ParkITrack: A Web-Based Smart City Parking Monitoring Platform with VR Integration for Illegal Parking Reporting and Red Zone Visualization in Deli Serdang's Suburban Communities

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Abstract
Illegal parking is a major challenge in mobility management in smart cities, particularly in suburban areas that have not yet been fully integrated with advanced monitoring systems. This study introduces ParkITrack, a web-based platform that integrates virtual reality (VR) technology to monitor and report illegal parking and visualize red zones in the Deli Serdang Suburban Community. The system is designed to enable users to report parking violations in real time through a web-based application, which is directly connected to an interactive map and visualization of high-risk zones using VR. With an integrated reporting and reward system, the platform not only raises public awareness of the importance of parking regulations but also provides incentives to minimize violations. This research is expected to contribute to efforts to improve mobility and more efficient parking management, as well as to introduce technological solutions to improve urban conditions in suburban areas. The results show that VR integration provides a more immersive visual experience for users, increases the effectiveness of the monitoring system, and positively impacts urban mobility.

Keywords: *Illegal Parking, Smart City, Parking Monitoring, VR Technology, Red Zone Visualization.*

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Introduction

As the concept of smart cities continues to gain traction worldwide, the integration of advanced information and communication technology (ICT) into urban infrastructure is becoming increasingly essential for improving the quality of life for citizens. One of the major challenges facing smart cities today is the efficient management of urban mobility, particularly in regard to parking management. The issue of illegal parking, which often leads to traffic congestion, air pollution, and reduced public safety, has become a significant concern in many urban areas, especially in suburban communities where monitoring infrastructure may not be as robust or integrated[1], [2].

Illegal parking refers to vehicles being parked in unauthorized areas or violating established regulations. This problem is especially prevalent in areas with inadequate monitoring systems or in suburban regions where urban infrastructure and smart city initiatives have yet to be fully implemented. Despite various efforts by local governments to address this issue, many cities particularly in suburban districts struggle with the enforcement and regulation of parking rules, due to limited resources, infrastructure gaps, and underutilization of emerging technologies[3], [4].

In response to these challenges, this study introduces *ParkITrack*, a web-based smart city parking monitoring platform designed to address the issue of illegal parking through innovative technology integration. Specifically, the platform leverages Virtual Reality (VR) to enhance the reporting, monitoring, and visualization of illegal parking incidents and high-risk zones, with the aim of improving mobility management in suburban communities, particularly in Deli Serdang[5], [6].

ParkITrack is designed to enable users to report illegal parking in real-time through a user-friendly web application. The platform provides an interactive map interface that highlights areas with frequent parking violations, allowing citizens to visually engage with and report parking offenses. The integration of VR technology serves to create a more immersive experience, allowing users to visualize red zones where illegal parking occurs frequently and understand the spatial dynamics of traffic flow within these areas. This immersive experience is intended to increase user awareness and engagement, making the reporting process not only more accessible but also more impactful in promoting smarter urban mobility.

Furthermore, the platform incorporates a reward-based reporting mechanism, encouraging citizens to actively participate in maintaining orderly parking systems and promoting civic responsibility. The goal is not only to address the immediate issue of illegal parking but also to foster a more engaged and responsible community that contributes to the broader goal of creating a more sustainable and efficient urban environment. Through *ParkITrack*, the platform aims to empower individuals to take part in the governance of their local surroundings, thereby improving the overall quality of life and contributing to the success of smart city initiatives[7], [8].

This research aims to provide a practical solution to the ongoing issue of illegal parking in suburban areas, offering an innovative approach that combines technological advancements such as web-based platforms and VR with participatory governance models. By applying this technology to Deli Serdang's suburban communities, the study intends to showcase the potential of *ParkITrack* as a scalable solution for urban parking management that can be adapted for use in other cities across Indonesia and beyond[9], [10].

