

Smart Tollgate System Using Image Processing, IOT, and Database Verification

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ABSTRACT

The increasing number of vehicles on highways has created major challenges in toll management, including traffic congestion, long waiting queues, fuel wastage, and inefficient manual verification processes. Traditional toll collection methods mainly depend on human operators or basic RFID systems, which are often unable to perform complete verification of vehicle-related records such as insurance validity, pollution certificates, pending penalties, and overloading conditions. These limitations reduce operational efficiency and may also affect road safety and revenue management. To address these issues, this research proposes a Smart Tollgate System that combines image processing, Internet of Things (IoT), and centralized database verification for intelligent and automated toll operations. In the proposed system, an HD camera captures the vehicle number plate when the vehicle reaches the tollgate. The captured image is processed using OpenCV-based image enhancement and Optical Character Recognition (OCR) techniques to identify the vehicle registration number automatically. After extracting the number plate information, the system communicates with a centralized database to verify the vehicle details, including insurance status, PUC validity, fine records, and registered category. At the same time, a load cell sensor integrated with the HX711 module measures the vehicle weight to identify overloaded vehicles. An ESP32 microcontroller manages sensor communication, decision making, and automatic gate operation through IoT connectivity. When the vehicle successfully satisfies all verification conditions and remains within the permissible weight limit, the barrier gate opens automatically using a servo

motor. If any violation is detected, such as expired documents, unpaid penalties, or excess weight, the system keeps the main gate closed and redirects the vehicle toward a verification lane. The proposed model improves toll efficiency, minimizes manual dependency, and supports safer transportation management. In addition, the system provides real-time monitoring and digital record maintenance, making it suitable for future smart highway and smart city applications. The integration of automated number plate recognition, IoT communication, and database validation creates a faster, more secure, and scalable toll collection framework for modern transportation systems.

Keywords: Smart Tollgate, IoT, OCR, OpenCV, ESP32, Vehicle Verification, Automated Toll Collection, Image Processing, Load Cell, Database System.

1. INTRODUCTION

Road transportation has become one of the most important parts of modern society because it supports daily travel, commercial logistics, industrial supply chains, and economic development. With the rapid increase in the number of vehicles on highways and urban roads, toll plazas are facing serious operational challenges such as traffic congestion, long waiting queues, increased fuel consumption, and inefficient monitoring of vehicles. Conventional toll collection methods generally rely on manual verification or RFID-based systems, which are unable to handle heavy traffic efficiently during peak hours. These systems also require significant human involvement, making the process slower and more vulnerable to operational mistakes and revenue leakage.

In many existing toll systems, the primary focus is only on collecting toll charges, while other important vehicle verification processes are ignored. Vehicles with expired insurance, invalid Pollution Under Control (PUC) certificates, unpaid traffic fines, or overloaded cargo often pass through toll plazas without proper checking. Such issues directly affect road safety, increase highway damage, and reduce the effectiveness of transportation monitoring systems. Overloaded vehicles are especially harmful because they reduce road lifespan, increase accident risks, and create maintenance burdens for highway authorities. Therefore, there is a growing need for an intelligent toll management system capable of performing both automated toll collection and real-time compliance verification.

The proposed Smart Tollgate System combines image processing, IoT communication, and database verification to create a more advanced toll management framework. In this system, an HD camera captures the image of the vehicle number plate when the vehicle arrives at the tollgate. The image is processed using OpenCV and OCR algorithms to extract the registration number accurately. The extracted number is then checked against a centralized database containing insurance details, PUC validity, pending fines, and vehicle category information. At the same time, a load cell sensor connected through the HX711 module measures the vehicle weight to detect overloaded vehicles. An ESP32 microcontroller manages communication between the sensors, database, and gate control mechanism.

Another important advantage of the proposed system is real-time monitoring and digital record maintenance. Every transaction, including vehicle number, verification status, toll information, and weight measurement, is stored in the database for future analysis and monitoring. These records can help authorities track violations, monitor highway usage patterns, and improve transportation planning. Furthermore, the integration of IoT communication enables remote monitoring and future scalability for smart city infrastructure.

