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GPS-Based Toll Collection System using Geofencing Concept

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Abstract: This paper presents a GPS-based automatic toll collection system using geofencing and distance-based toll calculation to overcome the limitations of conventional toll systems. Traditional toll collection methods often lead to traffic congestion, increased waiting time, and inefficient resource utilization due to manual intervention and fixed toll pricing. To address these challenges, the proposed system utilizes Global Positioning System (GPS) technology and Internet of Things (IoT) principles to enable seamless and automated toll collection.In this system, a virtual toll zone is defined using geofencing techniques based on latitude, longitude, and radius parameters. An ESP32 microcontroller integrated with a GPS module continuously tracks the vehicle's real-time location. When the vehicle enters the predefined toll zone, the system begins monitoring the distance travelled within the zone. The distance is calculated using the Haversine formula, ensuring accurate measurement between geographic coordinates. Based on the travelled distance, the toll amount is dynamically computed and automatically deducted from the user's digital wallet.The system is further enhanced with cloud integration using a real-time database, which stores vehicle data, wallet balance, and transaction details. A web-based user interface is developed to display real-time information such as vehicle location, toll status, and remaining balance, providing transparency and ease of access to users.The proposed solution eliminates the need for physical toll booths, reduces traffic congestion, minimizes fuel consumption, and ensures fair pricing based on actual road usage. This system demonstrates an efficient, scalable, and cost-effective approach for modern intelligent transportation systems.

I. INTRODUCTION

The rapid expansion of road transportation networks and the increasing number of vehicles have significantly raised the demand for efficient and intelligent toll collection systems. Conventional toll collection methods, such as manual toll booths and RFID-based systems, are widely used but still suffer from several limitations. Manual systems require vehicles to stop or slow down, leading to long queues, traffic congestion, increased fuel consumption, and time delays. Although RFID-based electronic toll collection systems reduce waiting time to some extent, they still depend on fixed toll plazas and predefined charges, which may not be fair for all users.In recent years, advancements in technologies such as the Global Positioning System (GPS) and the Internet of Things (IoT) have opened new possibilities for developing smarter transportation solutions. GPS technology enables real-time tracking of vehicle location using satellite signals, while IoT allows seamless communication between devices and cloud platforms. By combining these technologies, it is possible to design an automated toll collection system that eliminates the need for physical toll booths and enables dynamic pricing based on actual road usage.This project proposes a GPS-based automatic toll collection system using geofencing and distance-based toll calculation. In this system, a virtual boundary (geofence) is defined around a toll zone using specific latitude, longitude, and radius parameters.The vehicle's position is continuously monitored using a GPS module connected to an ESP32 microcontroller. When the vehicle enters the predefined toll zone, the system starts tracking the distance travelled within the zone. Once the vehicle exits the zone, the total distance is calculated using the Haversine formula, which provides accurate measurement between geographic coordinates on the Earth's surface.Based on the calculated distance, the toll amount is dynamically computed using a predefined rate per kilometer. This ensures a fair pricing mechanism where users are charged according to the actual distance travelled rather than a fixed toll fee. The calculated toll amount is then deducted from the user's digital wallet, and the updated balance is stored in a cloud-based database. Additionally, a web-based user interface is developed to display real-time information such as vehicle location, toll status, and wallet balance, enhancing transparency and user experience.The proposed system offers several advantages over traditional methods, including reduced traffic congestion, elimination of physical infrastructure, improved efficiency, and scalability.

By integrating GPS, IoT, cloud computing, and web technologies, this system represents a modern approach to intelligent transportation and smart toll management.

II. LITERATURE SURVEY

GPS-based toll collection systems have become an important area of research in intelligent transportation systems due to their ability to automate toll payment, reduce traffic congestion, and eliminate manual intervention. Various researchers have contributed to different aspects such as positioning systems, geofencing, communication technologies, cloud integration, and digital payment mechanisms..Smith et al. [1] studied the application of Global Positioning System (GPS) technology in vehicular tracking systems. Their work demonstrated that GPS provides accurate real-time location data, which is essential for location-based services such as toll detection. However, signal degradation in urban areas and tunnels remains a challenge.Johnson and Miller [2] focused on geofencing techniques, where virtual boundaries are defined using latitude and longitude coordinates. Their study showed that geofencing can be effectively used to trigger automated events, such as toll detection when a vehicle enters a predefined zone. The accuracy of geofencing depends on proper radius selection and GPS precision.