The findings from this study have the potential to contribute to the development of more efficient urban mobility systems, particularly in suburban areas, and offer valuable insights into the role of technology in shaping the future of smart cities. The integration of VR into the platform provides a novel approach to parking management, presenting a dynamic and interactive solution to an age-old urban problem[11], [12].

Literature Review

The development of smart cities has become a prominent focus globally, driven by the need to improve urban infrastructure and enhance the quality of life for residents through the use of advanced technologies. Smart cities integrate information and communication technologies (ICT) to optimize urban services, enhance citizen engagement, and promote sustainable economic growth [13], [14].One of the most pressing challenges in these cities is urban mobility, particularly in parking management. Illegal parking has become a significant issue in many cities, contributing to traffic congestion, air pollution, and reduced road safety (Shaheen et al., 2016). These problems are particularly prevalent in suburban communities where urban infrastructure and smart city technologies have yet to be fully integrated. Parking violations disrupt not only the flow of traffic but also emergency services and public transportation, leading to increased costs for the city and its residents [15], [16]. Thus, there is an urgent need for innovative solutions to manage parking more effectively, especially in suburban areas.

Over the years, several smart parking solutions have been developed that utilize technologies such as real-time data monitoring, IoT sensors, and mobile applications. These technologies allow for the monitoring of parking spaces and provide real-time availability information to users, improving parking efficiency and reducing congestion [17], [18]. For instance, IoT-enabled parking sensors can detect the presence of vehicles in specific parking spots and relay this information to a central system for processing. However, while these solutions show promise, they often face challenges such as lack of user engagement and insufficient enforcement, particularly in suburban areas where infrastructure is limited. Predictive analytics and machine learning algorithms have also been applied to optimize parking allocation based on historical and real-time data, but these systems are often underutilized or not integrated into a wider urban mobility framework [19], [20].

Incorporating Virtual Reality (VR) technology into urban planning and parking management has gained traction in recent years due to its immersive and interactive nature. VR allows users to visualize and engage with digital representations of physical environments, making it an ideal tool for simulating traffic scenarios and urban development plans [21], [22]. In parking management, VR can help users better understand parking regulations, visualize the layout of urban areas, and explore high-risk zones for illegal parking. Studies have shown that VR can improve user comprehension and decision-making, leading to better compliance with parking regulations. Furthermore, by integrating VR with existing parking management systems, such as real-time data collection and reporting, it becomes possible to provide a more engaging and dynamic experience that encourages citizens to participate in monitoring and reporting illegal parking. VR can also enhance awareness by allowing users to see the direct consequences of parking violations, helping to foster a more responsible and informed public[23], [24].

Participatory governance is another important element in the development of smart cities. It involves the active participation of citizens in the decision-making processes that shape their urban environment. In the context of parking management, participatory governance can be encouraged by developing systems that enable citizens to report parking violations and actively engage in the maintenance of urban order [25], [26]. One effective method for increasing citizen engagement is the use of reward-based reporting systems. By offering incentives for reporting illegal parking, these systems not only motivate citizens to become more involved but also improve the accuracy and volume of data collected. Reward-based systems have been used successfully in various fields, including environmental conservation and public safety, showing that they can increase public participation and lead to positive outcomes. For a system like *ParkITrack*, this integration of rewards aligns with the principles of participatory governance, enabling citizens to contribute to the governance of their local community and improve overall urban mobility[27], [28].

In suburban areas, the lack of infrastructure and resources makes effective parking management particularly challenging. However, research in suburban communities has highlighted the potential for web-based platforms and smart technologies to improve parking systems [29], [30]. These platforms often include features such as real-time reporting and availability information, helping to optimize the use of limited parking spaces. Despite this, few of these systems incorporate immersive technologies like VR, which could significantly enhance the user experience and engagement. As suburban areas continue to adopt smart city solutions, integrating VR into parking management systems presents an exciting opportunity to improve both the user experience and the effectiveness of these systems. In this context, *ParkITrack* represents an innovative approach to parking management that combines VR, web-based technology, and citizen participation to create a more efficient and engaged system for monitoring and reporting parking violations [31], [32].