The proposed system also contributes to environmental sustainability. Reduced vehicle waiting time at toll plazas decreases fuel wastage and lowers air pollution caused by engine idling. Automated operations minimize human effort and provide a more reliable toll collection process with improved accuracy and transparency.

Overall, the Smart Tollgate System provides an intelligent and efficient solution for modern highway management by integrating automated number plate recognition, IoT-based sensing, and centralized database verification. The system enhances operational speed, improves compliance checking, reduces traffic congestion, and supports safer transportation infrastructure for future smart mobility applications.

Table 1: Limitations of Existing Toll Systems and Proposed Improvements

Existing System Problems	Proposed Smart Tollgate Solution
Manual toll collection causes delays	Automated gate control using ESP32
No real-time document verification	Database verification of insurance, PUC, and fines
Overloaded vehicles pass unchecked	Load cell-based weight monitoring
High manpower requirement	IoT-enabled automated operation
Traffic congestion at toll plazas	Faster vehicle processing using OCR
Inaccurate manual record handling	Digital data logging and monitoring

2. LITERATURE SURVEY

Recent advancements in intelligent transportation systems have encouraged researchers to develop automated toll collection methods using technologies such as RFID, OCR, IoT, deep learning, and cloud-based verification systems. Earlier systems mainly focused on automatic toll payment and vehicle identification, while modern research has shifted toward real-time monitoring, AI-based number plate recognition, overload detection, and centralized database integration. However, many existing approaches still face limitations such as poor performance under varying lighting conditions, lack of regulatory verification, absence of overload monitoring, and high infrastructure dependency. The proposed Smart Tollgate System attempts to overcome these issues by integrating image processing, IoT communication, weight measurement, and database verification into a unified framework.

Table 2: Literature Survey of Existing Smart Tollgate Systems

Sr. No.	Author & Year	Research Focus	Technology Used	Key Limitations
1	Deepak K. R. and Shobana N. (2014)	OCR-based tollgate and theft detection	OCR, Image Processing, GSM	Sensitive to lighting and low image quality
2	Kavyashree M. et al. (2020)	RFID-based smart toll collection	RFID, IoT, Arduino	No overload detection or OCR verification
3	Ravichandran S. (2017)	IoT-based toll security system	IoT Sensors, Wireless Communication	No number plate recognition mechanism
4	Abraham M. et al. (2020)	Blockchain-enabled smart toll system	Blockchain, IoT, Smart Contracts	High implementation complexity and cost
5	Christian Creß et al. (2021)	Intelligent transportation infrastructure survey	ITS, Sensors, AI	Generalized study without toll-specific implementation
6	Rupali A. Zamare et al. (2023)	Image-processing-based toll collection	OCR, IoT, Camera Module	No centralized compliance verification

7	Saravana kumar P. et al. (2024)	AI-driven automated toll processing	Deep Learning, CNN, OCR	No vehicle weight monitoring
8	Karthik Sivakoti (2024)	Vehicle classification using YOLO and OCR	YOLOv11, Ensemble OCR	Does not include insurance or PUC verification
9	Rohith M. C. et al. (2025)	IoT tollgate with threat detection	ESP32, Sensors, IoT	Limited experimental performance analysis
10	Hamed Saghaei (2016)	Automatic number plate recognition system	OCR, Image Segmentation	Lacks integration with smart toll infrastructure

Research Gap Identified

From the reviewed literature, it is observed that most existing toll systems focus only on automatic toll deduction or vehicle identification. Very few systems provide integrated verification of vehicle compliance parameters such as insurance validity, PUC certification, pending fines, and overload detection simultaneously. In addition, several existing systems suffer from reduced OCR accuracy under poor environmental conditions and lack centralized monitoring support. Therefore, there is a requirement for a unified smart toll management system capable of combining image processing, IoT communication, real-time database verification, and vehicle weight analysis within a single automated framework. This research aims to bridge these gaps through a cost-effective and scalable solution suitable for modern highway infrastructure.

