for passengers. This predictive capability not only enhances user convenience but also promotes better planning and efficiency in transportation schedules. Moreover, the system includes a robust notification mechanism that alerts users about approaching buses, schedule changes, or delays. These alerts ensure that users can plan their journeys effectively, reducing stress and enhancing satisfaction.

In addition to technological advancements, the system focuses on inclusivity and user-centric design. Features such as voice commands and real-time notifications cater to diverse user needs, ensuring that visually impaired individuals and others with special requirements are not left behind. The combination of cutting-edge technology, secure payment solutions, and accessible features creates an ecosystem that modernizes public transportation in Sri Lanka, prioritizing user convenience, safety, and inclusivity. Overall, this innovative system represents a significant leap forward in addressing longstanding issues in Sri Lanka's public transportation network while setting a benchmark for future advancements in the sector.

***Index Terms*—Estimated Time of Arrival, Optical Character Recognition, Internet Of Things, Google Positioning System, Global System for Mobile Communications, General Packet Radio Service, Message Queuing Telemetry Transport, Hypertext Transfer Protocol, Near-field communication, Quick Response, Natural Language Processing, Application Programming Interface, Artificial intelligence,**

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I. Introduction

Public transportation plays a crucial role in ensuring mobility, convenience, and sustainability within a country's transportation ecosystem. In Sri Lanka, the public transit system faces significant challenges [2], primarily due to the lack of reliable real-time tracking, inefficiencies in schedule management, and outdated payment methods. Commuters frequently face long waiting times, uncertainty about bus schedules, and missed opportunities to board their desired vehicles. This inefficiency not only disrupts daily travel routines but also diminishes public confidence in the transportation system. One of the most vulnerable demographics affected by these shortcomings includes school children and their parents. Without proper systems in place, parents often lack real-time information on the whereabouts of school vans, raising concerns about their children's safety and well-being. Additionally, visually impaired individuals face accessibility barriers, limiting their ability to benefit from existing transportation services. Despite advancements in global transportation technologies, Sri Lanka's public transportation has lagged in adopting modern solutions to address these issues. The advent of IoT (Internet of Things), machine learning, and cloud-based technologies presents an opportunity to transform the transportation sector by providing real-time, intelligent, and user-centric solutions. The Voice-Enhanced Smart Vehicle Transportation and Alerts Management System has been designed as a comprehensive solution to bridge these gaps in Sri Lanka's public transit. This system not only addresses real-time vehicle tracking and Estimated Time of Arrival (ETA) predictions [3] but also incorporates accessibility features, secure payment systems, and an intelligent notification mechanism. At its core, the proposed system leverages IoT devices installed in vehicles to capture location and movement data, which is then transmitted to a cloud-based platform for processing. Machine learning algorithms analyze historical traffic patterns and real-time inputs to predict ETAs with high accuracy. The inclusion of a voice-activated interface ensures accessibility for visually impaired users, empowering them to navigate the public transit system seamlessly. Meanwhile, high-resolution cameras and OCR technology enable users to identify buses visually and receive alerts about unauthorized vehicle activity. Modernizing fare payment systems is another critical component of this research. Traditional cash-based systems are replaced with a re-loadable smart card integrated with a bitcoin-based payment platform, enabling secure, contactless transactions. This solution not only enhances convenience but also aligns with global trends toward digitized and decentralized payment methods.

A. Development of IoT Devices for Data Transfer

This component involves the design and integration of IoT devices to capture and transmit real-time vehicle data, such as GPS location, speed, and route information. Each device utilizes a GPS module for tracking, a GSM/GPRS module for communication, and a microcontroller like ESP32 for data processing. Data is securely transmitted to a Firebase server using communication protocols like MQTT or HTTP, ensuring reliability and low latency.

To handle connectivity issues, the device features offline functionality, storing data locally during outages and syncing with the server once the connection is restored. This system is pivotal for real-time vehicle tracking and accurate Estimated Time of Arrival (ETA) predictions, laying the groundwork for a reliable and user-friendly bus tracking app.

