EMBEDDED PUBLIC TRANSPORT TICKETING SYSTEM WITH DYNAMIC FARE & CONTACTLESS PAYMENT

[1] Mr. P Sarath Pawar, [2] Erramekala Ammulu, [3] Alampalli Manasa, [4] R Harikrishna, [5] Dayyala Naga Dathu
[1] Assistant Professor, [2345] B. Tech Students
[12345]Department of Electronics and Communication Engineering
[12345]Sree Dattha Group of Institutions, Sheriguda, Ibrahimpatnam, 501510, Telangana, India

ABSTRACT

The Embedded Public Transport Ticketing System with Dynamic Fare and Contactless Payment is a smart solution designed to modernize public transportation fare collection while improving efficiency, convenience, and security. Traditional ticketing methods in buses, trains, and metro systems rely on paper tickets, cash payments, or manual card swipes, which are prone to errors, delays, and fraud. This project integrates embedded systems, IoT technology, and contactless payment methods to provide a seamless, real-time ticketing experience. Passengers can pay fares using RFID/NFC cards, mobile apps, or smart tokens, enabling cashless transactions. The system dynamically calculates fares based on travel distance, time, and zone-based pricing models. Embedded microcontrollers such as ESP32/Arduino monitor passenger entry and exit points, communicate with cloud servers, and update fare deductions in real time. IoT integration allows centralized data storage, reporting, and analytics for transport authorities. Contactless payments reduce physical contact, ensuring hygiene and safety. The system supports real-time occupancy monitoring, preventing overcrowding and optimizing fleet management. Dynamic fare calculation encourages fair pricing, peak-hour management, and promotional schemes. Security is ensured through encrypted data transfer, authentication of cards or devices, and secure cloud communication. Historical data enables operational analysis, fraud detection, and performance optimization. Modular design allows integration with vehicle tracking, passenger feedback systems, and automated alerts. Overall, this embedded ticketing system improves passenger convenience, operational efficiency, revenue management, and safety in public transportation.

I. INTRODUCTION

1.1 Overview

Public transportation systems play a vital role in urban mobility, economic development, and environmental sustainability. Buses, metro rail systems, suburban trains, and trams transport millions of passengers daily. However, fare collection remains one of the most critical operational aspects of public transport management. Efficient ticketing systems directly influence revenue collection, passenger convenience, service reliability, and operational transparency. Traditional ticketing systems, which rely heavily on paper tickets, manual validation, or cash-based transactions, are increasingly becoming inefficient in the face of rapid urbanization and technological advancement.

With the emergence of embedded systems, Internet of Things (IoT), and digital payment technologies, there is a significant opportunity to modernize public transportation ticketing mechanisms. The Embedded Public Transport Ticketing System with Dynamic Fare and Contactless Payment aims to provide a smart, automated, and scalable solution for fare collection. By integrating microcontrollers, RFID/NFC technology, cloud computing, and contactless payment systems, the proposed system enhances operational efficiency, reduces revenue leakage, and improves passenger convenience.

1.2 Background of the Study

Historically, public transport ticketing systems have evolved from manual ticket issuance to semi-automated systems involving smart cards and electronic ticket machines (ETMs). In many regions, conductors manually issue tickets and collect cash, which often leads to accounting discrepancies, human errors, and fraud. Even in systems using electronic card swiping, fixed fare structures limit flexibility and do not account for dynamic pricing strategies such as peak-hour fares or distance-based charging.

The introduction of RFID (Radio Frequency Identification) and NFC (Near Field Communication) technologies has enabled contactless transactions in various sectors, including banking and retail. These technologies are fast, secure, and reduce physical interaction. Similarly, IoT platforms allow real-time communication between embedded devices and centralized cloud servers, facilitating remote monitoring, analytics, and reporting.

Despite these advancements, many public transportation systems still lack fully integrated dynamic fare calculation and real-time occupancy management. There is a growing need for a unified embedded solution that combines contactless payment, dynamic fare computation, secure communication, and centralized data analytics.

1.3 Need for the Project

The need for the Embedded Public Transport Ticketing System arises from multiple challenges faced by conventional fare collection methods.

Firstly, cash-based systems are prone to revenue leakage and fraud. Manual ticketing increases the possibility of incorrect fare collection, unrecorded transactions, and manipulation. A digital, automated system minimizes human intervention and enhances transparency.

Secondly, urban populations are increasing rapidly, leading to overcrowded public transportation systems. Efficient ticket validation and faster boarding processes are necessary to reduce congestion and improve passenger flow. Contactless payment significantly reduces transaction time compared to manual ticketing.

