Automated Toll Collection System

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This research project develops an automated toll collection system using geofencing, a web-based platform, and intelligent algorithms. Each day with a steady rise in the human population there is a steady rise in the number of vehicles on roads as well. This increase in vehicles eventually will demand for a better toll collection infrastructure and newer innovative methods and technologies. These technologies not only need to make toll collection easier but reduce the time that vehicles need to wait for in long queues that leads to traffics and human errors. This project aims to eliminate physical toll-booths, reduce congestion, and improve traffic flow. The most significant feature is there is no requirement of physical infrastructure and vehicles will not have to stop at certain locations thus eliminating congestions and long traffics at certain locations. The system calculates tolls based on distance travelled in the geofenced area and deducts them from virtual accounts. The research paper details the defining of geofence with the Google Maps API, toll calculation algorithms, and the design of the web platform. The project demonstrates the potential of automated toll collection for optimizing transportation infrastructure and inspires further advancements in toll collection technologies.

Keywords: Toll Collection, Web Based Platform, Distance Based Toll Tax, Geofence.

2023. In Satyasai Jagannath Nanda & Rajendra Prasad Yadav (eds.), *Data Science and Intelligent Computing Techniques*, 827–836. Computing & Intelligent Systems, SCRS, India. https://doi.org/10.56155/978-81-955020-2-8-70

1 Introduction

Toll collection systems need improvement due to long wait times, high costs, and security risks. Our project, "Automated Toll Collection," uses geofence, web plat-forms, and algorithms to create an efficient and user-friendly system. We automate toll collection by tracking vehicle distance with geofence and deducting tolls from virtual accounts managed through a website. This eliminates physical tollbooths, reducing congestion and improving traffic flow.

The system also provides convenience and secure transactions for drivers. Addition-ally, it has wider implications for transportation management and sustainability. Our research paper explores the technical aspects of integrating geofence & GPS technology, algorithms for toll calculation, and the web-based platform for managing virtual accounts and transactions. We aim to inspire further innovations in toll collection technologies and intelligent transportation systems.

2 Literature Review

Automated toll collection systems have gained significant attention in recent years due to their potential to enhance efficiency, reduce traffic congestion, and improve the overall user experience on roadways.

Traditional toll collection systems involve physical tollbooths, where tolls are collect-ed manually from drivers. These systems often suffer from long waiting times, traffic congestion, and high operational costs. Veena S et al. [1] conducted a survey on Smart Toll Collection Management Systems with a focus on security aspects. The study highlighted the security issues of RFID and GPRS-based ATCS systems. While these systems were considered secure enough, the researchers identified potential improvements in encryption and complex security measures. However, the survey did not delve into other aspects of toll collection, neglecting to address the requirement of skilled workforce, which is crucial for system maintenance and smooth operation.Sumathi SM et al. [2] proposed an Automatic Toll Collection system based on RFID technology. This system aimed to process debits and violations efficiently without causing traffic congestion. By placing RFID tags on vehicles and using RFID readers at toll booths, the system could deduct toll amounts automatically. This approach showed promising results, including reduced traffic congestion and the ability to identify stolen vehicles. However, it required each vehicle to have a unique RFID tag, which could be cumbersome to implement on a large scale.

Petter Arnesan et al. [3] introduced geofencing as a mechanism to enable differentiated user charging, with a focus on promoting the use of electric vehicles (EVs) in Norway. The researchers implemented geofencing in two cities to analyze user behavior to-wards switching to electric vehicles. The study revealed a rise in the usage of electric vehicles, indicating the potential of geofencing to incentivize cleaner transportation choices. However, a noteworthy observation was that non-electric vehicle users opted for alternative routes to avoid what they perceived as an unfair toll collection system.Anuj Patel et al. [4] proposed an ATCS that incorporates vehicle categorization and enhanced security measures. This system retained the existing infrastructure but introduced RFID tag reading at stop-through gates. The gates only opened after the toll amount was successfully deducted, and the toll charges varied based on the vehicle type. Public service vehicles were granted priority access through the gates. Although this approach enhanced security and ensured fair toll charges, the process proved time-consuming, potentially leading to traffic congestion during peak hours.