B. Implementation of a Secure Smart Card and Online Ticketing System

This module introduces an advanced payment system that combines reloadable smart cards, blockchain-based security, and a comprehensive online ticketing platform to revolutionize fare transactions. Users can recharge their smart cards through a mobile app or kiosks and make contactless payments using NFC or QR code technology for seamless boarding. The integration of a Bitcoin-based payment platform leverages blockchain to ensure secure, transparent, and tamper-proof transactions, building trust and minimizing fraud risks. The online ticketing platform allows users to purchase tickets, manage payments, and access transaction histories effortlessly. By offering a secure, efficient, and user-friendly payment solution, this system enhances the overall transit experience and operational transparency.

C. Real-Time ETA Prediction and Voice-Enabled User Interface

By leveraging machine learning algorithms, this component calculates precise ETAs based on real-time traffic data, historical patterns, and vehicle movements. The system continuously refines predictions through adaptive learning. A voice-enabled interface makes the system accessible to visually impaired users, allowing interaction through voice commands. Additional features like sound alerts and text-to-speech capabilities ensure inclusivity, making the application user-friendly for people with diverse needs.

D. Smart Vehicle Identification and Alert System

This component employs machine learning algorithms to calculate highly accurate Estimated Time of Arrival (ETA) predictions by analyzing real-time traffic conditions, historical travel patterns, and live vehicle movement data. The system dynamically improves its predictions over time through adaptive learning, ensuring reliability even in changing conditions. To enhance accessibility, a voice-enabled interface allows visually impaired users to interact with the application using voice commands. Additional inclusivity features, such as sound alerts and text-to-speech functionality, ensure that the platform caters to users with diverse needs, delivering a seamless and user-friendly experience for all.

E. Integration of Advanced Notification Mechanisms

This feature provides passengers with real-time updates on vehicle arrivals, delays, and schedule changes through intelligent alert notifications. Users can customize their preferences to receive notifications for frequently used routes or buses, ensuring a personalized experience. The system also delivers proactive, event-based alerts for disruptions like route changes or cancellations, keeping users informed about unexpected developments. By leveraging machine learning, the notification system optimizes the frequency and relevance of alerts, minimizing unnecessary notifications while ensuring critical updates are delivered promptly and effectively.

II. Literature Reviews

Public transportation in Sri Lanka is plagued by several challenges, including inconsistent schedules, overcrowded vehicles, and limited accessibility for groups such as tourists and visually impaired users. These issues contribute to significant passenger dissatisfaction, safety concerns, and inefficiencies in the transit system. Moreover, the competition-driven behavior of bus operators often results in reckless driving and a higher risk of accidents. Tackling these challenges necessitates a holistic approach that incorporates real-time tracking for better schedule reliability, user-friendly interfaces to improve accessibility, and safety-focused mechanisms to ensure a secure and inclusive transportation experience for all passengers.

A. Real-Time Tracking and Data Processing

Real-time tracking and ETA prediction [4] serve as the foundation of contemporary intelligent transportation systems. Leveraging IoT-enabled devices with integrated GPS and GSM modules, these systems capture vehicle location and operational data in real time. This data is processed using cloud platforms such as Firebase, offering users precise and timely updates on bus locations and estimated arrival times. Machine learning algorithms further enhance this process by analyzing both historical and real-time traffic data to improve the accuracy of ETA predictions. These advanced capabilities significantly boost user convenience and optimize the efficiency of transportation networks, addressing common challenges like schedule unreliability and inefficiencies.

B. Accessibility and User-Centric Features

The inclusivity of transportation systems is a vital yet frequently overlooked aspect of enhancing user satisfaction. Integrating voice-enabled systems and multilingual support ensures accessibility for visually impaired individuals and tourists alike. Features such as voice commands and sound notifications empower visually impaired users to interact with bus schedules and track vehicle locations independently, eliminating the need for visual assistance. Simultaneously, dynamic language translation, driven by advanced natural language processing models, bridges language barriers for tourists, creating a user-friendly and inclusive platform that caters to a diverse audience.