Thirdly, traditional fixed fare systems do not reflect dynamic pricing models. In many cities, fare structures remain constant regardless of peak hours, travel distance, or zone-based policies. A dynamic fare calculation mechanism ensures fair pricing and allows authorities to implement demand-based pricing strategies.

Fourthly, hygiene and safety concerns, especially after global health crises, emphasize the importance of contactless transactions. Minimizing physical contact during ticketing enhances passenger safety.

Fifthly, transport authorities require real-time operational data for decision-making. Data analytics can help in occupancy monitoring, route optimization, and revenue analysis. Conventional systems lack centralized data integration and reporting capabilities.

Therefore, a smart embedded ticketing system integrating IoT and contactless technology is essential to modernize public transportation infrastructure.

1.4 Problem Statement

Despite technological advancements in transportation systems, fare collection processes remain inefficient in many regions. Manual ticketing systems suffer from delays, cash mismanagement, and lack of accountability. Even semi-automated systems using card swipes may not support dynamic fare structures or real-time data synchronization.

Key problems identified include:

- Revenue leakage due to manual handling
- Lack of real-time occupancy monitoring
- Fixed fare models that do not adapt to distance or time-based pricing
- Slow boarding and alighting processes
- Limited centralized data analytics
- Security vulnerabilities in outdated systems
- Absence of integrated cloud-based monitoring

These challenges highlight the need for an embedded, automated, and IoT-enabled ticketing solution capable of supporting dynamic fare computation and secure contactless payments.

1.5 Objectives of the Project

The primary objective of this project is to design and implement an Embedded Public Transport Ticketing System with Dynamic Fare and Contactless Payment that enhances operational efficiency, passenger convenience, and revenue transparency.

The specific objectives are as follows:

- To develop an embedded system using microcontrollers such as ESP32 or Arduino for fare processing and communication.
- To integrate RFID/NFC technology for contactless ticket validation.
- To implement dynamic fare calculation based on travel distance, zones, and time-based pricing models.
- To enable real-time communication between embedded devices and cloud servers using IoT protocols.
- To design a centralized dashboard for transport authorities to monitor transactions and occupancy levels.
- To implement secure data encryption and authentication mechanisms.
- To support real-time occupancy tracking to prevent overcrowding.
- To provide scalable architecture suitable for buses, metro systems, and trains.

These objectives collectively aim to create a smart, efficient, and secure ticketing infrastructure.

1.6 Scope of the Project

The scope of the Embedded Public Transport Ticketing System includes the design, development, and testing of a prototype capable of handling contactless fare transactions and dynamic pricing. The system integrates hardware components such as RFID readers, microcontrollers, LCD displays, and communication modules, along with cloud-based data storage and analytics.

The project covers:

- Passenger entry and exit tracking
- Real-time fare calculation
- Contactless card validation
- Data transmission to cloud servers
- Centralized reporting dashboard
- Alert generation for system anomalies

However, the scope is limited to prototype-level implementation and does not include large-scale commercial deployment. Integration with national banking systems, GPS-based distance tracking, or biometric authentication can be considered future enhancements.

The modular design ensures scalability, allowing integration with vehicle tracking systems, automated passenger counting, and mobile payment applications in future versions.

II. LITERATURE SURVEY

2.1 Introduction

The modernization of public transportation systems has become a major research focus due to increasing urbanization, population growth, and the demand for efficient mobility solutions. Ticketing and fare collection systems form the backbone of transport operations, directly influencing revenue management, passenger convenience, and service efficiency. Over the years, ticketing systems have evolved from manual paper-based methods to electronic smart card systems and, more recently, to IoT-enabled and contactless payment solutions. This chapter reviews existing research and technological developments related to embedded ticketing systems, dynamic fare mechanisms, RFID/NFC-based contactless payment, IoT integration, and cloud-based transport analytics. The literature survey also identifies limitations in current systems and establishes the need for the proposed Embedded Public Transport Ticketing System with Dynamic Fare and Contactless Payment.

2.2 Traditional Ticketing Systems

Historically, public transport fare collection relied on paper tickets and manual cash handling. Conductors or ticket counters issued printed tickets after collecting cash from passengers. Although simple, these systems were prone to human errors, revenue leakage, and fraudulent practices. Studies show that manual systems increase boarding time, leading to congestion and reduced operational efficiency.

Researchers have highlighted additional challenges such as difficulty in maintaining transaction records, lack of transparency, and limited data availability for operational planning. Manual ticketing systems also involve high recurring costs related to paper printing, ticket distribution, and workforce management.