The paper by Walker J. [5] discusses a technology trial called Charging Electronically by Distance and Road (CEDAR) in Southern England. The trial involves testing Time-Distance-Place (TDP) Road User Charging using GPS-based On-Board Units (OBU) to track and charge vehicles based on their usage. The paper highlights successful GPS and map-matching technology in various conditions but mentions the need for corrections in the Back Office system, presenting initial findings with more results

expected to be shared later. Sanchit Agarwal and et al. [6] talk about toll collection through laser barcode, however it will still require for the vehicle to slow down to some extent or stop in order to scan the barcode and cannot be called a seamless system.

Rajkuwar [7] discusses the implementation of an automatic toll collection system on toll gates using a graphical user interface (GUI), real-time management, and monitoring. The system utilizes GPS to uniquely identify vehicles, collects toll fees from vehicle owners, and avoids traffic jams by streamlining toll collection.

To address the limitations of existing ATCS systems and leverage the benefits of geofencing, we propose an innovative Automatic Toll Collection System based on distance traveled using geofencing. This system aims to combine the advantages of distance-based toll collection and geofencing technology to create a more efficient, secure, and user-friendly tolling solution.

3 Automated Toll Collection System

To address the limitations of existing ATCS systems and leverage the benefits of geofencing, wepropose an innovative Automatic Toll Collection System based on distance traveled using geofencing. This system aims to combine the advantages of distance-based toll collection and geofencing technology to create a more efficient, secure, and user-friendly tolling solution.

The project's workflow is a comprehensive and systematic approach designed to monitor and manage vehicles effectively. Figure 1. is the representation of this workflow in the form of a flow chart. It all starts the moment a vehicle is started up. This initiation point activates a sophisticated tracking system, which plays a pivotal role in ensuring the project's success.

One of the first checks this system performs is the geofence check. This is a crucial step as it determines whether the vehicle is currently located within the predefined geofence area. The geofence acts as a virtual boundary, demarcating where the vehicle is authorized to operate. This preliminary check serves as a protective measure to make sure the vehicle is in the right place before any further actions are taken.

If the vehicle is confirmed to be inside a specified geofence, the system will move to the next step, which involves calculating the distance travelled by the vehicle. This distance calculation is necessary for a number of reasons, including keeping correct distance records, finding shorter routes, and continuously keeping track of the vehicle's movement make sure that the vehicle is present in the geofence.

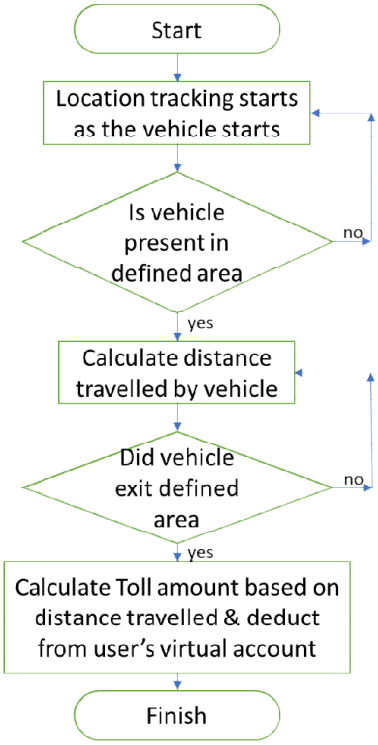

Figure 1. Flowchart - Process Specification of Automated Toll Collection based on distance travelled

While all of this is happening, the system doesn't lose sight of another crucial aspect of its job: monitoring the vehicle's position relative to the geofence boundaries. If, at any point, the vehicle exits the defined geofence area, the system swiftly goes into action. It calculates the applicable toll amount, deducts it from the vehicle's ac-count, and effectively concludes the process related to that particular journey.