C. Image and Text Detection for Security and Identification [5]

A notable innovation in the proposed system is the integration of high-resolution cameras with Optical Character Recognition (OCR) technology for real-time text detection. This feature allows passengers to identify buses accurately by recognizing license plates and route signage, ensuring they board the correct vehicle. Furthermore, the system enhances security by detecting unauthorized vehicles, thereby improving safety. With multilingual text processing capabilities, it accommodates the diverse linguistic landscape of the region, ensuring accessibility for all users and bolstering the system's reliability and user experience.

D. Blockchain and NFC-Based Payment Systems

Cashless payment systems are a cornerstone of contemporary public transportation, offering enhanced convenience and efficiency. By incorporating blockchain technology [6] alongside NFC-enabled smart cards, the proposed system delivers secure and transparent fare transactions. Blockchain ensures an immutable ledger for recording all transactions, reducing the risk of fraud and fostering user trust. NFC technology enables fast and contactless payments, streamlining boarding processes and minimizing delays. This integration not only modernizes fare collection but also improves user satisfaction and operational transparency, making public transportation more efficient and user-friendly.

E. Personalized Alerts and Notifications

Real-time notifications [7] play a pivotal role in enhancing the passenger experience by minimizing uncertainty and enabling better trip planning. By leveraging geofencing technology, the system can deliver timely alerts about bus arrivals, delays, or schedule changes, ensuring passengers are always informed. Furthermore, personalized updates tailored to user preferences, such as specific bus routes or stops, add a layer of customization that makes the system highly adaptable to individual needs. This dynamic and responsive approach significantly improves the overall convenience and reliability of public transportation.

F. Safety Enhancements

Safety is a paramount concern in public transportation, especially in Sri Lanka, where competitive driving often results in accidents. The proposed system tackles this issue by employing IoT sensors and real-time data analytics to monitor bus speeds and driver behavior. If unsafe conditions, such as speeding or erratic driving, are detected, alerts are immediately sent to drivers, encouraging corrective actions and minimizing collision risks. Additionally, the system integrates unauthorized vehicle detection to ensure only authorized buses operate within the network, adding a critical layer of security. Together, these features enhance passenger safety and promote a more reliable and secure transportation environment.

G. AI and IoT Integration for Optimization

The integration of IoT and AI technologies serves as the cornerstone of the system's operational framework. IoT devices installed in buses gather real-time data on location, speed, and occupancy levels, transmitting it to a centralized cloud platform for processing. Advanced AI models analyze these data streams to generate precise ETA predictions, optimize route planning, and provide personalized user recommendations. This synergy between IoT and AI enhances overall system efficiency, ensuring timely and accurate information delivery while offering a scalable and adaptable solution to meet increasing user demands and evolving transit challenges.

III. METHODOLOGY

The methodology for implementing the Voice-Enhanced Smart Vehicle Transportation and Alerts Management System is structured around key components, as depicted in the diagram. Below is a detailed breakdown of the approach:

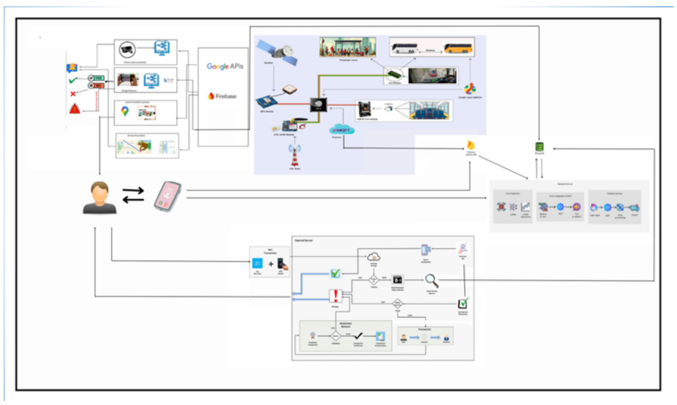

Fig. 1. Overall System Diagram

A. Data Collection and IoT Integration

- GPS and IoT Devices: Buses are equipped with GPS modules and IoT devices to track location, speed, and other metrics in real-time.
  - GPS Sensors: Collect location data and transmit it via GSM/GPRS to the backend server. [8]
  - IoT Sensors: Gather information about passenger count and other in-bus conditions.
  - Camera Modules: Capture high-resolution images for bus identification and text detection (e.g., license plates and route details).
- Data Transfer Protocols: The MQTT protocol ensures reliable data transmission from IoT devices to the cloud in near real-time.

B. Backend Infrastructure

- Server Architecture:
  - The backend server processes the data using various algorithms for:
    - ∗ ETA Calculation: Machine learning models (e.g., LSTM, Random Forest) predict accurate arrival times based on historical and real-time traffic data.
    - ∗ Data Integration: Natural Language Processing (NLP) and APIs such as Google Translate enable multilingual text recognition and translation.

C. Payment System

- NFC-Based Payment [9]:
  - NFC-enabled devices onboard buses facilitate contactless fare payment.
  - Passengers use reloadable NFC cards [2] or mobile wallets integrated into the application.
- Blockchain Integration:
  - Ensure secure, transparent transactions by maintaining an immutable record of payments [10].
  - Reduces fraud and adds user confidence through decentralized validation.

D. Mobile Application Development [11]

- User Interface:
  - Developed using React Native for cross-platform compatibility.
  - Provides real-time tracking, bus schedules, and notifications about arrivals, delays, or changes [12].
- Accessibility Features:
  - Voice commands and sound notifications enhance usability for visually impaired users.
  - Multilingual support through NLP models enables tourists to navigate the system effortlessly.
- Personalized Alerts:
  - Notification services alert passengers about their desired bus, upcoming stops, and any delays.
  - The system adapts to user preferences by learning frequently accessed routes and settings [13].

E. Security and Safety Mechanisms

- Image and Text Detection:
  - Advanced OCR and computer vision algorithms identify buses using their route numbers and license plates.
  - Unauthorized vehicle detection is implemented by cross-referencing images with the database.
- Collision and Speed Monitoring:
  - IoT devices monitor bus speeds and distances to reduce accidents caused by competition.
  - Alerts are sent to drivers and backend systems in case of unsafe driving conditions.

F. Cloud and API Integration

- Google APIs:
  - Google Maps API provides accurate geolocation and route mapping.
  - Cloud-based APIs process incoming data for traffic and environmental updates.
- Data Storage:
  - Historical and real-time data is stored in Firebase and MongoDB databases for scalability and easy access.

G. Advanced Analytics and Decision-Making

- Machine Learning Models:
  - Predictive models improve ETA accuracy and optimize resource allocation (e.g., bus scheduling).
  - AI processes user data to suggest alternative routes and identify patterns in transportation needs.
- Data Visualization:
  - Dashboard interfaces allow administrators to monitor system performance, vehicle locations, and payment trends.

H. Deployment and Testing

- System Integration:
  - Integrating IoT devices, servers, and mobile applications is a critical step to ensure smooth operation.
- Testing:
  - Conduct rigorous testing of hardware (e.g., GPS, NFC), backend algorithms, and user interfaces.
  - Simulate real-world conditions for validation, including multi-language scenarios, crowded buses, and traffic disruptions.

IV. Experiment Evaluation Results

A. Smart Contract and Blockchain Testing

To enhance security and decentralized transactions, our system integrates Erechtheum smart contracts using Hardhat for development and testing. The successful deployment of the contract confirms the feasibility of blockchain-based payment processing and transaction management. However, a contract call failure indicated a minor issue with an incorrect contract address, which was later rectified.