3. PROBLEM STATEMENT

The rapid increase in the number of vehicles on highways and urban roads has created serious challenges in toll management systems. Traditional toll plazas mainly depend on manual operations or basic RFID-based methods, which often result in long vehicle queues, traffic congestion, fuel wastage, and delays during peak traffic hours. These conventional systems are not capable of performing complete real-time verification of vehicle-related records such as insurance validity, Pollution Under Control (PUC) certification, pending traffic fines, and vehicle overloading conditions. Another major issue in existing toll systems is the passage of overloaded and non-compliant vehicles without proper monitoring. Overloaded vehicles damage road infrastructure, increase maintenance costs, and create safety risks for other road users. Similarly, vehicles with expired documents or unpaid fines continue to operate on highways due to the absence of integrated verification mechanisms at toll checkpoints. Manual checking of such records is impractical because of the high traffic volume and limited manpower availability. Current toll collection systems also suffer from operational inefficiencies such as inaccurate record maintenance, human errors in toll processing, and limited data monitoring capabilities. In many cases, authorities cannot maintain real-time digital records of vehicle movement and compliance status, reducing the effectiveness of highway surveillance and traffic management systems.

To overcome these limitations, there is a need for an intelligent and automated tollgate solution that can combine image processing, IoT communication, and centralized database verification into a single platform. The proposed Smart Tollgate System aims to automate vehicle identification, verify compliance records instantly, monitor vehicle weight, and control tollgate operations with minimal human intervention. The system is designed to improve toll accuracy, reduce traffic congestion, enhance road safety, and support future smart transportation infrastructure.

4. OBJECTIVES OF THE PROPOSED

The main objective of the proposed Smart Tollgate System is to develop an intelligent and automated toll management solution using Image Processing, IoT, and centralized database verification technologies. The system is designed to improve traffic flow efficiency, reduce manual intervention, and ensure safer highway operations through automated vehicle monitoring and verification.

The specific objectives of the proposed system are as follows:

- To automatically detect vehicles approaching the toll plaza using sensor-based monitoring.
- To capture and recognize vehicle number plates using image processing and OCR techniques.
- To verify vehicle information such as insurance validity, PUC status, and pending fines through a centralized database.
- To measure vehicle weight using load cell sensors and identify overloaded vehicles.
- To automate tollgate barrier operation using ESP32 and motor control mechanisms.
- To reduce traffic congestion and waiting time at toll plazas through faster processing.
- To minimize human errors and improve the accuracy of toll management operations.
- To maintain real-time digital records of vehicle transactions for monitoring and analysis.
- To enhance road safety by identifying non-compliant and overloaded vehicles.
- To support future smart transportation and smart city infrastructure development.

5. PROPOSED SYSTEM & METHODOLOGY

The proposed Smart Tollgate System is designed to automate toll collection and vehicle verification using image processing, IoT communication, and database connectivity. The system combines hardware and software modules to perform automatic vehicle detection, number plate recognition, weight monitoring, compliance verification, and barrier control with minimum human intervention. The working process begins when a vehicle approaches the toll plaza. An IR sensor detects the presence of the vehicle and activates the system. Once the vehicle is detected, a high-resolution camera captures the image of the vehicle number plate. The captured image is processed using OpenCV techniques such as grayscale conversion, filtering, edge detection, and segmentation to improve image quality and isolate the number plate region. Optical Character Recognition (OCR) is then applied to extract the alphanumeric registration number from the image.

After successful extraction of the vehicle number, the system sends the information to a centralized database through IoT communication protocols such as MQTT. The database verifies important vehicle details including insurance validity, Pollution Under Control (PUC) certificate status, pending traffic fines, and

registered vehicle category. Simultaneously, a load cell connected through the HX711 module measures the vehicle weight in real time. The ESP32 microcontroller compares the measured weight with predefined permissible limits to identify overloaded vehicles.