On the other hand, if the vehicle remains continuously inside the defined geofence of the system, it will be continuously monitored. The distance will be calculated continuously, providing useful data not only to calculate the toll but also to keep track of the total distance the vehicle travels inside the geofence. Once it exits the geofence, the toll amount will be calculated based on the total distance measured, predetermined by a certain formula or algorithm beforehand.

The development of the automated toll collection begins with the definition of system requirements and objectives, aligning them with the project's scope. The overall architecture of the system is designed, taking into account the integration of geofence and GPS technology, web-based platforms, and toll calculation algorithms.

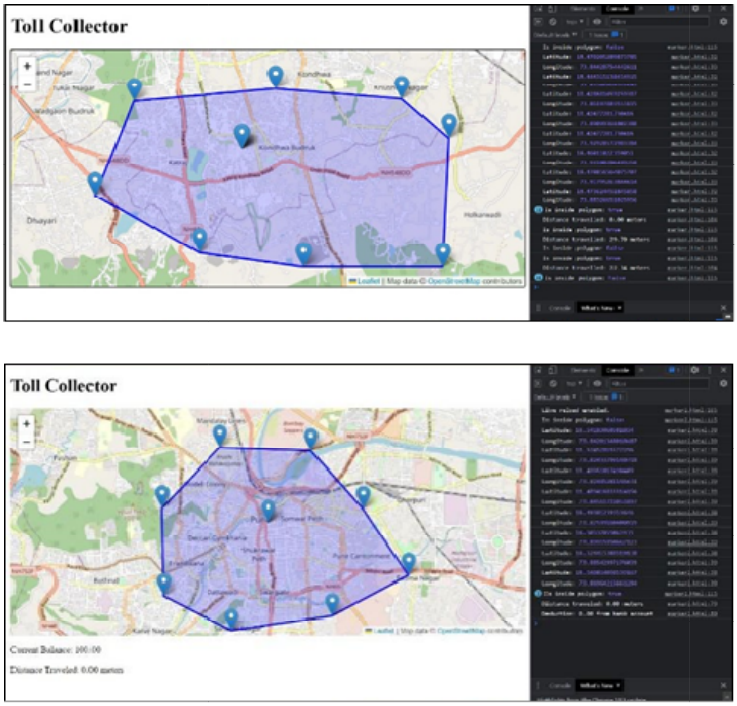

Figure 2. Defined Geofence on Map

Road segmentation plays a crucial role in the toll collection process. By leveraging the Google Maps API or a similar geolocation service, geofences are defined and road segments within these geofence get defined where tolls will be collected. These geofences are the polygons seen in the images of figure 2. Also, a pointer at the center of each polygons represents the user's current location.

The integration of GPS technology stands as a cornerstone of this project, offering a robust and technologically advanced approach to manage participating vehicles. It leverages the ubiquity of smartphones, each equipped with GPS capabilities, which are seamlessly incorporated into these vehicles. This integration enables the real-time collection of GPS data, including essential information such as the vehicle's precise location, current speed, and the distance it has covered during its journey.

To make the most of this data, sophisticated software is developed to process it efficiently. This software plays a pivotal role in ensuring the accuracy and reliability of the information collected from the GPS devices. The two images in figure 2 represent how the map and geofence will look for a user. The two different polygons shown in figure two are the geofences that have been plotted manually. When this system is implemented for application, we will have to make polygons only around the major roads and not huge areas as shown in the images. However, for testing purposes, a large area has been selected in the maps. The website manages the continuous stream of data, transforming it into meaningful and actionable insights, thus forming the basis for other critical functions within the project.

Distance calculation and toll amount determination are among the key functionalities driven by this GPS data. Specialized algorithms are developed to process this information, considering the distance

traveled by each vehicle on the predefined road segments. These algorithms are meticulously crafted and rigorously tested to ensure that the toll amounts they calculate are both precise and equitable. This is vital for guaranteeing that users are charged correctly for their use of the road network.

Furthermore, these algorithms are fine-tuned and refined over time to meet the project's evolving needs. Continuous testing and optimization ensure that they re-main up-to-date and capable of handling various scenarios, including complex road networks and variable toll rates. The goal is to provide a seamless, transparent, and fair tolling system that benefits both the users and the broader transportation infra-structure.

