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Automated Toll Plaza

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Abstract: The rapid growth of vehicular traffic on Indian highways has exposed major limitations in conventional toll collection systems, including long queues, manual cash handling, and service disruptions. This paper presents a smart automated toll gate system that integrates RFID-based toll collection with vehicle monitoring and driver assistance features to improve traffic flow and user experience. The proposed system enables automated toll deduction while allowing controlled vehicle passage even in cases of insufficient balance, thereby preventing congestion. An in-vehicle interface provides real-time balance notifications and service request options for fuel, mechanical help, or towing. Additionally, an idle monitoring mechanism detects stalled vehicles and initiates polite alerts to maintain lane efficiency. The system is designed to be modular, low-cost, and compatible with existing FASTag infrastructure, making it suitable for practical deployment in real-world toll plazas.

Keywords: RFID, Automated Toll Collection, Intelligent Transportation Systems, Vehicle Monitoring, Driver Assistance System, FASTag, Embedded Systems, Smart Toll Plaza

I. INTRODUCTION

Toll collection systems are a vital component of highway transportation infrastructure, directly influencing traffic flow, fuel efficiency, and commuter experience. Despite the adoption of electronic toll collection methods such as FASTag in India, toll plazas continue to face challenges including unreadable RFID tags, insufficient account balance, network latency, and limited driver communication, which often result in congestion and delays. The increasing volume of vehicles on highways has further intensified these issues, making toll booths significant bottlenecks. Moreover, toll plazas frequently serve as informal assistance points for vehicles facing fuel or mechanical issues, yet existing systems lack structured mechanisms to manage such scenarios efficiently. To overcome these limitations, this work proposes a smart automated toll gate system that integrates RFID-based toll collection with vehicle monitoring and driver assistance features. The proposed system enhances lane throughput, reduces manual intervention, and improves overall toll plaza efficiency while remaining compatible with existing FASTag infrastructure.

II. PROBLEM STATEMENT AND OBJECTIVE

Despite the deployment of electronic toll collection systems such as FASTag, toll plazas in India continue to experience operational inefficiencies due to unreadable RFID tags, insufficient account balance, network latency, and limited driver–system communication. These issues often result in manual intervention, vehicle stoppages, and long queues, significantly reducing lane throughput and increasing fuel consumption and emissions. Existing toll systems primarily focus on payment authorization and barrier control, while overlooking real-time driver assistance, stalled vehicle management, and structured communication within the toll plaza environment. Moreover, the absence of a flexible passage policy during low-balance scenarios leads to congestion that propagates across multiple lanes. Therefore, there is a need for an intelligent, integrated toll management system that automates toll collection while ensuring smooth traffic flow, driver support, and operational resilience without compromising safety or privacy.

Objectives:

- To design and develop a smart automated toll gate system using RFID technology for efficient and contactless toll collection.
- To implement a permissive-pass mechanism that allows controlled vehicle movement during low-balance conditions while providing private in-vehicle notifications.
- To integrate vehicle monitoring and driver assistance features, enabling structured requests for fuel, mechanical help, and towing services.
- To reduce toll plaza congestion and lane dwell time through automated identification, real-time communication, and idle vehicle detection.
- To ensure system scalability, cost-effectiveness, and compatibility with existing FASTag infrastructure while maintaining data security and user privacy.

III. SCOPE

The scope of this project is limited to the design and implementation of a smart automated toll gate system that integrates RFID-based toll collection with vehicle monitoring and driver assistance features. The system focuses on improving toll plaza efficiency by enabling automated identification, controlled vehicle passage during low-balance conditions, and real-time in-vehicle communication. It includes structured service request handling for fuel assistance, mechanical help, and towing, along with idle vehicle detection to reduce lane congestion. The proposed solution is designed as a modular, low-cost prototype compatible with existing FASTag infrastructure, making it suitable for scalable deployment across highway toll plazas. The scope does not include advanced computer vision-based vehicle recognition or full nationwide backend integration, which may be considered for future enhancements.

IV. LITERATURE REVIEW

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4.1 Gaps or Areas for Improvement

Existing electronic toll collection systems primarily emphasize automated payment and barrier control, with limited consideration for real-time driver communication and lane-level traffic management. Most RFID-based tolling solutions adopt a strict access-control policy that blocks vehicles with insufficient balance, often resulting in congestion and cascading delays across multiple lanes. Additionally, current systems lack integrated mechanisms to handle stalled vehicles or driver assistance requests in a structured and automated manner, relying instead on manual intervention or external helplines.