Based on the verification and weight analysis, the system makes an automated decision. If the vehicle satisfies all compliance conditions and the weight remains within the allowed range, the servo motor opens the tollgate barrier automatically. If any violation is detected, such as expired insurance, unpaid fines, invalid PUC certificate, or excessive weight, the main gate remains closed and the vehicle is redirected to an inspection lane. A buzzer and LCD display provide status notifications and alerts for operators and drivers.

5.1 Block Diagram Architecture

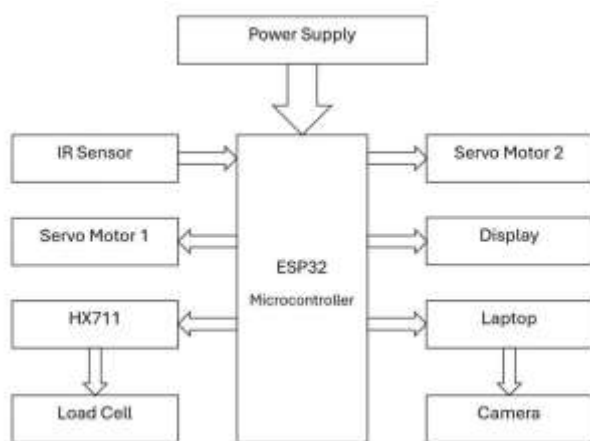


Fig.1: Block Diagram

1. Power Supply Unit

The power supply provides regulated voltage to all hardware components used in the system such as ESP32, sensors, display module, and servo motors. It ensures stable and uninterrupted system operation.

2. ESP32 Microcontroller

ESP32 acts as the main controlling unit of the Smart Tollgate System. It receives data from sensors, communicates with the database, processes system decisions, and controls gate operations automatically.

3. IR Sensor Module

The IR sensor is used for vehicle detection. When a vehicle arrives near the tollgate, the sensor detects its presence and sends a trigger signal to the ESP32 to start the toll verification process.

4. Camera Module and Laptop

The camera captures the image of the vehicle

number plate. The captured image is sent to the laptop where image processing and OCR techniques are performed using OpenCV and Python to extract the vehicle registration number.

5. Database Verification

After extracting the vehicle number, the system checks vehicle details such as insurance validity, PUC certificate status, pending fines, and vehicle category from the centralized database.

6. Load Cell with HX711 Module

The load cell measures the weight of the vehicle. Since the output signal from the load cell is very small, the HX711 amplifier module amplifies and converts the signal into digital data for processing by the ESP32.

7. Servo Motor 1 (Main Gate Control)

Servo Motor 1 controls the main tollgate barrier. If the vehicle satisfies all verification conditions and weight limits, the ESP32 activates the motor to open the gate automatically.

8. Servo Motor 2 (Diversion Gate Control)

Servo Motor 2 is used for controlling the diversion or inspection lane. Vehicles with invalid documents or overload conditions are redirected to the inspection area.

9. Display Module

The display unit shows real-time system information such as vehicle detection status, toll verification results, overload warnings, and gate operation messages.

10. Overall System working

The complete system performs automatic vehicle detection, number plate recognition, compliance verification, overload checking, and intelligent gate control. This reduces traffic congestion, minimizes manual errors, and improves toll management efficiency.

5.2 KEY FEATURES OF THE SYSTEM

The proposed Smart Tollgate System is designed with intelligent automation and real-time monitoring capabilities to improve the overall efficiency of toll plaza operations. One of the important features of the system is automatic vehicle identification using image processing and OCR technology, which helps in recognizing vehicle number plates without manual intervention. The system also includes centralized database verification for checking insurance validity, PUC certification, pending fines, and vehicle category

details in real time. Another major feature is overload detection using a load cell sensor integrated with the HX711 module. This enables the system to identify vehicles exceeding the permissible weight limit and redirect them for inspection. The ESP32 microcontroller provides IoT-based communication and controls the automatic gate operation through servo motors. In addition, the system supports digital transaction logging and real-time monitoring, which improves record management and operational transparency. The integrated design reduces traffic congestion, minimizes human errors, and provides a faster and more secure toll collection process suitable for modern intelligent transportation systems.