Chen et al. [3] analyzed RFID-based electronic toll collection systems, which are widely used in many countries. These systems provide fast and contactless toll payment, reducing waiting time at toll plazas. However, they require dedicated infrastructure like RFID readers and tags, increasing overall system cost.

Kumar and Singh [4] proposed a GSM-based toll collection system where communication between the vehicle and the server is established through mobile networks. This approach allows remote data transfer and payment processing but may suffer from network delays and connectivity issues in remote areas.Lee et al. [5] explored Internet of Things (IoT)-based smart transportation systems, integrating sensors, microcontrollers, and cloud platforms. Their research highlighted that IoT enables real-time monitoring, data analysis, and efficient traffic management, making it suitable for automated toll systemsPatel et al. [6] investigated cloud-based data storage systems for vehicular applications. Their work demonstrated that cloud platforms allow centralized data management, real-time updates, and remote monitoring of vehicle transactions. However, issues related to data security and latency need to be addressed.

Rao et al. [7] studied digital payment systems integrated with embedded devices. Their research showed that automatic deduction of toll charges improves user convenience and reduces human errors. Secure transaction protocols are essential to ensure reliability.

III. EXISTING METHODS

Existing toll collection systems primarily rely on manual and semi-automated approaches, which often lead to inefficiencies, traffic congestion, and increased operational costs. One of the most widely used methods is manual toll collection, where vehicles are required to stop at toll plazas and make payments in cash. This process is time-consuming, prone to human error, and results in long queues, especially during peak hours.To overcome these limitations, RFID-based electronic toll collection systems have been introduced. In this method, vehicles are equipped with RFID tags, and toll plazas are installed with RFID readers. When a vehicle passes through the toll booth, the system automatically deducts the toll amount from the user’s account. Although this method reduces waiting time, it still requires dedicated infrastructure, including toll gates and scanning systems, which increases installation and maintenance costs.Another approach involves GSM-based toll collection systems, where communication between the vehicle and the toll system is established through mobile networks. These systems enable remote transaction processing and notification services. However, they are dependent on network availability and may experience delays or failures in areas with poor connectivity.Some existing systems also utilize Automatic Number Plate Recognition (ANPR) technology, which captures vehicle registration numbers using cameras and processes them for toll deduction. While ANPR eliminates the need for physical tags, it is highly dependent on image processing accuracy and can be affected by environmental conditions such as low light, weather, and camera quality.In addition, sensor-based systems are used in certain applications to detect vehicle presence and trigger toll operations. These systems are limited in functionality as they do not provide real-time location tracking or dynamic toll management.Despite these advancements, most existing methods lack complete automation, scalability, and real-time adaptability. They often depend on physical infrastructure and are not efficient in handling increasing traffic volumes. These limitations highlight the need for a more advanced solution that utilizes GPS, geofencing, and IoT technologies to enable seamless and fully automated toll collection without the need for toll plazas.

IV. PROPOSED WORK

This paper proposes a GPS-based automated toll collection system that eliminates the need for physical toll plazas and enables seamless toll deduction using geofencing and IoT technologies. The system is designed to provide a fully automated, real-time, and efficient toll collection mechanism using an ESP32 microcontroller integrated with GPS, Wi-Fi communication, and cloud-based data monitoring.