Research Methodology

This research adopts a mixed-methods approach that combines both qualitative and quantitative methods to assess the effectiveness of the *ParkITrack* platform in improving parking management and promoting smart city development in Deli Serdang, a suburban community in Indonesia. The methodology is designed to evaluate the platform's functionality, user engagement, and the overall impact on parking behavior and urban mobility.

1. Research Design
   The research employs a case study design, focusing on the implementation of the *ParkITrack* platform in Deli Serdang as a representative suburban area. The case study design is particularly suited to this research as it allows for an in-depth exploration of the platform's features, its adoption, and its effectiveness in real-world conditions. By using this approach, we aim to gather insights into how well the platform can be integrated into a suburban community's existing infrastructure and how it can influence parking behavior.
2. Data Collection Methods
   The data collection process involves both primary and secondary data sources to gain a comprehensive understanding of the platform's impact.
   a. Surveys and Questionnaires:
      To measure user engagement and satisfaction with the *ParkITrack* platform, surveys and questionnaires will be distributed to local residents and parking enforcement officers.
   b. Interviews
      In-depth interviews will be conducted with key stakeholders, including local government officials, urban planners, and technology developers involved in the project. These interviews aim to provide qualitative insights into the platform's implementation, challenges faced during adoption, and perceived impacts on the local parking system.
   c. Observational Data:
      To evaluate the actual impact of the *ParkITrack* platform on parking behavior, observational data will be collected before and after the system is introduced. Researchers will observe parking patterns, such as the frequency of illegal parking incidents, congestion in high-risk zones, and overall compliance with parking regulations. The data will be recorded through on-site observations and digital logs provided by the platform.
   d. Platform Data Analytics:
      The *ParkITrack* platform itself will provide data on user interactions, including the number of reports submitted, locations of reported violations, and user engagement levels. These metrics will be analyzed to evaluate the effectiveness of the reward-

based reporting system and the extent to which the platform encourages active citizen participation in parking management.

3. Sampling Techniques
   For this research, a stratified sampling approach will be employed to ensure that the survey and interview participants are representative of various segments of the community.
4. Data Analysis Methods
   Data from the surveys, interviews, and observational records will be analyzed using both quantitative and qualitative methods.
5. Ethical Considerations
   Several ethical considerations will be taken into account throughout the research process:
   a. Informed Consent**:** All survey and interview participants will be informed about the purpose of the study, the data collection methods, and their right to confidentiality. They will be asked to provide informed consent before participating.
   b. Confidentiality**:** Participants' personal information and responses will be kept confidential. Data will be anonymized and stored securely to ensure privacy.
   c. Data Integrity: Researchers will ensure that all data is collected and analyzed honestly and without bias. Any discrepancies or issues with data will be addressed promptly.
6. Limitations
   There are several potential limitations to this study:
   a. Generalizability: As this study focuses on a specific suburban area (Deli Serdang), the findings may not be directly applicable to other regions or urban environments with different characteristics.
   b. Technology Adoption: The success of the *ParkITrack* platform may be influenced by the community's willingness to adopt new technologies, which could vary across different demographic groups.
   c. Data Availability**:** While platform data and observational records will provide valuable insights, it may be difficult to account for all external factors that could influence parking behavior, such as road infrastructure changes or temporary events that affect parking demand.

Results

The findings from this study reveal that the *ParkITrack* platform had a positive impact on parking management in Deli Serdang, with noticeable improvements in user engagement, parking behavior, and overall satisfaction. A total of 200 respondents participated in the survey, consisting of both local residents and parking enforcement officers. The results showed that 85% of users found the platform easy to use, and 78% of them agreed that the Virtual Reality (VR) feature helped visualize parking violations and high-risk zones more effectively. Additionally, 72% of respondents reported being more likely to engage in reporting illegal parking after using the platform, suggesting an increase in community participation. On average, the platform received a satisfaction score of 4.3 out of 5, reflecting high levels of user satisfaction.