6. MATERIALS & IMPLEMENTATION

The proposed Smart Tollgate System is developed by integrating image processing, IoT communication, automated verification, and intelligent gate control technologies into a single platform. The system is designed to reduce traffic congestion, improve toll collection efficiency, and ensure real-time vehicle compliance verification at toll plazas. The implementation combines both hardware and software modules to perform vehicle detection, number plate recognition, overload monitoring, database verification, and automated barrier control operations.

The hardware section mainly consists of ESP32 microcontroller, camera module, IR sensor, load cell with HX711 amplifier, servo motors, LCD display, buzzer module, and regulated power supply unit. The ESP32 acts as the central processing and communication controller of the system. It receives input signals from different sensors, communicates with the database system, and controls the gate operation based on the verification results. The IR sensor is installed near the toll lane to detect the arrival of vehicles automatically. When a vehicle enters the detection area, the sensor sends a trigger signal to the ESP32 microcontroller. After vehicle detection, the camera module captures the image of the vehicle number plate. The captured image is transferred to the laptop or processing system for image analysis.



Fig. 2: ESP32 DEVKIT V1 Pin Configuration and Functional Overview

The extracted vehicle number is verified through a centralized MySQL database containing vehicle-related records such as insurance validity, Pollution Under Control (PUC) certificate status, pending traffic fines, and registered vehicle category details. MQTT communication protocol is used for real-time data exchange between the ESP32 microcontroller and the database server to ensure faster processing and reliable communication.

The system also integrates a load cell sensor with the HX711 amplifier module for vehicle weight measurement. The load cell measures the weight of the vehicle in real time, while the HX711 module amplifies the sensor signal and converts it into digital form for ESP32 processing. The measured weight is compared with predefined threshold values to identify overloaded vehicles.

The software implementation of the system is carried out using Arduino IDE for ESP32 programming, OpenCV for image processing, MySQL for database management, MQTT for IoT communication, and Proteus software for circuit simulation and testing. The integrated implementation improves toll collection speed, reduces manual intervention, enhances highway safety, and provides a reliable smart transportation solution for future intelligent toll management systems.

6.1 Hardware Requirements

Table 2: Hardware Components Used in Smart Tollgate System

Hardware Component		Purpose
ESP32 Module	WiFi	Main controlling and IoT communication unit
Camera Module / USB Camera		Captures vehicle number plate images
IR Sensor Module		Detects vehicle arrival
Load Cell with HX711		Measures vehicle weight
Servo Motor		Controls tollgate barrier operation
LCD Display		Displays system messages and status
Buzzer Module		Generates warning alerts
Power Supply Unit		Provides regulated power to the system
Laptop / PC		Performs OCR and image processing

The hardware components are selected to ensure accurate sensing, reliable communication, and efficient tollgate automation. The ESP32 microcontroller coordinates all system operations, while the camera and load cell modules provide vehicle identification and overload monitoring functionalities.

6.2 Software Requirements

Table 3: Software Tools Used in Smart Tollgate System

Software Tool	Purpose
Arduino IDE	Programming ESP32 microcontroller
Python	Image processing and OCR implementation

OpenCV	Vehicle image preprocessing and analysis
MySQL	Vehicle database management
MQTT Protocol	Real-time IoT communication
Proteus	Circuit simulation and testing
Anaconda	Python development environment

The software tools are used for implementing image processing algorithms, database communication, IoT connectivity, and system simulation. These technologies ensure efficient and reliable operation of the proposed smart tollgate system.

6.3 System Modules

The Smart Tollgate System is divided into several functional modules to ensure organized and efficient operation.