In the proposed system, a GPS module is used to continuously track the real-time location of the vehicle in terms of latitude and longitude coordinates. These coordinates are processed by the ESP32 microcontroller, which acts as the central processing unit of the system. A predefined toll location is stored in the controller along with a specific radius, forming a virtual boundary known as a geofence.The system continuously calculates the distance between the current vehicle location and the predefined toll location using appropriate distance calculation algorithms. When the vehicle enters the geofenced toll zone, the system automatically detects the event and initiates the toll deduction process without requiring the vehicle to stop.A digital wallet is maintained within the system to store the user's balance. Upon detecting entry into the toll zone, the system checks the available balance and deducts the predefined toll amount if sufficient funds are available. In case of insufficient balance, the system generates a low balance alert.For user interaction and feedback, a 16×2 LCD display is used to show important information such as current location, wallet balance, toll deduction status, and system alerts. Additionally, a buzzer is incorporated to provide audible notifications when a toll event is detected or when a payment is processed.The ESP32 utilizes its built-in Wi-Fi capability to transmit real-time data such as vehicle coordinates, wallet balance, toll events, and payment status to a cloud platform. This enables remote monitoring and integration with a web-based user interface, allowing users to track vehicle movement and transaction history in real time. The proposed system offers several advantages, including reduced traffic congestion, elimination of manual intervention, improved accuracy, and enhanced user convenience. By removing the dependency on physical toll infrastructure, the system provides a scalable and cost-effective solution suitable for modern intelligent transportation systems.

V. BLOCK DIAGRAM

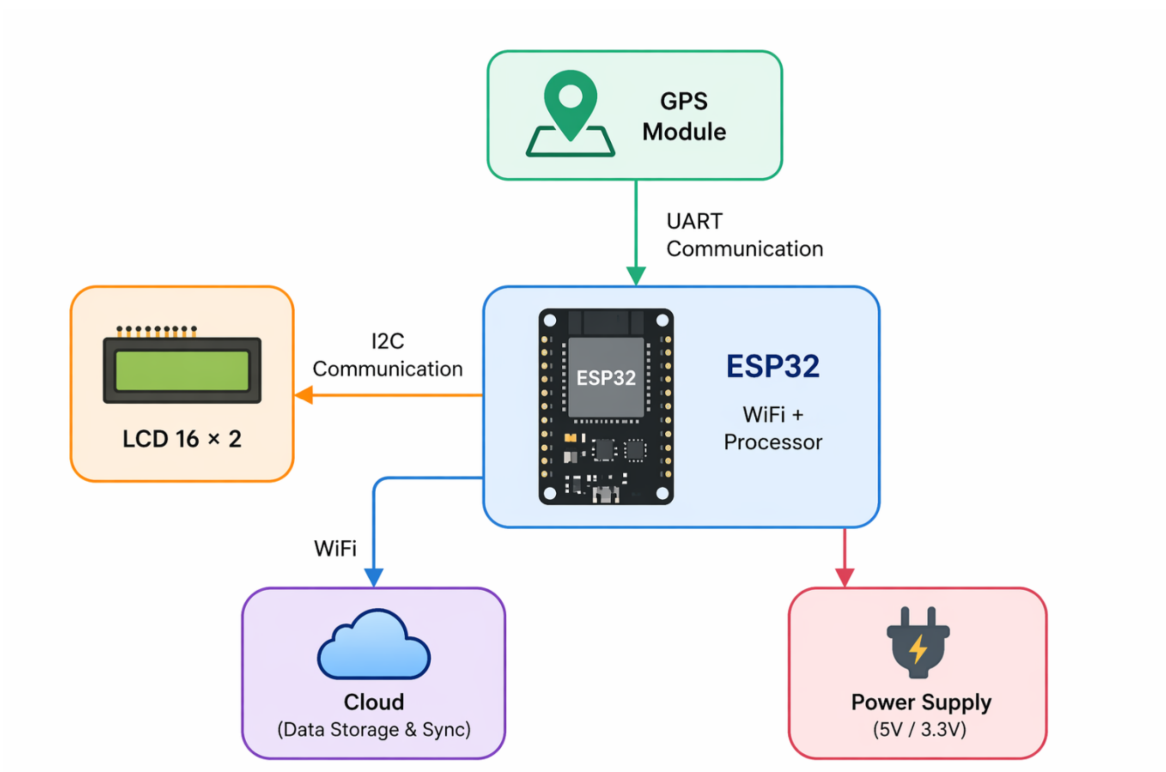

Fig no.1:Block Diagram

The block diagram represents the overall architecture of the proposed GPS-based automated toll collection system. It illustrates the interaction between different hardware components and communication modules used in the system.At the core of the system is the ESP32 microcontroller, which acts as the central processing unit. It is responsible for processing data, controlling peripheral devices, and managing communication between different modules. The ESP32 is chosen due to its built-in Wi-Fi capability, high processing speed, and support for multiple communication protocols.The GPS module is connected to the ESP32 through UART communication. It continuously provides real-time location data in the form of latitude and longitude coordinates.