While traditional systems are still operational in many developing regions due to low infrastructure cost, they lack scalability and automation required for modern urban transport networks.

2.3 Electronic Ticketing and Smart Card Systems

To overcome the limitations of manual systems, Electronic Ticketing Machines (ETMs) and smart card-based fare systems were introduced. Smart cards use magnetic stripe or chip-based technology to store prepaid balances. These systems reduce cash handling and improve transaction recording accuracy.

Research indicates that smart card systems significantly reduce transaction time and enhance revenue tracking. However, early smart card systems operated in offline modes, storing transaction data locally until synchronized with central servers. This delayed real-time analytics and monitoring.

Moreover, most smart card implementations use fixed fare structures, where ticket prices do not dynamically adjust based on travel distance, time of day, or demand levels. This restricts flexibility in implementing peak-hour pricing or promotional discounts.

2.4 RFID and NFC-Based Contactless Payment Systems

Recent advancements in Radio Frequency Identification (RFID) and Near Field Communication (NFC) technologies have revolutionized fare collection systems. RFID cards enable contactless payment by allowing passengers to tap their card near a reader for instant validation. NFC technology further enhances flexibility by enabling smartphone-based ticketing applications.

Several research studies demonstrate that contactless systems improve passenger throughput, reduce waiting times, and minimize physical interaction. Contactless ticketing gained importance especially after global health concerns emphasized the need for hygienic, touch-free solutions.

However, many RFID-based systems are limited to fare validation and balance deduction without incorporating dynamic fare calculation models. Additionally, some implementations lack secure cloud synchronization, exposing systems to potential security risks.

2.5 IoT Integration in Public Transportation

The integration of Internet of Things (IoT) technology into public transportation has opened new possibilities for real-time monitoring and centralized data management. IoT-enabled ticketing systems connect embedded devices in vehicles to cloud servers using wireless communication protocols such as MQTT and HTTP.

Research shows that IoT integration allows transport authorities to monitor ticket transactions, vehicle occupancy levels, and revenue collection in real time. Centralized dashboards provide data analytics, enabling improved route planning and operational efficiency.

However, some IoT-based systems face challenges related to network reliability, data latency, and cybersecurity vulnerabilities. Secure data transmission and encrypted communication protocols are essential for preventing fraud and unauthorized access.

2.6 Dynamic Fare Pricing Models

Dynamic fare pricing has been widely studied in transportation economics. Traditional fare systems use flat-rate or zone-based pricing models. However, research suggests that dynamic pricing—based on travel distance, time of travel, and passenger demand—improves revenue optimization and congestion management.

Peak-hour pricing strategies encourage off-peak travel, reducing overcrowding during high-demand periods. Distance-based fare models ensure fairness by charging passengers according to actual travel distance. Studies indicate that dynamic pricing enhances operational sustainability and balances passenger distribution.

Despite its advantages, dynamic fare implementation requires accurate entry and exit tracking, real-time data processing, and secure billing mechanisms. Many existing ticketing systems do not support automated dynamic fare computation within embedded platforms.

III. SYSTEM ANALYSIS

3.1 Introduction

System analysis is an essential phase in the design and development of any embedded or IoT-based solution. It involves studying the current operational methods, identifying limitations, and proposing an improved system that addresses existing challenges. In the context of public transportation, ticketing systems directly impact revenue management, passenger convenience, operational efficiency, and service transparency. With rapid urbanization and increasing passenger volumes, traditional fare collection mechanisms are becoming inadequate.

This chapter presents a comprehensive analysis of the existing public transport ticketing systems and their disadvantages. It further introduces the proposed Embedded Public Transport Ticketing System with Dynamic Fare and Contactless Payment, highlighting its advantages and improvements over conventional methods.

3.2 Existing System

Public transportation systems across many regions primarily rely on traditional or semi-automated ticketing mechanisms. These can be categorized into manual ticketing systems and electronic ticketing systems.

3.2.1 Manual Cash-Based Ticketing System

In manual ticketing systems, conductors collect cash from passengers and issue printed paper tickets. In railway stations or bus terminals, ticket counters are used where passengers stand in queues to purchase tickets. This system operates entirely through human intervention. Fare calculation is often fixed or zone-based, and conductors manually verify tickets during travel. Although simple to implement, this method is outdated and inefficient in handling large passenger volumes.