Camera-based and sensor-driven congestion management approaches, although effective in controlled environments, suffer from high deployment costs, sensitivity to environmental conditions, and scalability challenges. In-vehicle assistance systems developed in prior work operate independently of toll infrastructure, leading to fragmented workflows and delayed response times. Furthermore, limited research has explored privacy-preserving, in-cabin notification mechanisms that provide persistent and private alerts without distracting drivers or exposing personal information. These gaps highlight the need for an integrated, low-cost, and intelligent toll management system that combines permissive passage, driver assistance, and idle vehicle monitoring while maintaining compatibility with existing FASTag infrastructure.

V. SYSTEM ARCHITECTURE

The proposed system architecture consists of a vehicle-side unit, an embedded controller, a backend server, and a web-based monitoring interface. The vehicle unit integrates RFID, GPS, and a keypad module to uniquely identify the vehicle, capture location data, and support driver inputs. These components communicate with the Arduino-based controller through UART communication, enabling reliable data exchange and preprocessing at the edge. A NodeMCU (ESP8266) module provides Wi-Fi connectivity for transmitting processed data to the backend server.

The backend system is implemented using a Flask-based REST API that handles toll processing logic, emergency requests, and communication with the database. Vehicle and transaction details are securely stored in a MySQL database, including user information and wallet balances. An admin web dashboard interfaces with the backend to allow real-time monitoring of vehicle movements, toll transactions, and emergency alerts. This layered architecture ensures modularity, scalability, and seamless integration with existing electronic toll collection infrastructure.

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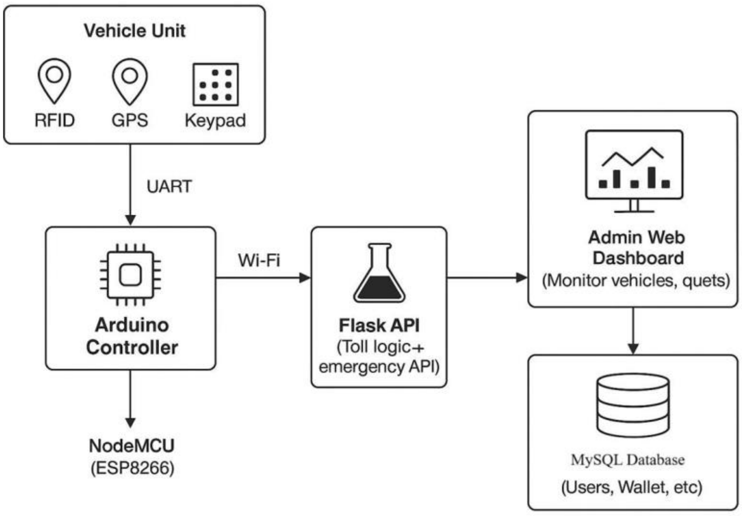

Figure 1. System Architecture

VI. METHODOLOGY

The proposed Automated Toll Plaza system follows a layered methodology that begins with vehicle identification and ends with centralized monitoring and decision support. The major stages of operation are designed to ensure fast toll processing, smooth traffic flow, and real-time driver assistance. The overall workflow of the system is described below.

A. Overall Workflow

When a vehicle enters the toll plaza, its RFID tag is detected automatically without requiring the vehicle to stop. The identification data is processed by the embedded controller and transmitted to the backend server through a wireless communication module. Based on toll authorization and wallet balance, the system allows vehicle passage while simultaneously providing feedback to the driver. All activities are logged and monitored through an administrative dashboard for supervision and analysis.

B. Data Collection and Preprocessing

Vehicle-related data is collected in real time using hardware components installed at the toll plaza. The primary data elements include:

- RFID tag identification number,
- Vehicle location data obtained from the GPS module,
- Driver-generated inputs from the keypad (emergency requests),
- Timestamp of vehicle entry and exit.

C. Toll Logic and System Processing

The backend system processes the collected data to perform toll authorization and transaction handling. Wallet balance verification, toll deduction, and low-balance handling are executed according to predefined rules. Additional system functions such as idle vehicle detection, emergency request handling, and driver notification are also processed at this stage. The processed information is stored in the database and displayed on the admin dashboard, enabling real-time monitoring and effective toll plaza management.