The ESP32 reads this data and uses it to determine the current position of the vehicle. Based on these coordinates, the system performs geofencing and distance calculations to detect whether the vehicle has entered a predefined toll zone.A 16×2 LCD display is interfaced with the ESP32 using I2C communication. The LCD is used to display important information such as current coordinates, wallet balance, toll deduction status, and system alerts. The use of I2C communication reduces the number of required GPIO pins and simplifies wiring.The ESP32 is also connected to a cloud platform through Wi-Fi communication. This enables real-time data transmission, including vehicle location, toll events, and payment status. The cloud integration allows remote monitoring and supports the development of a user interface for tracking vehicle activity and transaction history.A power supply unit is provided to supply the required voltage to all components in the system. It ensures stable operation of the ESP32, GPS module, LCD, and other peripherals.Overall, the block diagram demonstrates how the system integrates GPS-based location tracking, microcontroller processing, user interface display, and cloud communication to achieve automated toll collection. The coordinated operation of these components enables real-time detection of toll zones and seamless toll deduction without manual intervention.

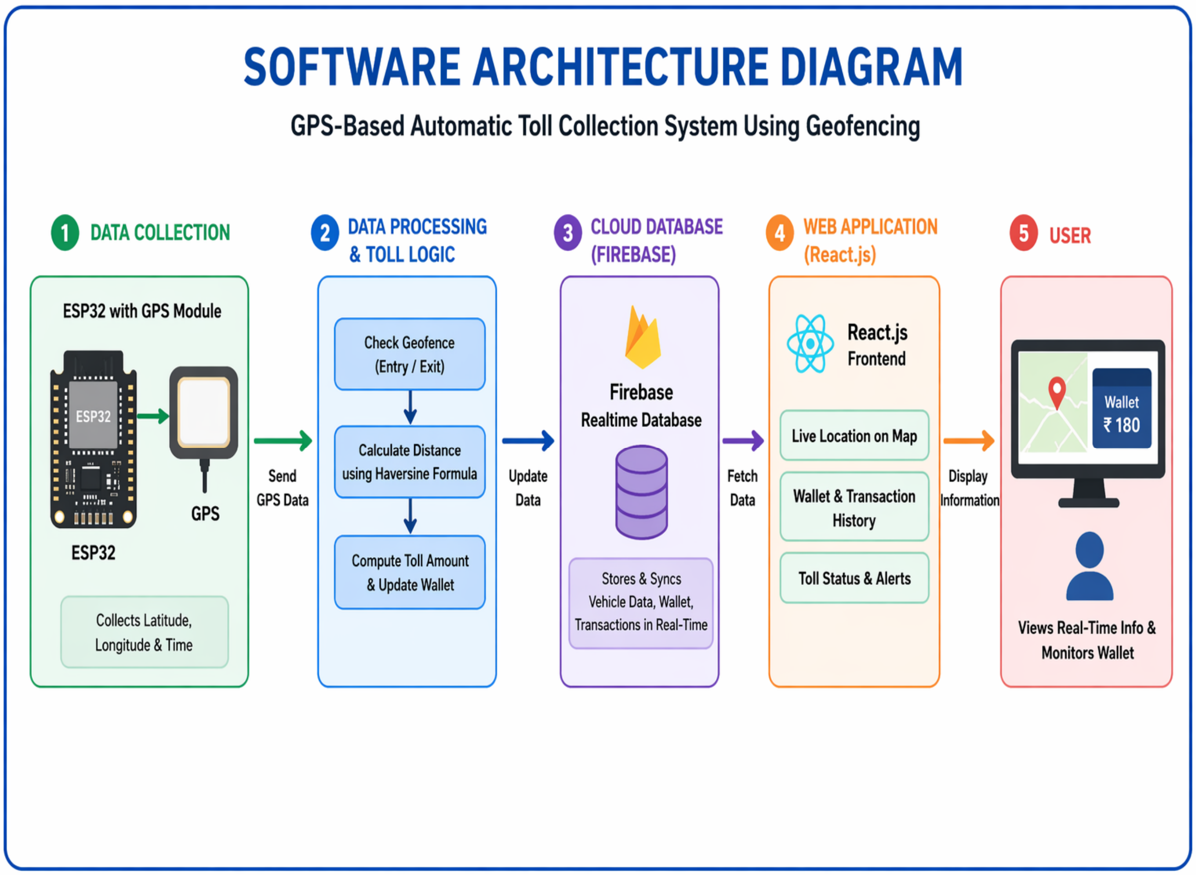

Fig no.2:Software Architecture diagram

The software architecture represents the functional workflow of the proposed GPS-based automated toll collection system. It describes how real-time location data is processed, transmitted, and displayed through different software components.

The ESP32 microcontroller receives GPS coordinates and processes them using geofencing techniques to detect vehicle entry into a toll zone. The system then calculates the distance travelled and determines the toll amount dynamically. A controlled logic is implemented to ensure that toll deduction occurs only once per defined distance interval, avoiding repeated charges .

The processed data, including location, distance, and wallet balance, is transmitted to a cloud-based database such as Firebase via Wi-Fi. This enables real-time data storage and synchronization.

A web-based user interface retrieves the data from the cloud and displays live vehicle location, toll status, and wallet information to the user. Overall, the architecture ensures efficient, automated, and real-time toll collection with minimal manual intervention.