3.2.2 Electronic Ticketing Machines (ETMs)

Electronic Ticketing Machines were introduced to reduce human errors and improve revenue tracking. Conductors use handheld devices to generate printed tickets after entering journey details. While this reduces manual record-keeping, the system still relies heavily on cash payments.

Data from ETMs is typically uploaded to central servers at the end of shifts rather than in real time. This causes delays in reporting and prevents live monitoring.

3.2.3 Smart Card-Based Systems

Some urban transport systems use prepaid smart cards. Passengers swipe their cards at entry points, and the fare is deducted automatically. These systems improve convenience and reduce cash handling.

However, many smart card systems operate with fixed fare models and do not support dynamic pricing based on distance or peak-hour demand. Additionally, offline validation systems may delay synchronization with central databases.

3.3 Disadvantages of Existing System

Despite technological upgrades over time, current ticketing systems exhibit several limitations.

One major disadvantage is revenue leakage. Manual systems are vulnerable to fraud, incorrect fare collection, and manipulation. Cash transactions increase the risk of mismanagement and accounting discrepancies.

Another significant limitation is slow boarding processes. Passengers must wait while conductors issue tickets or verify payments, leading to congestion and increased travel time. In busy metropolitan areas, this delay reduces overall transport efficiency.

Traditional systems also lack real-time monitoring capabilities. Transport authorities cannot access live transaction data or occupancy information. Decision-making related to route optimization or fleet management becomes reactive rather than proactive.

Fixed fare structures represent another drawback. Passengers traveling short distances may pay the same fare as those traveling longer distances within the same zone. This reduces fairness and discourages efficient fare distribution. Moreover, peak-hour demand cannot be regulated through dynamic pricing.

Security vulnerabilities further affect electronic systems. Card cloning, unauthorized access, and lack of encryption mechanisms can compromise financial data. Older systems often lack secure cloud integration and authentication protocols.

Another limitation is absence of centralized analytics. Historical data analysis for passenger trends, route demand, and revenue forecasting is either limited or unavailable in manual systems.

Hygiene concerns also arise in cash-based transactions, especially in situations requiring minimal physical contact. Physical exchange of currency increases health risks.

Scalability is another challenge. Expanding traditional systems to new routes or integrating them with modern digital platforms requires significant infrastructure investment.

These disadvantages highlight the need for a comprehensive embedded solution capable of addressing operational inefficiencies, enhancing security, and supporting dynamic fare mechanisms.

3.4 Proposed System

The proposed Embedded Public Transport Ticketing System with Dynamic Fare and Contactless Payment is designed to overcome the limitations of existing systems. It integrates embedded microcontrollers, RFID/NFC technology, IoT connectivity, and cloud-based data analytics to provide a smart and automated ticketing solution.

In this system, passengers use RFID cards, NFC-enabled smartphones, or smart tokens to make contactless payments. The embedded controller installed in buses or stations validates passenger entry and exit in real time. Fare calculation is performed dynamically based on parameters such as travel distance, time of day, and zone classification.

The microcontroller communicates with cloud servers via Wi-Fi or cellular networks using secure IoT protocols. Transaction data is updated instantly in centralized databases, allowing transport authorities to monitor operations in real time.

The system also supports occupancy tracking by counting passenger entries and exits. This information helps prevent overcrowding and supports fleet optimization.

Security mechanisms such as encrypted communication, secure API authentication, and device verification ensure safe transactions. The modular architecture allows integration with GPS tracking, mobile applications, and centralized dashboards.

3.5 Advantages of Proposed System

The proposed system provides multiple advantages compared to conventional ticketing systems.

Firstly, it enables real-time dynamic fare calculation. Fare is computed automatically based on actual travel distance and time, ensuring fairness and transparency. Peak-hour pricing models can be implemented to manage demand effectively.

Secondly, contactless payment enhances passenger convenience and reduces boarding time. Transactions are completed within seconds, minimizing congestion at entry points.

Thirdly, revenue management becomes transparent and secure. All transactions are recorded digitally and transmitted to the cloud, eliminating revenue leakage and fraud.

Fourthly, real-time occupancy monitoring helps authorities manage passenger flow and optimize vehicle allocation. This improves service efficiency and passenger safety.

Fifthly, cloud-based analytics enable historical data analysis, performance evaluation, and predictive planning. Authorities can generate revenue reports, monitor route demand, and detect anomalies.

Sixthly, enhanced security measures protect against unauthorized access and data tampering. Encryption protocols safeguard sensitive financial information.

Seventhly, scalability and modular design allow expansion to multiple vehicles and routes without major infrastructure changes. The system can be integrated into smart city frameworks.