1. Vehicle Detection Module

Detects the arrival of vehicles using IR sensors and activates the system automatically.

2. Image Processing Module

Captures vehicle number plate images and performs OCR-based number extraction using OpenCV.

3. Database Verification Module

Verifies vehicle details such as insurance, PUC certificate, pending fines, and vehicle category from the centralized database.

4. Weight Measurement Module

Measures vehicle weight using load cell and HX711 amplifier to identify overloaded vehicles.

5. Gate Control Module

Controls the opening and closing of tollgate barriers using servo motors based on verification results.

6. Monitoring and Alert Module

Displays system messages on LCD and generates warning alerts through buzzer modules.

7. Data Logging Module

Stores toll transaction records, vehicle details, and verification results for future monitoring and analysis.

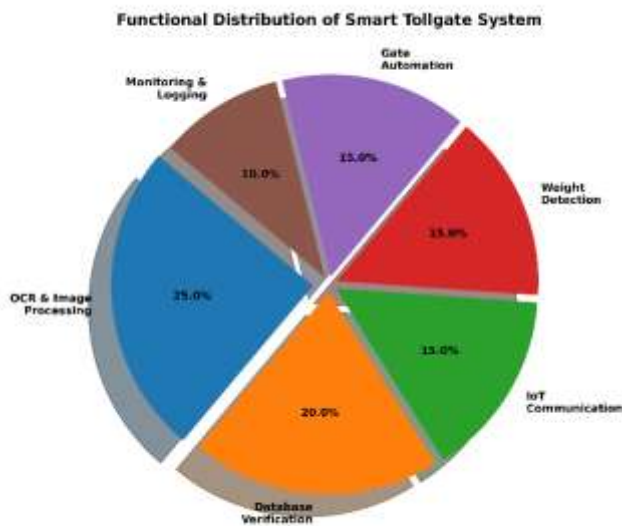


Fig. 3: Functional Distribution of Smart Tollgate System

7. RESULTS AND DISCUSSION

The proposed Smart Tollgate System was tested to evaluate its performance in terms of vehicle detection accuracy, OCR recognition efficiency, overload monitoring, database verification, and automated gate operation. The system demonstrated reliable operation under normal testing conditions and successfully automated toll management activities with reduced human intervention. The IR sensor accurately detected the arrival of vehicles at the tollgate and triggered the image capture process without noticeable delay. The camera module captured vehicle number plate images successfully, while the OpenCV and OCR-based image processing module extracted registration numbers with good accuracy under proper lighting conditions. The database verification module efficiently checked insurance validity, PUC certificate status, pending fines, and vehicle category information in real time.

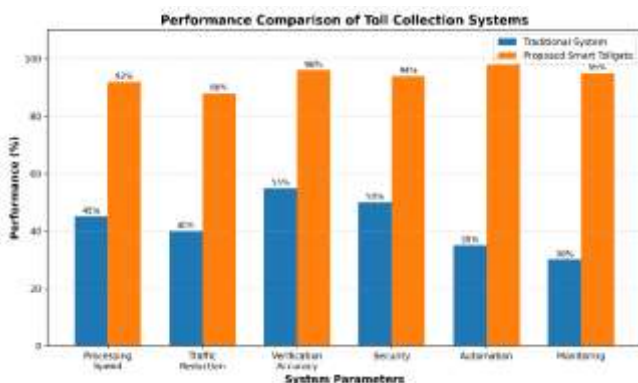


Fig. 4: Performance Comparison of Traditional and Proposed Toll Collection Systems

The load cell and HX711 module successfully measured vehicle weight and identified overloaded vehicles based on predefined threshold values. The ESP32 microcontroller processed all verification conditions and controlled the gate operation automatically using servo motors. Vehicles satisfying all verification requirements were allowed to pass through the main gate, while overloaded or non-compliant vehicles were redirected toward the inspection lane. The system also maintained digital transaction records including vehicle number, verification status, weight information, and toll operation details. Real-time monitoring through display messages and alert indications improved system usability and operational transparency. The experimental implementation showed that the proposed system can reduce toll processing time, minimize traffic congestion, and improve highway safety.