VI. EXPERIMENTAL RESULTS

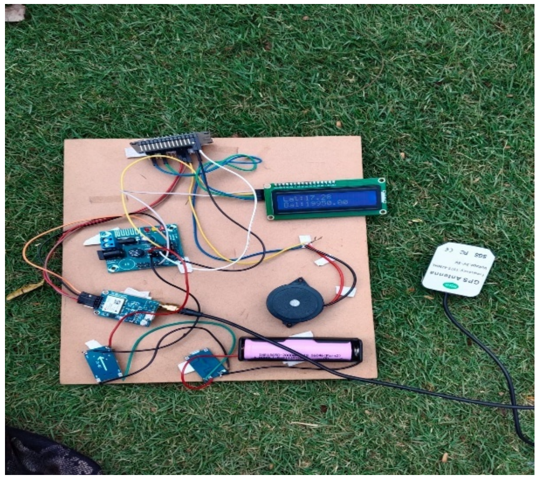

Fig no.3: Hardware LCD displaying live toll balance & latitude

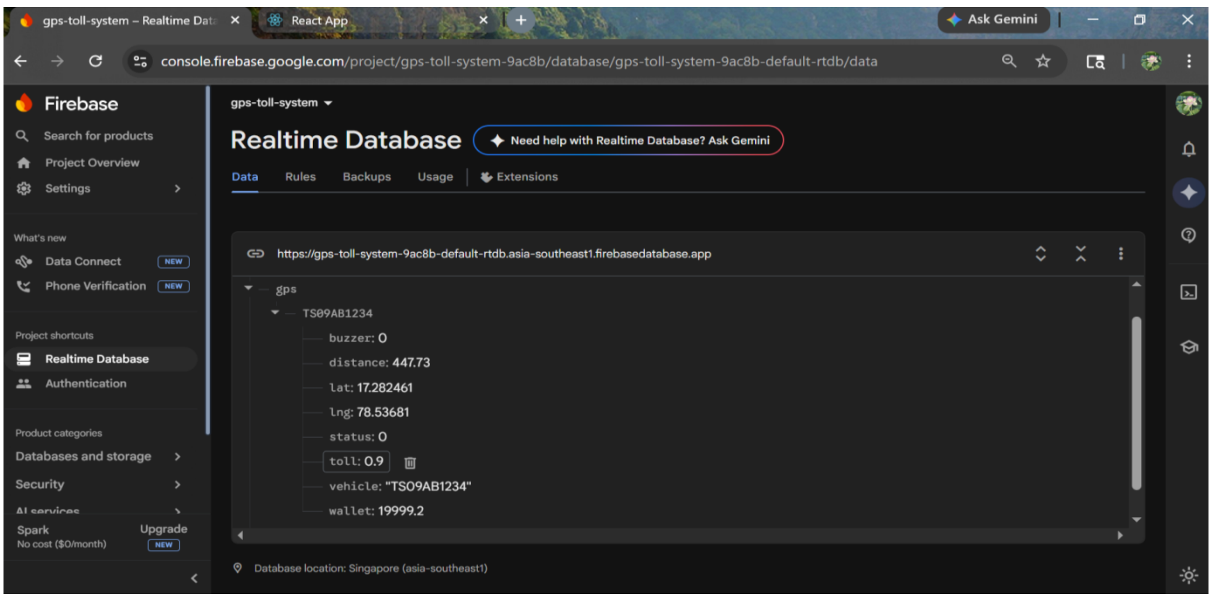