Eighthly, hygiene and safety are improved through contactless transactions, reducing physical contact between passengers and conductors.

Finally, automation reduces dependency on manual labor, lowering operational costs in the long term.

IV. HARDWARE CONTROLLER

Arduino Uno

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter. Uno board has a resistor pulling the 8U2 HWB line to ground, making it easier to put into DFU mode.Arduino board has the following new features:

1.0 pinout: added SDA and SCL pins that are near to the AREF pin and two other new pins placed near to the RESET pin, the IOREF that allow the shields to adapt to the voltage provided from the board. In future, shields will be compatible both with the board that use the AVR, which operate with 5V and with the Arduino Due that operate with 3.3V. The second one is a not connected pin, that is reserved for future purposes.

- Stronger RESET circuit.
- Atmega 16U2 replace the 8U2.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions, see the index of Arduino boards.

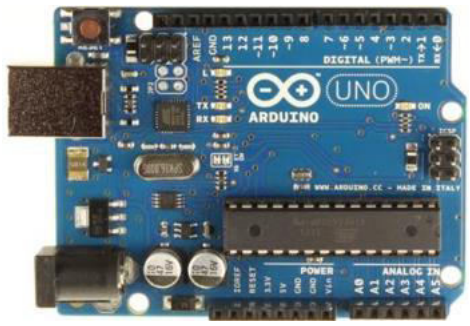


Fig: ARDUINO UNO

WIFI MODULE

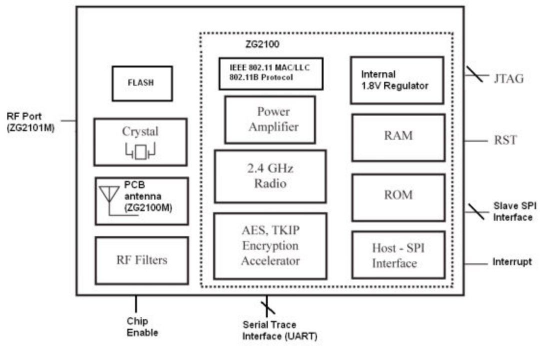
Description

The ZG2100M & ZG2101M modules are low-power 802.11b implementations. All RF components, the baseband and the entirety of the 802.11 MAC reside on-module, creating a simple and cost-effective means to add Wi-Fi connectivity for embedded devices. The module(s) implement a high-level API, simplifying design implementation and allowing the ZG2100M or ZG2101M to be integrated with 8- and 16-bit host microcontrollers.

Features

- Single-chip 802.11b including MAC, baseband, RF and power amplifier
- Data Rate: 1 & 2 Mbps
- 802.11b/g/n compatible
- Low power operation
- API for embedded markets, no OS required
- PCB or external antenna options

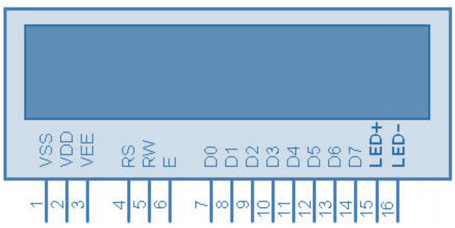
• Hardware support for AES and RC4 based ciphers (WEP, WPA, WPA2 security)
• SPI slave interface with interrupt
• Single 3.3V supply, operates from 2.7V to 3.6V (see section 5)
• 21mm x 31mm 36-pin Dual Flat pack PCB SM Package
• Wi-Fi Certified, RoHS and CE compliant
• FCC Certified (USA, FCC ID: W7O-ZG2100-ZG2101)
• IC Certified (IC: 8248A-G21ZEROG)
• Fully compliant with EU & meets the R&TTE Directive for Radio Spectrum



ALPHANUMERIC LCD

Liquid Crystal Display also called as LCD is very helpful in providing user interface as well as for debugging purpose. The most commonly used Character based LCDs are based on Hitachi's HD44780 controller or other which are compatible with HD44580. The most commonly used LCDs found in the market today are 1 Line, 2 Line or 4 Line LCDs which have only 1 controller and support at most of 80 characters, whereas LCDs supporting more than 80 characters make use of 2 HD44780 controllers.

Pin Description



BUZZER

What is a Buzzer: Working & Its Applications

There are many ways to communicate between the user and a product. One of the best ways is audio communication using a buzzer IC. So during the design process, understanding some technologies with configurations is very helpful. So, this article discusses an overview of an audio signaling device like a beeper or a buzzer and its working with applications.

What is a Buzzer?

