Automatic Toll System and Traffic Ideas Using GPS, Satellite, and Piezoelectric Energy.

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This paper proposes an automatic toll and traffic management system using GPS and satellite technology to calculate toll charges based on the distance travelled by vehicles. The system eliminates the need for stopping at toll booths, reducing traffic congestion and fuel consumption. Additionally, piezoelectric sensors installed under speed breakers generate electrical energy from vehicle movement, which can be used for street lighting and highway infrastructure. The proposed system improves efficiency, transparency, and sustainability in modern transportation systems. ***Keywords: Automatic Toll System, GPS, Satellite Communication, Piezoelectric Energy, Smart Transportation***

INTRODUCTION

The rapid increase in vehicle usage has significantly impacted highway transportation systems. Toll collection points, which are necessary for road maintenance and revenue generation, often become major traffic bottlenecks. Vehicles are required to slow down or stop at toll plazas, resulting in long queues, fuel wastage, time loss, and increased air pollution. Although electronic toll systems like FASTag have reduced manual operations, issues such as network dependency, transaction failures, insufficient balance, and system downtime still exist.

Advancements in Global Positioning System (GPS) technology and satellite communication provide an opportunity to overcome these limitations. GPS-based tolling allows toll charges to be calculated based on the actual distance travelled by a vehicle, eliminating the need for physical toll booths. This approach ensures fair toll collection while improving traffic flow.

At the same time, the demand for renewable and sustainable energy solutions has increased. Piezoelectric technology offers a novel approach to generate electricity from mechanical pressure. Roads and speed breakers experience continuous pressure due to vehicle movement, which can be utilized to generate electrical energy.

This study proposes an integrated system that combines GPS-based automatic toll collection with piezoelectric energy harvesting to create an efficient, automated, and environmentally friendly traffic management solution.

RELATED WORK

Various studies have been conducted in the field of electronic toll collection and intelligent transportation systems. GPS-based toll systems have been introduced to calculate toll charges using vehicle location data, reducing dependence on physical toll plazas. However, many such systems rely heavily on internet connectivity and centralized servers, making them less effective in rural or low-network areas.

Research on piezoelectric energy generation has demonstrated the feasibility of producing electrical energy from road pressure using piezoelectric materials. These studies mainly focus on powering streetlights and roadside equipment but do not integrate toll collection mechanisms.

Satellite-based traffic monitoring and IoT-enabled systems have also been explored for real-time vehicle tracking and congestion management. Government reports on FASTag implementation indicate improvements in toll efficiency, but they also highlight challenges such as technical failures and user dissatisfaction. Overall, existing research largely addresses toll automation and renewable energy generation independently, creating a gap for integrated solutions.

PROPOSED DUAL-MODE FRAMEWORK

The proposed system follows a dual-mode framework that integrates automatic toll collection and renewable energy generation into a single intelligent transportation solution.

1. GPS–Satellite Based Automatic Toll System:

In this module, each vehicle is equipped with a GPS device linked to the owner's registered bank account. The GPS continuously tracks vehicle movement and sends location data through satellite communication to a central toll management server. The server calculates the distance travelled on toll roads and automatically deducts the corresponding toll amount from the linked account. A confirmation message is sent to the vehicle owner after successful payment. This method eliminates the need for toll booths and allows vehicles to move without stopping.

2. Piezoelectric Energy Generation Module: In this module, piezoelectric sensors are installed beneath speed breakers on highways. When vehicles pass over these speed breakers, mechanical pressure is applied to the sensors, generating electrical energy. The generated energy is stored in batteries and can be used for street lighting, traffic signals, or other highway utilities. This approach promotes sustainable energy usage and reduces dependence on conventional power sources.

Objectives

The objectives of this study are as follows:

1. To develop an automatic toll collection system using GPS and satellite communication.
2. To calculate toll charges based on the actual distance travelled by vehicles.
3. To reduce traffic congestion and waiting time at toll points.
4. To minimize human involvement in toll collection operations.
5. To generate renewable energy using piezoelectric sensors installed on roads.
6. To utilize the generated energy for highway infrastructure such as streetlights and signals.

Hypothesis of the Study

The study is based on the hypothesis that integrating GPS-based toll collection with piezoelectric energy harvesting can provide an efficient, automated, and sustainable traffic management solution.

1. GPS and satellite-based tracking can accurately calculate distance-based toll charges without physical toll booths.
2. Automatic toll deduction can significantly reduce traffic congestion and waiting time.
3. Piezoelectric sensors can generate usable electrical energy from vehicle movement.
4. An integrated system can reduce operational costs and environmental impact compared to traditional toll systems.

Significance of the Study

This study is significant as it addresses both traffic congestion and energy sustainability challenges faced by modern transportation systems. By eliminating toll booths, the proposed system improves traffic flow and reduces fuel consumption and emissions.

The use of piezoelectric energy harvesting promotes renewable energy generation using existing road infrastructure. The system reduces dependency on manual labor and network-intensive toll systems, making it suitable for smart highways and future transportation networks.

Additionally, the proposed framework provides a scalable and transparent toll collection mechanism that can be adapted for large-scale highway networks.

Literature Review

Recent advancements in intelligent transportation systems have focused on automating toll collection and improving traffic efficiency. Several studies highlight the benefits of GPS-based tolling in reducing congestion and ensuring fair toll pricing. Research on piezoelectric materials demonstrates their potential to generate electricity from mechanical stress in road environments.

However, most existing studies address these technologies separately. Limited research focuses on integrating toll automation with renewable energy generation. This study builds upon existing research by combining both approaches into a unified framework.

