International Journal of Engineering &Technology, 13 (2) (2024) 281-285

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Automatic toll collection system using RFID with vehicle classification using convolutional neural network

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Abstract

The need for efficient and secure toll collection systems has prompted the development of advanced technologies that streamline toll collection and enhance traffic management. This paper presents an automatic toll collection system that integrates Radio Frequency Identification (RFID) technology with vehicle classification using convolutional neural network algorithms. The proposed system aims to improve the accuracy and efficiency of toll collection processes while reducing illegal use of Fast-tags (RFID) on unauthorized vehicles. The RFID-based component of the system facilitates contactless payment by detecting vehicles equipped with RFID tags as they approach the toll booth. The system automatically processes the payment, enabling swift passage for vehicles and minimizing delays. To enhance security and accuracy, the system incorporates a vehicle classification module based on Single Shot Detector (SSD) and You Only Look Once (YOLO) models. Cameras capture images of approaching vehicles, which are then processed by CNN algorithms trained to classify vehicles based on features such as type, make, model and Size. This classification enables the system to apply appropriate toll rates according to vehicle category and ensure compliance with toll regulations. The integration of RFID and deep learning technologies provides a robust approach to managing toll collection, minimizing fraud or evasion, and ensuring a seamless experience for drivers. The proposed system also offers valuable data insights for traffic analysis and management, contributing to smarter transportation infrastructure like toll fee SMS services and automatic toll gate opening and closing system. The results demonstrate that the system significantly improves the efficiency and accuracy of toll collection while providing a reliable and secure method for vehicle classification. The proposed system holds potential for widespread adoption, aligning with the growing demand for intelligent transportation solutions.

Keywords: *Automatic Toll Collection; RFID; Deep Learning; Vehicle Classification; Intelligent Transportation; Smart Infrastructure.*

1. Introduction

As the world's population continues to grow and urbanization increases, managing road traffic and transportation infrastructure becomes more challenging. Efficient toll collection systems play a crucial role in ensuring smooth traffic flow, maintaining infrastructure, and providing a seamless experience for drivers. Traditional toll collection methods, such as manual toll booths, often lead to traffic congestion, delays, and higher operating costs. Moreover, these methods are prone to human error and fraud, which can negatively impact toll revenue [1].

A literature survey is essential to understand the existing work and research in the field of automatic toll collection systems, RFID technology, and vehicle classification using deep learning (DL). This section reviews key papers and studies that have contributed to the development of efficient and intelligent toll collection systems[2].

Automated Toll Collection Using RFID: Studies have explored the use of RFID technology in automated toll collection systems. RFID readers detect RFID tags attached to vehicles, enabling seamless and contactless payment as vehicles pass through toll booths (Sabbir Ahmed, Tamkin Mahmud Tan, Anna Mary Mondol,et.al 2019 IEEE). These systems have been shown to significantly improve the speed and efficiency of toll collection while reducing congestion and operational costs [3].

Radio Frequency Identification (RFID) Based Toll Collection System: Despite the benefits, there are challenges in RFID-based toll collection systems, including tag detection accuracy and interference from other signals (Atif Ali Khan; Adnan I. Elberjaoui Yakzan et,al 2011, IEEE) . Addressing these challenges is crucial for the successful deployment of RFID-based toll collection[4].

A Machine Learning Method for Vehicle Classification by Inductive Waveform Analysis: Bruno R. Vasconcellos , Marcelo Rudek , Marcelo de Souza et.al 2020 IFAC Machine learning algorithms, such as support vector machines (SVMs), have been applied to classify vehicles based on features extracted from images or videos. These model can accurately categorize vehicles according to type, size, and license plate recognition[5].

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A Vehicle Classification System for Intelligent Transport System using Machine Learning in Constrained Environment: Mursi et.al, (IJACSA) International Journal of Advanced Computer Science and Applications, Created a more realistic and more powerful vehicle sort grouping system for real-world constrained environment with encouraging results, obtaining 90.85 for validation accuracy and 87% for testing accuracy. Consequently, they propose a framework of vehicle type classification from vehicle images based on machine learning. It gets trained automatically at several stages to have invariant features for the given task. However, they also compared our model's performance with other machine learning algorithms such as Decision Trees, SVM and Naïve Bayes during testing stage [1].
This literature survey highlights the current state of research in automatic toll collection using RFID and DL-based vehicle classification. By identifying challenges and potential areas for further research, the survey sets the stage for the proposed system's design and development.
In addition to RFID, CNN algorithms are leveraged to classify vehicles based on data from cameras installed at the toll booth. These algorithms analyze images of approaching vehicles and classify them according to type, make, model, and Size. Vehicle classification is essential for applying appropriate toll rates and ensuring compliance with toll regulations [5].
The combination of RFID and DL-based vehicle classification creates a robust and efficient toll collection system. This approach reduces the risk of toll evasion and fraud, improves traffic flow, and provides valuable data for traffic management and planning. The proposed system aligns with the increasing demand for intelligent transportation solutions and the development of smart infrastructure [6].
This paper presents the design, implementation, and evaluation of an automatic toll collection system that integrates RFID technology with vehicle classification using Deep learning. The findings demonstrate the potential benefits of this approach for improving the efficiency and security of toll collection systems.
To address these challenges, automated toll collection systems using advanced technologies have been developed. These systems aim to improve the speed and accuracy of toll collection, enhance security, and provide drivers with a more convenient experience. One such solution involves the integration of Radio Frequency Identification (RFID) technology and vehicle classification using Deep learning (DL) algorithms.