6.1. Requirement Analysis and System Definition

The first stage involves defining system requirements based on toll plaza operational challenges such as congestion, manual intervention, insufficient balance handling, and lack of driver assistance. Functional requirements include automatic vehicle identification, toll deduction, driver notification, emergency handling, and idle vehicle monitoring. Non-functional requirements such as reliability, low latency, scalability, and data security are also identified. The system is designed to function as an automated toll management solution with minimal human intervention while supporting operator supervision.

6.2. Vehicle Identification and Data Acquisition

Each vehicle is equipped with a passive RFID tag linked to a prepaid wallet. When the vehicle enters the toll zone, the RFID reader detects the tag and extracts the unique identification number. Additional inputs such as GPS location data and driver-generated keypad inputs (for emergencies) are captured at this stage. All collected data is transmitted to the Arduino controller via UART communication for further processing.

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6.3. Embedded Processing and Communication

The Arduino controller performs initial validation and formatting of the received data. Processed information is forwarded to the NodeMCU (ESP8266) module, which establishes Wi-Fi communication with the backend server. This stage ensures fast, reliable, and continuous data transfer between the toll lane hardware and centralized processing units. Temporary buffering mechanisms are used to prevent data loss during network interruptions.

6.4. Toll Logic and Backend Processing

The backend system, implemented using a Flask-based REST API, handles toll computation and authorization. Wallet balance is verified from the database, and toll deduction is performed according to predefined rules. If the balance is insufficient, the system allows controlled passage while recording the transaction and issuing a recharge notification. All transaction details, alerts, and vehicle logs are stored in a MySQL database for consistency and auditability.

6.5. Driver Notification and Assistance Handling

Real-time feedback is provided to drivers through an in-vehicle LCD display. Messages such as toll deduction confirmation, low balance warnings, and operational instructions are displayed automatically. In case of emergencies such as fuel shortage or mechanical breakdown, drivers can generate assistance requests using the keypad. These requests are processed by the backend and forwarded to toll operators or service providers for prompt response.

6.6. Idle Vehicle Detection and Traffic Management

The system continuously monitors the time a vehicle spends within the toll zone. If a vehicle remains stationary beyond a predefined threshold, it is identified as idle. Notifications are sent to the driver and operators to initiate corrective action. This mechanism prevents lane blockage and ensures smooth traffic flow during peak hours.

6.7. Monitoring, Logging, and System Supervision

An admin web dashboard provides real-time visualization of vehicle movement, toll transactions, emergency alerts, and idle vehicle status. Operators can monitor system performance and intervene when necessary. All operational data is logged securely for analysis, auditing, and future optimization. This stage ensures transparency, accountability, and effective toll plaza management.

VII. IMPLEMENATION ENVIRONMENT

The implementation of the Automated Toll Plaza system integrates embedded hardware, wireless communication, backend services, and database management to enable seamless toll operations and driver assistance. When an RFID-tagged vehicle enters the toll zone, the RFID reader captures the tag ID and forwards it to the Arduino controller, which communicates the data to the NodeMCU (ESP8266) via UART. The NodeMCU establishes Wi-Fi connectivity and transmits the data in JSON format to the Flask-based backend server through REST APIs. The backend validates the tag, retrieves vehicle and wallet details from the MySQL database, and processes entry or exit events accordingly. Toll deductions are performed during exit, while low or insufficient balance cases are handled using a permissive-pass approach to maintain uninterrupted traffic flow.

The system also supports driver assistance and traffic management through emergency handling and idle vehicle monitoring. Emergency requests generated using the keypad are combined with GPS coordinates and transmitted to the backend, where they are logged and displayed on the admin dashboard for immediate response. An idle-time monitoring mechanism periodically checks vehicle timestamps and sends alerts to drivers if prolonged inactivity is detected within the toll zone. Real-time feedback such as toll status, balance alerts, emergency confirmations, and idle warnings is displayed on the in-vehicle LCD. The admin dashboard provides centralized monitoring of transactions, emergency alerts, and vehicle activity, ensuring efficient toll plaza supervision and long-term data management.

VIII. MODULES

8.1 User Authentication Module

To manage access for different users, ensuring that only authorized personnel can access sensitive system features.

8.2 RFID-Based Toll Collection Module

Automates toll payments using RFID tags to reduce congestion at toll plazas.