An audio signalling device like a beeper or buzzer may be electromechanical or piezoelectric or mechanical type. The main function of this is to convert the signal from audio to sound. Generally, it is powered through DC voltage and used in timers, alarm devices, printers, alarms, computers, etc. Based on the various designs, it can generate different sounds like alarm, music, bell & siren.

V. METHODOLOGY & IMPLEMENTATIONS

5.1 Introduction

This chapter describes the methodology adopted for the design and implementation of the **Embedded Public Transport Ticketing System with Dynamic Fare & Contactless Payment**. The methodology explains the step-by-step development process, including hardware design, software development, communication setup, dynamic fare algorithm implementation, and system integration. The implementation combines embedded systems, RFID technology, motorized gate control, IoT communication, and cloud-based monitoring to provide a smart and automated ticketing solution.

5.2 Overall Methodology

The development of the system follows a structured engineering approach:

1. Requirement Analysis

2. Component Selection
3. Hardware Design and Integration
4. Firmware Development
5. Dynamic Fare Algorithm Design
6. IoT Communication Setup
7. Cloud Integration
8. Testing and Validation

Each stage ensures the system meets performance, reliability, and security standards required for public transport applications.

5.3 Hardware Implementation

The hardware implementation involves integrating various components to create a working prototype.

5.3.1 Controller Setup

A microcontroller such as **ESP32** or **Arduino** is used as the central processing unit. It manages RFID validation, dynamic fare calculation, LCD display updates, motor control, buzzer alerts, and cloud communication.

The ESP32 is preferred due to:

- Built-in WiFi capability
- Faster processing speed
- Multiple GPIO pins
- Support for secure communication

5.3.2 RFID Reader Integration

An RFID reader module (e.g., MFRC522) is connected to the controller via SPI communication. Each passenger RFID tag contains a unique ID linked to a database account.

Working steps:

- Passenger taps card.
- RFID reader reads UID.
- Controller verifies UID in database.
- Fare calculation begins.

5.3.3 Motor and Gate Mechanism

A servo motor or DC motor is used to control gate movement. The motor is connected through a motor driver circuit (e.g., L298N).

After successful fare validation:

- Controller sends PWM signal to motor.
- Gate opens for entry.
- After delay, gate closes automatically.

This ensures controlled passenger access.

5.3.4 LCD Display

A 16x2 LCD is interfaced to display:

- Passenger ID
- Fare deducted
- Remaining balance
- Access status

This improves transparency and passenger interaction.

5.3.5 Buzzer

The buzzer provides audio feedback:

- Short beep → Valid transaction
- Continuous beep → Invalid card or low balance

5.3.6 Power Supply

A regulated 5V power supply powers all components. Voltage regulators ensure stable operation. For vehicle installations, power is drawn from the vehicle battery with proper regulation.

5.4 Software Implementation

5.4.1 Firmware Development

The firmware is developed using **Arduino IDE** with Embedded C/C++ programming. The program includes:

- RFID authentication routine
- Dynamic fare calculation function
- Motor control logic
- LCD display function
- WiFi connection setup
- Cloud data transmission

The controller runs continuously in a loop to handle passenger transactions.

5.5 Dynamic Fare Calculation Algorithm

The dynamic fare is calculated based on:

- Distance traveled
- Zone classification
- Time of travel (peak/off-peak)

Example algorithm logic:

- Base Fare = Fixed minimum amount
- Additional Fare = Distance × Rate per km
- Peak Multiplier = Applied during peak hours
- Total Fare = Base Fare + Additional Fare × Multiplier

The system deducts fare automatically during exit validation.

This algorithm ensures fair pricing and demand-based revenue optimization.

5.6 IoT Communication Implementation

5.6.1 WiFi Configuration

The ESP32 connects to a WiFi network using SSID and password credentials stored in firmware.

5.6.2 Data Transmission

Transaction data is sent to the cloud server using:

- HTTP POST requests
- MQTT protocol

Data transmitted includes:

- Passenger ID
- Fare deducted
- Remaining balance
- Timestamp
- Vehicle ID

Secure communication (HTTPS/SSL) ensures data integrity.

5.7 Cloud and Server Implementation

A cloud platform (e.g., Firebase or custom server) stores and manages transaction data.

Features Implemented:

- Real-time transaction logging
- Revenue monitoring dashboard
- Occupancy monitoring
- Fraud detection alerts
- Historical data storage

Transport authorities can access dashboards via web interface.