2. Research methodology

This system is based on both hardware and software integration, in the hardware system we have arduino nano as a development board which is used to control the hardware mechanism like toll gate opening and closing system via Servo motors and also alerting system like SMS service, light and sound when unauthorized vehicle is detected. The arduino nano is also interfaced with RFID reader for reading the RFID tags (Fastags) which are on the vehicles and for the two level authentication is done by camera(web camera) for vehicle classification This system involves equipping vehicles with RFID tags that contain unique identification information. As a vehicle approaches the toll booth, RFID readers installed at the toll gate capture the information from the RFID tag. Based on this information, a convolutional neural network classifies the vehicle into different categories such as cars, trucks, bus, etc. Using the classification results, the system automatically calculates the toll fee based on predefined rates for each vehicle category and a SMS is send to the respective owner of the vehicle via GSM module and at the same time the toll gate gets opened and green led gets turned on for successful transaction. With this automated system, drivers no longer have to manually pay tolls or wait in long queues, resulting in reduced congestion and improved traffic flow [7]. If in case the RFID tag doesn't match with the classified vehicle type and then an alerting system gets activated and a SMS is sent to the authorities for illegal access.

2.1. Block diagram

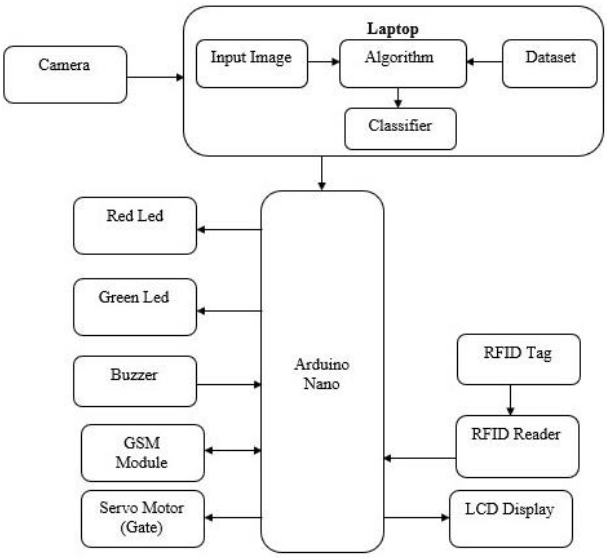


Fig. 1: Block Diagram.

2.2. Hardware and software description

2.2.1. Hardware

Arduino Nano: The Arduino Nano is a miniaturized yet powerful microcontroller board designed for hobbyists and professionals alike. Despite its small size (45mm x 18mm), it packs a punch with an ATmega328P microcontroller, 32KB of flash memory, and 8 analog input pins. This allows it to handle various tasks, from reading sensor data to controlling motors. Significantly, the Nano operates on 5V but can accept a range of input voltages (7-20V) thanks to its built-in voltage regulator. Fourteen digital I/O pins provide flexibility for connecting electronic components, with 6 of them offering pulse width modulation (PWM) for controlling LEDs or motors with varying intensity.

RFID reader and tag

The EM-18 RFID reader module is a communication device for delving into the world of RFID technology. It pairs well with basic RFID tags operating at the 125 kHz frequency. This frequency offers a good balance between affordability and performance, making it suitable for short-distance applications like access control systems with keycard entry or simple inventory tracking. However, the read range is typically limited to around 10 cm, depending on the tag.

Servo Motor: The SG90 servo motor is a valuable learning tool for understanding servo motors, but its limitations make it unsuitable for real-world toll gate control. Opt for high-torque servos, barrier gate motors, or linear actuators designed for the demanding requirements of a toll gate system, along with prioritizing safety features and reliable power supply.

GSM Module: GSM modules, like the SIM900, can enhance a toll gate system by enabling remote monitoring, management, and communication. However, they require careful integration with other crucial components for a fully functional toll collection system.

LCD Display: LCD displays are an essential component of modern toll collection systems. By providing clear and user-friendly information for both drivers and operators, they contribute to a smooth and efficient toll booth experience.