Fig no.4: Real-time GPS and toll data transmitted from ESP32 to Firebase database

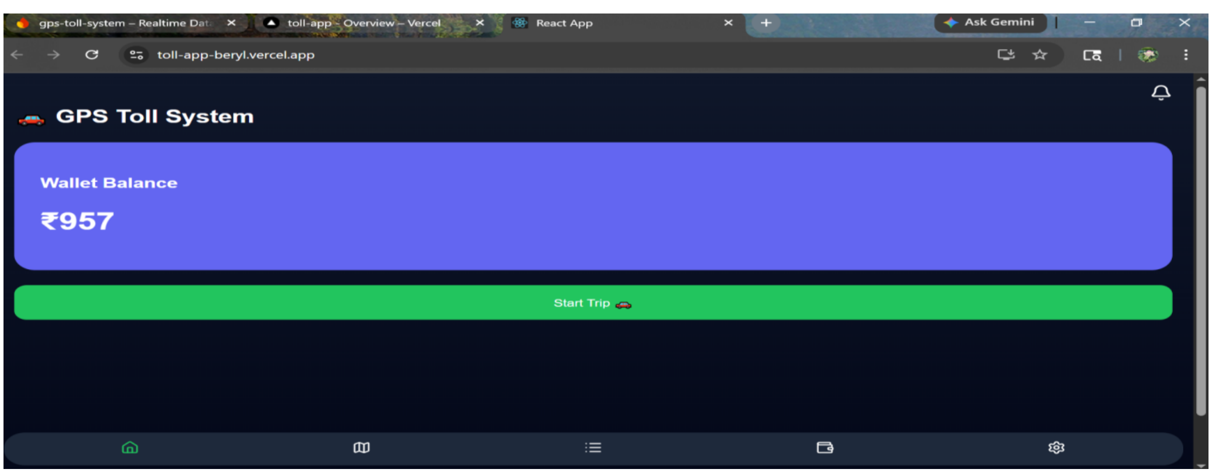

Fig no.5: User interface displaying Home page and wallet balance.