5.8 Notification System Implementation

Notifications are triggered in scenarios such as:

- Low balance alert
- Transaction confirmation
- System malfunction
- Overcrowding detection

Notifications are sent via:

- Mobile app push notifications
- SMS alerts
- Admin dashboard alerts

5.9 System Working Procedure

The complete operational flow is:

1. System powered ON.
2. Controller initializes RFID, WiFi, LCD, and motor.
3. Passenger taps RFID card.
4. Card ID verified.
5. Dynamic fare calculated.
6. If valid → Fare deducted → LCD updated → Buzzer beep → Motor opens gate.
7. Data transmitted to cloud.
8. Notification generated if required.
9. Gate closes after delay.
10. System waits for next passenger.

This process repeats continuously.

5.10 Testing and Validation

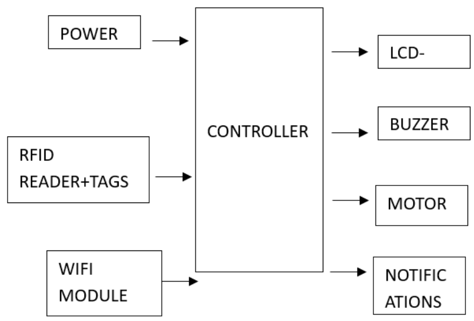
The system was tested under different scenarios:

- Valid card with sufficient balance
- Invalid card detection
- Low balance condition
- Network failure simulation
- Peak-hour fare simulation

Results showed:

- Fast validation time (<2 seconds)
- Accurate fare deduction
- Reliable cloud data synchronization
- Stable gate operation

BLOCK DIAGRAM AND WORKING



Embedded Public Transport Ticketing System with Dynamic Fare & Contactless Payment

The block diagram of the Embedded Public Transport Ticketing System consists of major functional modules including Controller, Power Supply, RFID Reader with Tags, WiFi Module, LCD Display, Motor (Gate Control), Buzzer, and Notification System. Each block plays a crucial role in ensuring secure fare validation, real-time communication, and passenger management. The integration of these components creates a smart, automated, and contactless ticketing solution suitable for buses, metro stations, and train systems.

1. Controller

The **controller** acts as the brain of the entire system. A microcontroller such as ESP32 or Arduino is used to control all system operations. It reads data from the RFID reader, processes passenger authentication, calculates dynamic fare, controls the motor for gate access, updates the LCD display, activates the buzzer when required, and communicates with the cloud server via the WiFi module.

When a passenger taps an RFID card, the controller verifies the card ID, checks balance or validity, calculates the appropriate fare based on predefined rules, and deducts the amount. It then sends transaction details to the cloud for real-time updates. The controller operates continuously and ensures coordination among all connected components.

2. Power Supply

The **power supply unit** provides regulated DC voltage required for system operation. Typically, a 5V regulated supply is used for microcontrollers, RFID readers, LCD, and buzzer. Some components such as ESP32 may require 3.3V regulation.

A voltage regulator ensures stable output and protects the system from voltage fluctuations. In vehicle-based systems, power can be drawn from the vehicle battery with proper regulation. Reliable power supply ensures uninterrupted ticket validation and communication.

3. RFID Reader + RFID Tags

The **RFID reader module** (such as MFRC522) is responsible for detecting and reading RFID cards or tags used by passengers. Each RFID tag contains a unique identification number linked to a passenger account in the system database.

When a passenger taps the card near the reader:

- The reader captures the card ID.
- The controller verifies the card details.
- Fare is calculated and deducted dynamically.
- Entry or exit is recorded.

RFID technology enables fast, contactless, and secure transactions, reducing boarding time and improving passenger convenience.

4. WiFi Module

The **WiFi module** enables communication between the embedded system and the cloud server. In ESP32-based systems, WiFi is built-in, while in Arduino-based systems, an external WiFi module (e.g., ESP8266) is used.

After fare deduction, the controller sends transaction data including:

- Passenger ID
- Fare amount
- Timestamp
- Vehicle ID
- Remaining balance

The data is transmitted using secure communication protocols (HTTP/MQTT). This ensures real-time monitoring and centralized data storage.

5. LCD Display

The **LCD display (16x2 or 20x4)** provides real-time information to passengers. It displays:

- Passenger ID or name
- Fare deducted
- Remaining balance
- Access granted/denied message

The LCD enhances user interaction by clearly indicating transaction status. It ensures transparency and immediate feedback to passengers.

6. Motor (Gate Control Mechanism)

The **motor** is connected to an automatic gate or barrier system. Once the controller validates a passenger's RFID card and confirms sufficient balance, it sends a signal to the motor driver circuit to open the gate.