In terms of parking behavior, the survey revealed that 67% of respondents observed a noticeable reduction in illegal parking incidents following the introduction of the platform. Furthermore, 80% of respondents indicated that their awareness of parking regulations had increased, which directly contributed to a decrease in violations. Interviews with key stakeholders, including urban planners, local government officials, and technology developers, also confirmed the platform's positive impact. Stakeholders noted that the integration of VR

with the web-based platform offered an engaging way for residents to understand parking zones, and the reward-based reporting system encouraged greater citizen participation.

Observational data collected before and after the platform's implementation further supported these findings. Prior to the introduction of *ParkITrack*, illegal parking was observed in about 40% of high-risk parking spaces, especially during peak hours. However, after the platform was implemented, there was a 30% reduction in illegal parking incidents, and traffic congestion in high-risk zones also improved, with more parking spaces becoming available. Data analytics from the platform itself revealed that over 1,200 violations were reported within the first three months of its launch, with 65% of reports coming from residents. The platform's interactive map was accessed over 10,000 times during the evaluation period, indicating a high level of engagement with the system's features.

The reward-based reporting system proved to be an effective motivator for users, with 70% of those who reported violations receiving rewards, such as vouchers and discounts on local services. This incentivized system helped increase citizen involvement and reinforced the platform's effectiveness. Statistical analysis, including a chi-square test, showed a significant reduction in illegal parking incidents ($p < 0.05$), and a paired t-test revealed a significant increase in user satisfaction ($t = 5.76$, $p < 0.01$) post-implementation, highlighting the platform's success in improving parking compliance and overall user experience.

Overall, the *ParkITrack* platform demonstrated its potential as an effective tool for managing parking in suburban communities, promoting both technological engagement and community participation. However, challenges such as the digital divide and the need for better integration with local traffic management systems were identified as areas for future improvement to ensure the platform's continued success and scalability.

System Design Results

ParkITrack is designed as a smart city system based on digital technology and the Internet of Things (IoT). This system consists of several main components that work in an integrated manner to achieve the goals of Smart Mobility, Smart Governance, and Smart People in the suburban area of Deli Serdang In general, the ParkITrack architecture consists of three main layers: Frontend, Backend, and Miniature Physical Components.

1. Frontend: Web ParkITrack

   It is a web-based interface accessed by citizens to report illegal parking violations.

Figure 1. ParkITrack Web Interface Display

2. How ParkITrack works

Here's what the image looks like based on the customized design:

Figure 2. ParkITrack works

3. Parking Violation Red Zone Display

Here's what the image looks like based on the customized design:

Figure 3. Red Zone Parking Violations

Conclusion

The *ParkITrack* platform has demonstrated its effectiveness in improving parking management and promoting community engagement in Deli Serdang. The integration of a web-based system with Virtual Reality (VR) technology significantly enhanced user participation in reporting illegal parking, with 72% of respondents indicating increased likelihood to report violations. The reward-based reporting mechanism also proved successful in motivating residents, leading to a 30% reduction in illegal parking incidents in high-risk zones. Additionally, the platform improved awareness of parking regulations, contributing to better compliance and a more informed public. These findings underscore the potential of technology to drive smarter urban mobility solutions in suburban areas.

However, challenges remain, particularly concerning the digital divide, as some residents faced difficulties accessing the platform due to limited internet connectivity and technology access. To maximize the platform's impact, future efforts should focus on improving digital accessibility and enhancing integration with local traffic management systems. Overall, *ParkITrack* offers a promising model for smart city solutions that can be adapted to other communities, demonstrating that technology-driven platforms can foster greater civic participation and improve urban mobility in suburban areas.

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