1) Result Analysis
2) Vehicle Approach: As a vehicle approaches the toll booth, the RFID reader captures its unique identifier from the tag.
3) Vehicle Classification: The camera captures an image of the vehicle. The CNN analyzes the image and classifies the vehicle type.
4) Toll Fee Calculation: Based on the pre-defined toll rates for each vehicle category and the classification results, the system automatically calculates the appropriate toll fee.
5) Transaction and Gate Control:

- Authorized Access: If the RFID tag information matches the classified vehicle type:
- The corresponding account linked to the RFID tag is charged electronically and SMS notification can will be sent.
- The toll gate opens via the servo motor.
- A green LED indicates a successful transaction Fig 2 .
- Unauthorized Access: If there's a mismatch between the tag information and the classified vehicle type (e.g., truck with a car tag):
- The alert system activates (red lights and sound).
- An SMS notification will be sent to authorities.
- The toll gate remains closed Fig 3.

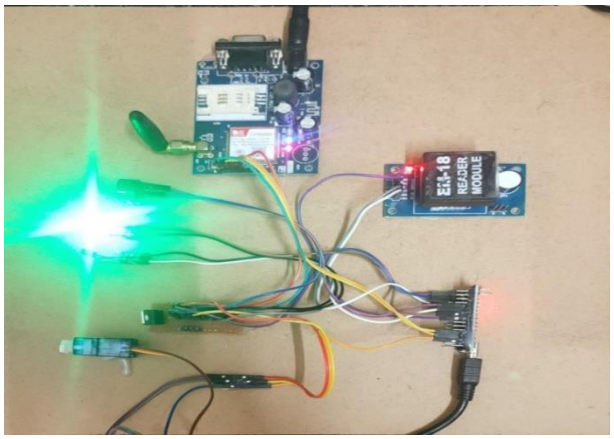


Fig. 2: Authorized Access.

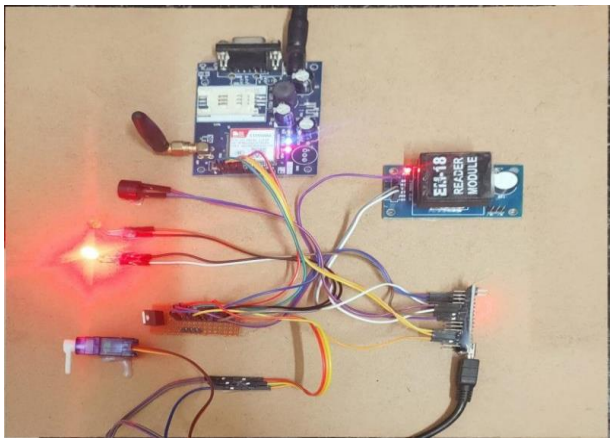


Fig. 3: Unauthorized Access.



Fig. 4: Car Detection.



Fig. 5: Truck Detection.

3. Conclusion

This project investigated the development of an Automatic Toll Collection System utilizing RFID technology for vehicle identification and a Convolutional Neural Network (CNN) for vehicle classification. Here's a summary of the key takeaways:

- RFID Integration: RFID tags provide a contactless and reliable method for identifying vehicles, eliminating the need for manual intervention and streamlining the toll collection process.
- CNN-powered Vehicle Classification: A Convolutional Neural Network effectively categorizes vehicles into different classes (cars, trucks, buses, etc.), enabling accurate toll calculation based on pre-defined rates.
- Enhanced Efficiency: The combined power of RFID and CNN automates vehicle identification and classification, leading to faster toll processing and reduced congestion at toll plazas.
- Improved Revenue Management: Accurate vehicle classification ensures proper toll collection for different vehicle types, optimizing revenue generation.
- Benefits of the Proposed System:
- Reduced Wait Times: Faster processing times translate to smoother traffic flow and shorter wait times for drivers.
- Lower Operational Costs: Automating vehicle identification and classification minimizes the need for manual toll collectors, potentially reducing labor costs.
- Improved Data Collection: The system can gather valuable data on traffic patterns and vehicle types, aiding in toll booth optimization and traffic management strategies.
- Future Directions:
- Advanced CNN Training: Continuously training and refining the CNN with a wider dataset of vehicle images can further enhance classification accuracy for various vehicle types and models.
- Integration with Payment Systems: Seamless integration with electronic payment systems like credit cards or dedicated toll accounts will offer drivers a convenient and contactless payment experience.
- Security Measures: Implementing robust security protocols safeguards sensitive data like vehicle identification and toll transactions.

In conclusion, the proposed Automatic Toll Collection System using RFID and CNN technology offers a promising solution for modern toll collection systems. By combining automation with intelligent vehicle classification, this system can significantly improve efficiency, revenue management, and the overall toll booth experience for both drivers and operators.

Acknowledgment

The authors would like to thank Chairman, Dean, and Principal, Institutions of St. Mary's Group, Deshmukhi, Yadadri Bhongiri, India-508116.

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