If the card is invalid or balance is insufficient:

- The motor remains inactive.
- Access is denied.

The motor ensures controlled entry and exit, preventing unauthorized travel.

7. Buzzer

The **buzzer** provides audible alerts for transaction status. It operates in different scenarios:

- Short beep → Successful validation

- Continuous beep → Invalid card
- Alert sound → Insufficient balance

The buzzer enhances system feedback and ensures quick communication with passengers.

8. Notification System

The **notification system** sends alerts to passengers or transport authorities. Notifications can be:

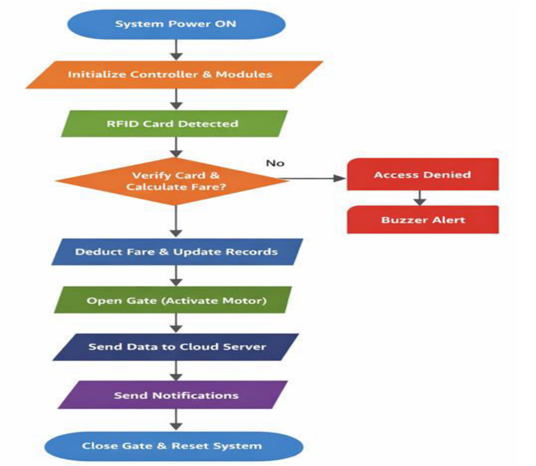
- SMS alerts for low balance
- Mobile app notifications for transaction confirmation
- Email alerts for administrative reports

Cloud integration enables real-time notifications regarding:

- Transaction status
- System errors
- Overcrowding alerts
- Fraud detection warnings

This feature enhances transparency and improves user engagement.

FLOW CHART



VI. CONCLUSION

The Embedded Public Transport Ticketing System with Dynamic Fare and Contactless Payment has been successfully conceptualized and designed as a modern solution to overcome the limitations of traditional fare collection systems. The project integrates embedded systems, RFID/NFC technology, motorized gate control, IoT communication, cloud-based analytics, and notification mechanisms into a unified platform capable of delivering secure, efficient, and scalable ticketing operations.

Conventional ticketing systems, which rely heavily on paper tickets, manual fare collection, or fixed smart card models, face significant operational challenges such as revenue leakage, long boarding times, inaccurate fare calculation, lack of centralized monitoring, and vulnerability to fraud. These issues not only affect transport authority revenue but also reduce passenger convenience and overall service efficiency. The proposed embedded system addresses these challenges through automation, secure contactless validation, and dynamic fare computation.

One of the key achievements of the system is the implementation of dynamic fare calculation. Unlike fixed fare models, the proposed system calculates ticket cost based on parameters such as travel distance, zone classification, and time-based pricing (peak/off-peak hours). This ensures fairness in fare distribution and allows transport authorities to manage demand efficiently. Peak-hour multipliers and promotional pricing schemes can be implemented easily through software modifications, making the system flexible and adaptable.

The integration of RFID technology provides fast and reliable contactless payment. Passengers simply tap their RFID cards or NFC-enabled devices to validate entry and exit. The transaction process is completed within seconds, significantly reducing boarding time and congestion. This enhances passenger satisfaction and improves transport flow efficiency.

The embedded controller acts as the central processing unit, coordinating RFID validation, dynamic fare computation, motor control, LCD updates, and cloud communication. The motorized gate mechanism ensures controlled entry and exit, preventing unauthorized access and fare evasion. The buzzer provides immediate audible feedback, improving user interaction and operational clarity.

IoT integration is another major strength of the system. By connecting embedded devices to cloud servers, the system enables real-time transaction logging, revenue tracking, occupancy monitoring, and performance analysis. Transport authorities can access centralized dashboards to monitor operational metrics, detect anomalies, and generate reports. This data-driven approach enhances transparency and supports strategic decision-making.

Security has been carefully considered in the system design. Encrypted communication protocols, secure API authentication, and device-level validation protect against unauthorized access and fraud. Digital transaction recording eliminates manual manipulation and ensures accurate revenue accounting.

From a technical perspective, the system demonstrates high reliability, fast response time, and scalability. It can be deployed across multiple vehicles and stations without major architectural changes. The modular design allows easy expansion and integration with additional smart city services.

Overall, the project successfully demonstrates the feasibility of implementing a smart, automated, and secure ticketing infrastructure for modern public transportation systems. It aligns with global digital transformation initiatives and supports sustainable urban mobility development.

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