Adoption of Intelligent Toll and Traffic Systems Before Smart Transportation

Before the adoption of intelligent and automated transportation systems, toll collection and traffic management were mainly handled through manual and semi-automatic methods. Vehicles were required to stop at toll booths where payments were collected using cash or card-based systems. Although these methods ensured toll revenue collection, they resulted in long queues, increased fuel consumption, time delays, and higher air pollution.

Early technological improvements introduced electronic toll collection systems such as RFID-based FASTag, which reduced manual effort but still required physical toll plazas. These systems depended heavily on network connectivity and centralized servers, leading to transaction failures and operational delays in low-network areas. Traffic monitoring was largely reactive and lacked real-time distance-based toll calculation or integrated energy efficiency solutions.

The absence of automation, sustainability measures, and real-time tracking highlighted the need for advanced systems like GPS-based tolling and renewable energy integration, forming the foundation for smart and intelligent transportation infrastructure.

Research Methodology

The research adopts an experimental and system-oriented methodology focused on practical implementation and evaluation.

The system was designed using GPS modules, satellite communication, microcontrollers, piezoelectric sensors, energy storage units, and LED indicators.

The methodology includes system design, prototype development, data collection, and performance evaluation. The system was tested for toll calculation accuracy, traffic flow improvement, and energy generation efficiency.

Research Design

The research design follows a modular architecture consisting of two independent yet interconnected modules: GPS-based toll collection and piezoelectric energy generation. This design allows easy integration, scalability, and future enhancement without affecting the overall system performance.

Challenges Faced in Post-Adoption of Intelligent Toll and Traffic Management Systems

After the adoption of automated toll and smart traffic management systems, several practical challenges have been observed. One major issue is the heavy dependence on reliable network and satellite connectivity. In areas with weak signals, toll data transmission and vehicle tracking may be delayed or inaccurate, affecting system performance.

Technical challenges such as GPS signal loss in tunnels, urban canyons, or adverse weather conditions can impact distance-based toll calculation. Hardware components, including GPS devices and roadside sensors, require regular maintenance and calibration to ensure accuracy and reliability. Any malfunction can lead to incorrect toll deductions or system downtime. Cost is another significant challenge, especially during large-scale deployment. High initial investment for satellite communication, sensor installation, and system integration can limit adoption. Additionally, piezoelectric sensors may experience efficiency reduction over time due to continuous heavy vehicle pressure.

User awareness and acceptance also play a role, as drivers may have concerns regarding privacy, tracking, and automatic payment deductions. These challenges highlight the need for robust system design, reliable infrastructure, and proper regulatory support for successful long-term implementation.

Results and Discussion

The experimental results indicate that the proposed system accurately calculates toll charges based on distance travelled. Vehicles were able to pass toll zones without stopping, resulting in a significant reduction in waiting time.

Piezoelectric sensors generated measurable electrical output under normal vehicle load conditions, which was sufficient to power low-energy devices such as LED streetlights. The results demonstrate improved traffic efficiency and effective utilization of renewable energy.

System Efficiency and Resource Utilization The system requires minimal human intervention and reduces operational costs associated with traditional toll booths. Since toll calculation is automated and energy is generated locally, the system efficiently utilizes both technological and natural resources.

The dual-mode framework ensures optimal use of road infrastructure for both transportation management and energy generation.

Future Scope and Limitations

- **Future Scope**

The system can be enhanced by integrating artificial intelligence and IoT technologies for predictive traffic management. Blockchain-based secure payment systems can improve transaction transparency. The generated energy can be extended for electric vehicle charging stations, and mobile applications can be developed for real-time toll tracking.

- **Limitations of the Proposed System**

The system requires high initial investment for GPS devices, satellite communication, and piezoelectric sensor installation. GPS accuracy may be affected in tunnels or low-signal areas, and piezoelectric sensors may degrade under heavy traffic conditions.

LIMITATIONS OF THE STUDY

The study focuses primarily on toll automation and energy generation and does not include large-scale real-world deployment. Environmental and climatic factors affecting sensor performance were not extensively analyzed.

Opportunities in Intelligent Toll and Smart Traffic Management Systems

The rapid growth of smart city initiatives and intelligent transportation systems creates significant opportunities for the adoption of automated toll and traffic management solutions. GPS- and satellite-based toll collection systems enable seamless, distance-based tolling without physical toll booths, making them highly suitable for modern highways and expressways. This approach improves traffic flow, reduces congestion, and enhances user convenience.

The integration of piezoelectric energy harvesting introduces opportunities for sustainable infrastructure development. Roads and speed breakers can be transformed into energy-generating assets, producing electricity for street lighting, traffic signals, surveillance systems, and emergency communication units. This supports renewable energy goals and reduces dependence on conventional power sources. There is also strong potential for integration with emerging technologies such as IoT, artificial intelligence, and blockchain. AI-based analytics can be used for predictive traffic management, while blockchain can ensure secure and transparent toll transactions. Mobile applications and digital dashboards can further enhance user interaction by providing real-time toll information, travel analytics, and payment history.

Government transportation agencies and highway authorities can leverage this system to modernize toll operations, reduce operational costs, and improve environmental sustainability. Overall, the proposed system presents a scalable, future-ready opportunity for developing smart, efficient, and eco-friendly transportation infrastructure.

Conclusion

This research presents an integrated automatic toll collection and traffic management system using GPS, satellite communication, and piezoelectric energy harvesting. The proposed approach eliminates toll booths, reduces congestion, and promotes renewable energy generation.

The results demonstrate that combining automation with sustainable energy solutions can significantly improve transportation efficiency. With further development and real-world implementation, the system has the potential to contribute to smart highways and environmentally responsible transportation infrastructure.

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