In summary, the integration of GPS technology is not merely a feature of the project; it's a central component that drives data collection, accuracy, and efficiency. By effectively harnessing the power of GPS data and developing robust algorithms, the project ensures that distance calculations and toll determinations are carried out with the highest level of precision and fairness, contributing to an advanced and reliable vehicle management and tolling system.

Virtual account management is an essential component of the system. A user-friendly web-based platform is designed and developed to enable drivers to create and manage virtual accounts. Secure authentication and transaction mechanisms are implemented to facilitate toll deductions from the virtual accounts. Payment gate-ways or services are integrated to allow drivers to add funds to their virtual accounts conveniently.

4 Results and Discussion

The automated toll collection system is a reliable method for distance calculation by integrating geofence technology and utilizing geolocation services like the Google Maps API. This provides precise positioning data, resulting in accurate distance calculations. The system captures and updates the vehicle's location in real-time, ensuring accurate toll determination based on the actual distance covered on designated road segments.

The toll calculation algorithms implemented in the system effectively determine the appropriate toll amount based on factors such as vehicle type, travel time, and applicable discounts or surcharges. By considering multiple variables, the system calculates toll amounts fairly and in accordance with the predefined pricing structure.

The web-based platform for virtual account management provides a convenient and secure method for drivers to manage their toll payments. Users could create accounts, add funds, and view transaction history. The integration of reliable payment gate-ways or services facilitates seamless transactions, ensuring timely deduction of toll amountsfrom virtual accounts.

The automated toll collection system significantly improves the user experience by eliminating the need for physical tollbooths. Drivers experience reduced waiting times and smoother traffic flow, resulting in enhanced overall roadway efficiency. The convenience of virtual account management allows drivers to seamlessly make toll payments without the need for cash transactions, reducing complexities and improving satisfaction levels.

The system consistently collects and processes GPS data, calculates toll amounts, and deducts funds from virtual accounts without major disruptions or errors. The design allows for scalability, enabling potential expansion to cover additional road segments or integration with existing toll collection infrastructure.

While the system yields positive results, there are opportunities for further enhancements. These include the integration of advanced technologies like incorporation of data analytics to analyze traffic

patterns and optimize toll pricing based on real-time demand and congestion levels, and exploration of interoperability with other transportation systems for a comprehensive and integrated mobility experience.