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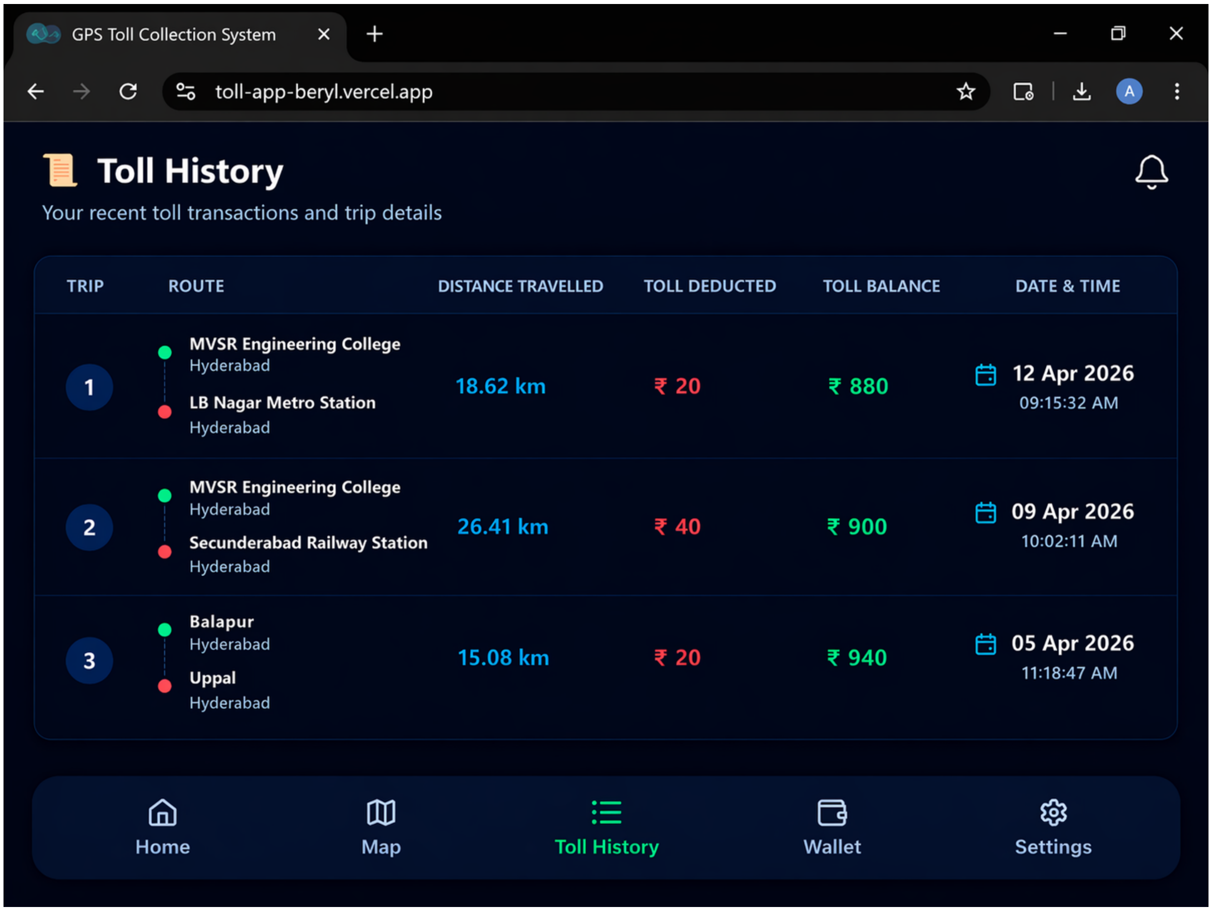

Fig no.5: Trip history

VII. CONCLUSION

The proposed GPS-based automated toll collection system successfully demonstrates an efficient and intelligent approach to modern toll management. By integrating GPS technology, geofencing techniques, and IoT-based communication, the system eliminates the need for conventional toll plazas and manual intervention. This results in reduced traffic congestion, minimized waiting time, and improved overall transportation efficiency.The implementation using the ESP32 microcontroller, along with GPS, LCD display, and cloud connectivity, provides a real-time and automated solution for toll detection and deduction. The system accurately determines the vehicle's location, identifies entry into the toll zone using predefined coordinates, and performs automatic toll deduction through a digital wallet mechanism. The inclusion of a user interface and cloud platform enhances transparency by allowing users to monitor vehicle movement and transaction details in real time.One of the key advantages of the proposed system is its scalability and cost-effectiveness, as it does not require expensive physical infrastructure such as toll booths, RFID readers, or camera-based systems. Additionally, the use of wireless communication enables remote monitoring and future integration with smart city applications.However, certain limitations such as dependency on GPS signal accuracy and internet connectivity may affect system performance in specific conditions like tunnels or low-network areas. These challenges can be addressed in future work by integrating additional technologies such as hybrid positioning systems and secure payment gateways.In conclusion, the proposed system provides a reliable, automated, and user-friendly solution for toll collection. It represents a significant step towards the development of smart transportation systems and has the potential to be implemented on a larger scale for real-world applications.