7.1 Data Management Performance

The centralized database system successfully stored and managed vehicle-related records such as registration details, insurance status, PUC validity, pending fines, and toll transaction history. The database provided reliable real-time verification and supported faster retrieval of vehicle information during toll operations.

The system also maintained accurate digital logs for monitoring and future analysis. No major data loss or duplication issues were observed during testing, indicating stable database performance and reliable communication between the ESP32 controller and MySQL server.

7.2 System Efficiency

The proposed system improved overall toll management efficiency by automating vehicle verification and gate control operations. Compared to manual toll systems, the automated process reduced waiting time and improved traffic movement at the toll plaza. The ESP32 microcontroller responded quickly to sensor inputs and verification results, enabling faster gate operation. The OCR-based number plate recognition process reduced manual checking efforts and improved verification speed. The system also minimized operational errors caused by human intervention.

7.3 Discussion

The experimental results indicate that the Smart Tollgate System effectively addresses the limitations of conventional toll collection methods. The integration of image processing, IoT communication, and centralized database verification provides a reliable and intelligent

toll management solution. Compared to traditional systems, the proposed model offers improved automation, real-time compliance verification, overload detection, and digital record management. The system also contributes to reduced traffic congestion, improved road safety, and better highway monitoring. Although OCR accuracy may decrease under poor lighting or unclear number plate conditions, the overall performance of the system remains effective for real-time toll management applications.

The proposed system demonstrates the practical implementation of intelligent transportation technologies and can be extended further for smart city infrastructure, cloud-based monitoring, and AI-driven traffic management systems.

8. CONCLUSION & FUTURE SCOPE

8.1 Conclusion

The proposed Smart Tollgate System using Image Processing, IoT, and Database Verification provides an intelligent and automated solution for modern toll management applications. Traditional toll collection systems often suffer from problems such as traffic congestion, manual errors, delayed verification processes, and inefficient monitoring of overloaded or non-compliant vehicles. To overcome these limitations, the proposed system integrates OCR-based number plate recognition, real-time database verification, IoT communication, and automated gate control into a single platform. The system successfully performs automatic vehicle detection, extracts vehicle registration numbers using image processing techniques, verifies compliance records such as insurance validity, PUC certificates, and pending fines, and identifies overloaded vehicles using load cell sensors. Based on these verification results, the ESP32 microcontroller automatically controls the tollgate barrier operation with minimum human intervention. The implementation results show that the proposed system improves toll collection efficiency, reduces vehicle waiting time, minimizes traffic congestion, and enhances highway safety. The integration of centralized database management and real-time monitoring also improves operational transparency and digital record maintenance. Overall, the Smart Tollgate System provides a reliable, cost-effective, and scalable solution suitable for intelligent transportation and smart highway infrastructure.

8.2 Future Scope

The proposed Smart Tollgate System can be further enhanced by integrating advanced technologies and additional smart transportation features. Future improvements may include:

1. Integration with FASTag and digital payment gateways for fully cashless toll transactions.
2. AI-based vehicle classification and fake number plate detection using deep learning algorithms.
3. Cloud-based centralized monitoring for managing multiple toll plazas from a single control system.
4. Real-time traffic analysis and smart traffic management using AI and IoT technologies.
5. Solar-powered tollgate units for energy-efficient and environmentally sustainable operation.
6. Mobile application support for vehicle status monitoring and instant notification services.
7. GPS and RFID integration for advanced vehicle tracking and faster verification processes.
8. Implementation of advanced security mechanisms and encrypted database communication.
9. Expansion of the system for smart city checkpoints, parking management, and industrial vehicle monitoring.
10. Development of fully unmanned toll plazas with intelligent decision-making and automated surveillance systems.

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