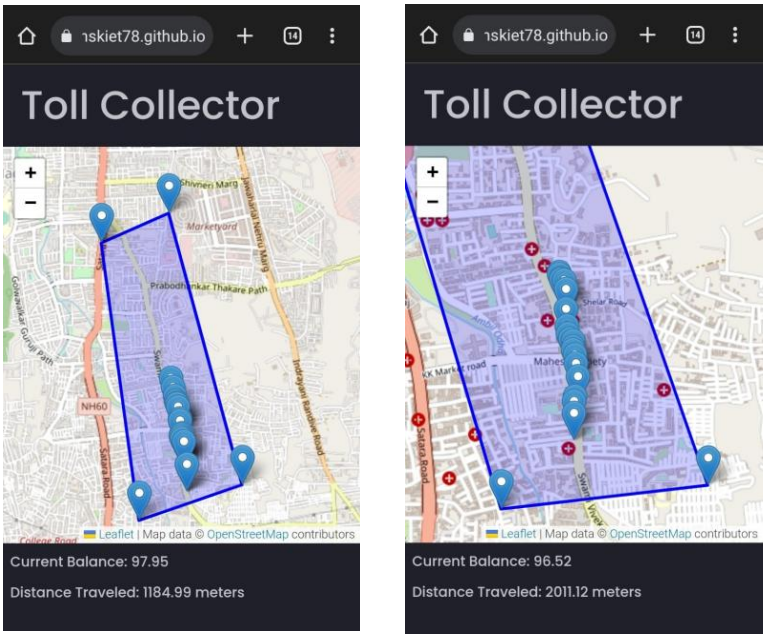

Figure 3. Toll Collection on a trip and return trip

The automated toll collection system, integrating geofence technology, a web-based platform, and intelligent algorithms, unequivocally demonstrates its feasibility and effectiveness. This comprehensive solution not only streamlines toll collection but also significantly improves the user experience, contributing to the advancement of transportation management. As seen in figure 3, a four-sided polygon maps the roads that are to be considered for toll collection. And as the location of the user is changing, the pointers are also changing location indicating the path or the road that the user is using. A series of pointers that are seen figure 3 are along the road that the user travelled and the corresponding distance and the balance available in users account is also being displayed simultaneously in real time.

The hallmark of this system is its ability to provide incredibly precise distance calculations. By leveraging GPS technology, it captures the exact routes taken by vehicles, leaving no room for ambiguity. This level of accuracy is invaluable for a range of applications, including route optimization, mileage tracking, and ensuring that toll charges align with the actual distance covered.

Furthermore, the system's use of intelligent algorithms ensures equitable toll amounts. It carefully considers the road segments utilized by each vehicle, resulting in transparent toll calculations. This fairness minimizes potential disputes, as users are billed in accordance with their actual road usage. These algorithms are adaptable, capable of accommodating varying pricing models and shifting road conditions, thus promoting flexibility and responsiveness in the toll collection process.

The online platform does real-time data processing and lets users interact easily. This makes it simple for users to get information quickly about toll charges, routes, and more. The goal is to make toll collection user-friendly and efficient, supporting the improvement of transportation systems that focus on convenience and effectiveness.

In short, integrating geofence technology, a web-based platform, and smart algorithms in this automated toll collection system is a big step forward in managing transportation. It ensures accuracy, fairness, and user satisfaction, leading to more efficient and user-friendly transportation systems on a larger scale.

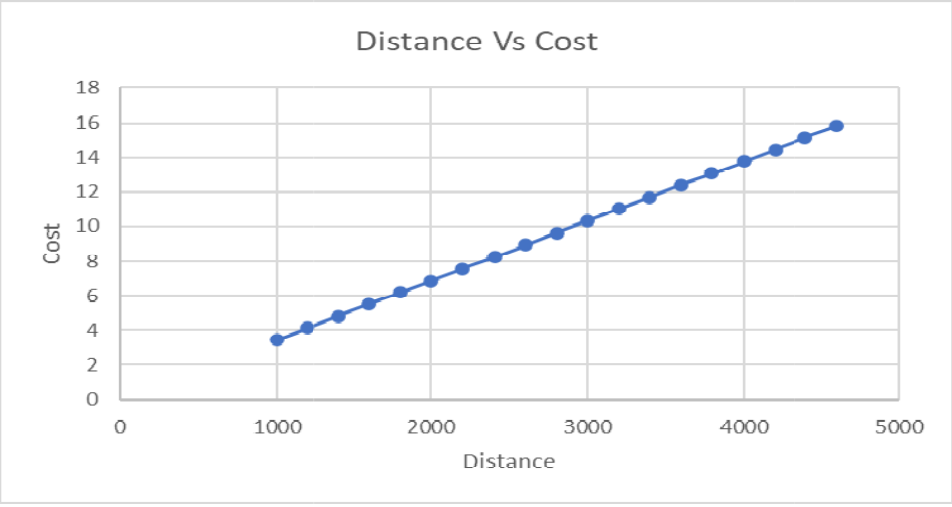

Figure 4. Distance (in meters) versus Cost (in Rupees) plot of the Automatic toll collection system

Figure 4. is a plot of how the toll amount will have a linear relationship with an increasing distance in the automatic toll collection system and is due to the fact that the amount is predefined in the system. As a result, there will be no chances of false toll charging and the amount calculation made each easier. Even if there are other parameters that might affect toll amount, they can be integrated into the system with ease.

5 Future Scope

5.1 Road-Based Geofence Automation

Future developments can aim to automate geofence creation along road networks, eliminating manual setup and improving system efficiency. Real-time road data integration can dynamically adjust toll zones, ensuring accurate toll calculations based on the vehicle's route.