B. ETA Prediction Model Evaluation

The core of our system relies on a machine learning-based Estimated Time of Arrival (ETA) predictor, which was rigorously tested with real-time transportation data. Our model takes multiple factors into account, including distance, bus speed, traffic density, time of day, and day of the week. The experimental evaluation produced the following key results:

- Prediction Accuracy:
  - The model's output was validated using real-time data.
  - The actual vs. predicted ETA scatter plot confirms that predictions closely align with real-world arrival times.
- Performance Metrics:
  - Mean Absolute Error (MAE): 0.99 minutes (indicating an average error of less than 1 minute).
  - Root Mean Squared Error (RMSE): 1.31 minutes (suggesting that errors are minimal and do not significantly impact usability).
  - R-squared Score (R^2): 0.75 (showing that the model explains 75% of variations in bus arrival times).
  - These results demonstrate that the model is highly reliable in predicting ETAs, minimizing passenger uncertainty.

C. Blockchain-Based Payment Security

The Ethereum-based test environment provided multiple test accounts with 10,000 ETH each for development purposes. The simulated transactions on the test network successfully executed without latency issues, ensuring secure and transparent payments for bus fare transactions. Future enhancements may include Layer 2 scaling solutions (e.g., Polygon) to optimize transaction speeds.

D. Real-Time Data Processing and API Testing

To validate the functionality of real-time data integration, the API was tested using Flask (http://127.0.0.1:5000/predict). The response showed an accurate ETA prediction of 4.47 minutes, confirming that:

- The API correctly ingests and processes user requests.
- The model returns accurate results in real-time.
- The system is ready for mobile application integration.

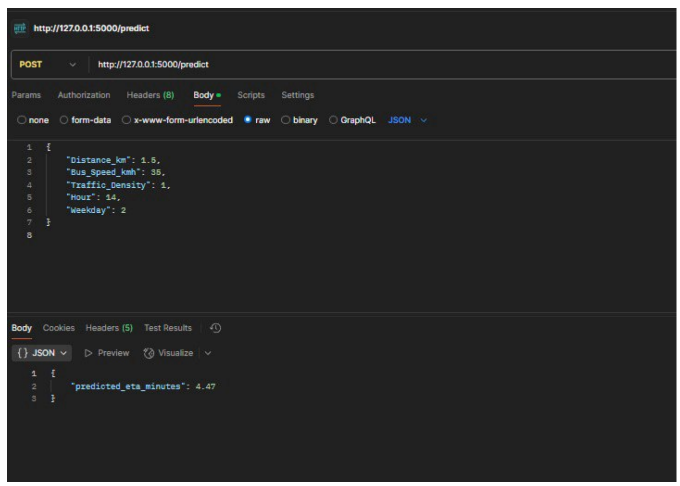

Fig. 2. API Testing

E. Real-World Usability and System Reliability

The experimental results suggest that the Voice-Enhanced Smart Vehicle Transportation and Alerts Management System is highly effective. By leveraging machine learning, blockchain technology, and IoT, our system significantly improves public transport reliability, accessibility, and user experience.

V. Conclusion

The Voice-Enhanced Smart Vehicle Transportation and Alerts Management System represents a trans formative approach to modernizing public transportation in Sri Lanka. By integrating cutting-edge technologies like IoT, machine learning, blockchain, and advanced user-centric interfaces, the system addresses critical challenges such as real-time tracking, accessibility for the visually impaired, and secure payment mechanisms. Through the implementation of features like precise ETA predictions, multilingual support, and robust notification systems, the solution enhances user convenience, safety, and inclusive. Furthermore, the adoption of smart card and blockchain technology ensures transparency and trust in fare transactions. This comprehensive solution not only improves the efficiency of public transportation but also aligns with global trends, setting a benchmark for innovation in transit systems. The successful deployment of this system can lead to significant improvements in commuter satisfaction, operational reliability, and overall public confidence in Sri Lanka's transportation network.

VI. Acknowledgment

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