8.3 Wallet Management Module

Handles account balances, deductions, recharges, and notifications.

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8.4 Driver Assistance Module
Provides real-time support to drivers facing emergencies.

8.5 GPS Tracking Module
Monitors vehicle location in real-time for emergencies and traffic management.

8.6 Idle Vehicle Monitoring Module
Prevents lane congestion by identifying vehicles that remain stationary in toll areas.

8.7 Admin Dashboard Module
Provides a centralized control and monitoring interface for toll plaza operators.

8.8 Notification System Module
Keeps drivers informed and reduces manual intervention.

IX. PERFORMANCE EVALUATION

The prototype Automated Toll Plaza system is implemented using commonly available embedded hardware and open-source software tools to ensure ease of reproduction, testing, and future enhancement. The system performance is evaluated based on real-time responsiveness, reliability of RFID detection, accuracy of toll transactions, and effectiveness of driver assistance features.

A. Technology Stack
The core components used for implementation and evaluation are as follows:

- **Embedded Hardware:** Arduino Nano is used for local control and sensor interfacing, while NodeMCU (ESP8266) provides wireless communication. RFID readers, GPS modules, LCD displays, keypads, and indicators support vehicle identification and driver interaction.
- **Backend:** Python with Flask is used to implement REST APIs for toll processing, emergency handling, idle vehicle detection, and communication with field devices.
- **Database:** MySQL is used to store vehicle records, RFID details, wallet balances, transaction logs, emergency requests, and timestamps for auditing and analysis.
- **Frontend:** A web-based admin dashboard developed using HTML, CSS, and JavaScript displays real-time vehicle activity, balance status, emergency alerts, and system logs.
  This technology stack ensures low latency, platform independence, and reliable real-time system operation.

B. Modular Design
The system is designed using a modular architecture to simplify testing, maintenance, and performance evaluation. The major modules include:

- **RFID Detection and Vehicle Identification Module**, responsible for fast and accurate tag reading,
- **Toll Processing and Wallet Management Module**, which handles balance verification, toll deduction, and low- balance scenarios,
- **Wireless Communication Module**, ensuring reliable data transfer between hardware and backend services,
- **Driver Assistance and Emergency Handling Module**, used for processing emergency requests and GPS-based location reporting,
- **Idle Vehicle Monitoring Module**, which detects prolonged vehicle stoppage within the toll zone,
- **Admin Dashboard and Reporting Module**, enabling real-time supervision and operational analysis.

X. CONCLUSION

The Automated Toll Plaza system presented in this work demonstrates an efficient and intelligent approach to modern toll management by integrating RFID technology, embedded systems, wireless communication, and backend web services. The proposed system successfully automates vehicle identification and toll deduction while minimizing manual intervention and reducing traffic congestion at toll plazas. By introducing real-time driver notifications, permissive low-balance handling, emergency assistance, and idle vehicle monitoring, the system enhances both traffic flow and driver safety.

The experimental implementation and performance evaluation show that the proposed solution significantly reduces toll processing time and improves vehicle throughput compared to conventional toll collection methods. The modular and

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scalable architecture allows seamless integration with existing FASTag-based infrastructure while supporting future enhancements. Overall, the system provides a practical, cost-effective, and reliable solution for intelligent toll plaza management and can be extended to applications such as parking systems, gated communities, and smart transportation networks.

10.1 Future work

The proposed Automated Toll Plaza system can be further enhanced by integrating advanced communication technologies such as Dedicated Short-Range Communication (DSRC) or 5G-based vehicle-to-infrastructure (V2I) systems to support high-speed and multi-lane toll operations. Future versions may include mobile application integration to provide drivers with real-time notifications, digital wallet management, and remote recharge facilities. Machine learning techniques can be incorporated to predict traffic congestion, identify abnormal vehicle behavior, and optimize lane allocation dynamically during peak hours.

Additionally, the system can be extended with advanced sensing mechanisms such as camera-based vehicle classification or low-cost radar to improve idle vehicle detection accuracy. Stronger security mechanisms, including encrypted RFID authentication and anomaly detection, can be introduced to mitigate cloning and fraud risks. With these enhancements, the proposed architecture can be scaled for nationwide toll deployment and adapted for related applications such as smart parking systems, gated communities, fuel stations, and intelligent transportation infrastructure.

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