5.2 Advanced Security and User Authorization

Emphasis can be placed on bolstering system security and user authentication. Implementation of authentication methods can enhance data protection. Additional-ly, solutions for scenarios like phone unavailability or shutdown can be explored for system robustness.

5.3 Data-Driven Optimization and Maintenance

Leveraging data analytics for predictive maintenance and traffic management is vital. Analyzing vehicle movements, toll transactions, and system performance can optimize toll rates, reduce downtime, and contribute to smarter traffic management strategies, benefiting both users and transportation authorities.

6 Challenges

As this project transitions from the traditional physical infrastructure method of toll collection to a digital approach, it encounters several challenges inherent to this technological shift.

In the initial phase of project implementation, issues surfaced with the use of independent GPS modules for location tracking. To address this, compatibility with smartphone GPS and integration with the inbuilt GPS systems found in contemporary vehicles were established. During testing, an observation was made wherein, even when stationary, the GPS module registered an increase in distance after a few minutes. While seemingly negligible, the cumulative effect over time could result in excess toll deductions from users. A proposed solution involves employing accurate GPS modules and, in some instances, multiple modules to ensure precise distance and toll calculations.

Technical complications, including system failures, sensor malfunctions, or GPS inaccuracies, pose potential disruptions to the seamless operation of this system. Proposed mitigations encompass enhanced error detection algorithms and the incorporation of multiple GPS modules to offset the impact of failures.

Considering that a substantial number of vehicles lack integrated GPS systems, the successful implementation of this system mandates the installation of GPS technology in each individual vehicle. A phased initiation, commencing with vehicles equipped with GPS, is recommended. As congestion diminishes, collaboration with traditional physical toll booths can be explored to ensure compliance with toll payment.

Considering the digital nature of this automatic toll collection system, the security risk associated with hacking and data breaches emerges as a pertinent concern. Hence, it is imperative to institute robust security protocols, encompassing data encryption and regular security updates, to mitigate these potential threats.

In conclusion, the introduction of any new technology invariably encounters challenges during its initial stages. Consequently, a prudent approach involves commencing the implementation on a smaller scale, assessing its efficacy, addressing identified issues, and subsequently expanding the implementation for maximum benefit.

7 Conclusion

The "Automated Toll Collection" project has truly brought forth an innovative and transformative system that holds the potential to revolutionize conventional toll collection processes. By cleverly integrating geofence technology, a web-based platform, and intelligent algorithms, the project has ushered in a new era of efficiency, alleviating congestion and enhancing the overall user experience.

A notable achievement of this system lies in its remarkable precision when calculating distances. This accuracy is crucial for various applications, ranging from optimizing routes to minimizing disputes over toll charges. It ensures users are billed based on the actual distance covered, promoting transparency and fairness in toll collection.

Moreover, the incorporation of intelligent algorithms in toll calculations ensures fairness and adaptability. This fairness cultivates user trust and minimizes conflicts, as individuals are charged in accordance with their actual road usage. The adaptability of these algorithms allows the system to evolve with changing road conditions and pricing models, ensuring flexibility and responsiveness in the toll collection process.

The web-based platform has significantly contributed to streamlining user interactions and facilitating real-time data processing capabilities. It has transformed toll collection into a user-friendly process, providing swift access to information related to routes, toll charges, and virtual account management. In doing so, it has set a standard for convenience and effectiveness in the domain of toll collection.

The project's success not only confirms its reliability but also underscores its scalability and the promising potential for future improvements.The groundwork has been laid for further advancements in automated toll collection, with the possibility of integrating other emerging technologies and advanced data analytics. This offers a glimpse into a future where toll collection becomes even more streamlined, efficient, and user-centric.

In conclusion, the "Automated Toll Collection" project not only presents a practical and efficient approach to toll collection but also lays the groundwork for a more sustainable and user-friendly system. It represents a significant stride towards improving transportation management and envisions a future where toll collection is not merely a functional necessity but an experience that benefits all parties involved.

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