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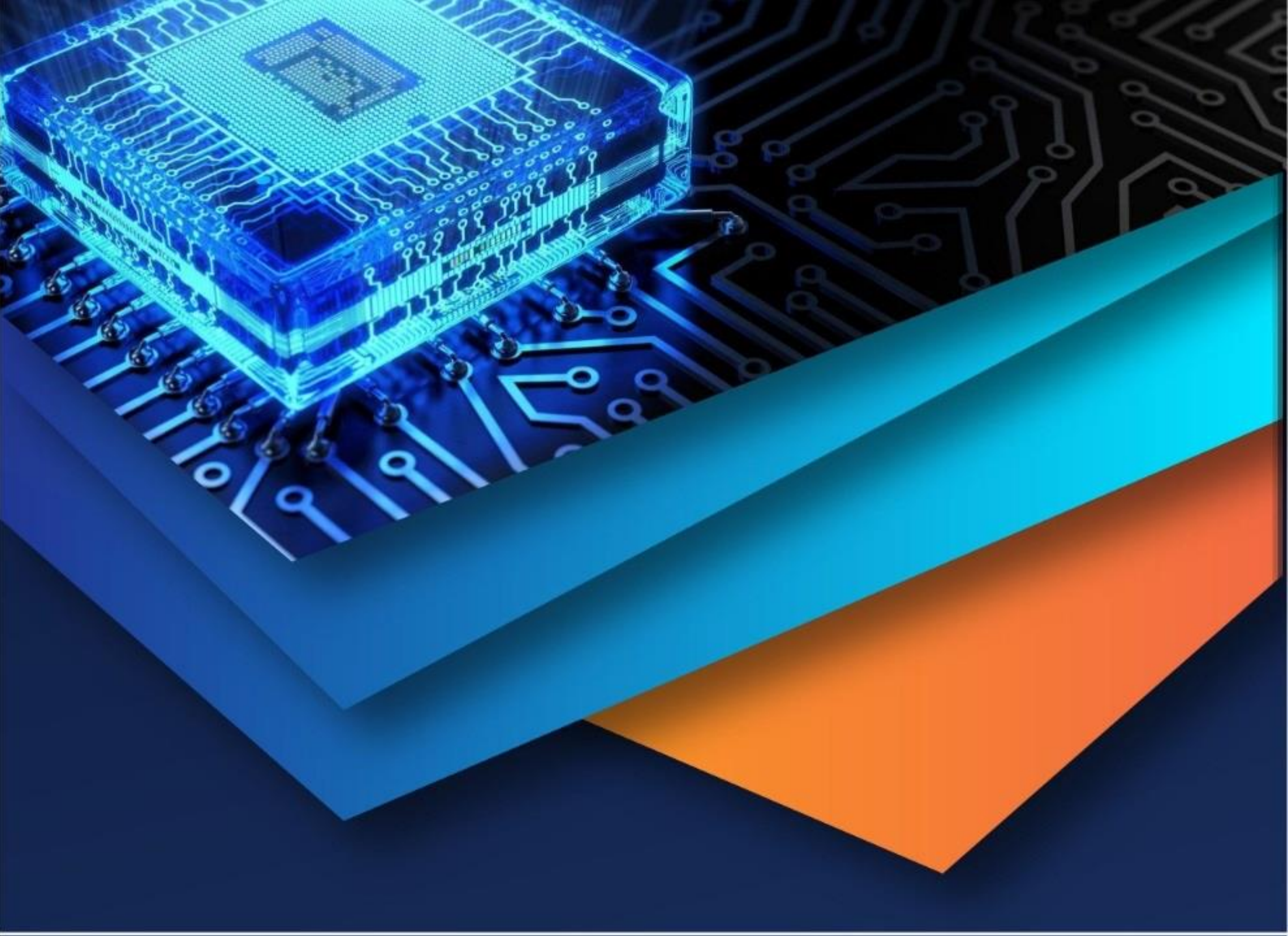

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