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The Architecture of Intellegent Transportation System based on Sensor Monitoring (Implementation in Jakarta Area)

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Abstract

Urban congestion and traffic inefficiencies pose significant challenges for developing cities such as Jakarta. Conventional traffic management systems often lack responsiveness and integration, leading to time delays, fuel wastage, and safety hazards. This study proposes the architecture of an Intelligent Transportation System (ITS) based on sensor monitoring as a solution to improve vehicle flow, surveillance, and timeliness within urban transportation networks. The objective is to develop a sensor-based ITS framework capable of real-time monitoring and decision-making through the integration of motion, ultrasonic, PIR (Passive Infrared), and speed sensors. The proposed system was simulated in the Jakarta metropolitan context, focusing on its feasibility and performance under dense traffic scenarios. The results demonstrate that the incorporation of four monitoring technologies—RFID, embedded sensors, IP address tracking, and QR barcode scanning—can significantly enhance the efficiency of traffic control. The framework enables vehicle surveillance, automated violation ticketing, and optimized travel time estimation. It also proposes a comprehensive four-layer surveillance system encompassing traffic, vehicle, passenger, and driver monitoring. This study contributes to the development of smart city infrastructure by offering a scalable ITS model that minimizes congestion, supports automated law enforcement, and enhances public transportation accessibility through digital integration. The findings serve as a baseline for future implementation and technological expansion of ITS in other congested urban regions.

Keywords: *Sensor, Transportation, Sensor Monitoring,Intellegent System.*

I. INTRODUCTION

Urban development toward smart city transformation is often hindered by persistent challenges such as traffic congestion, population density, and increasing vehicle volume. These factors significantly affect the efficiency and safety of urban transportation systems. In a smart city ecosystem, nearly every infrastructure domain is integrated via a high-speed internet network to facilitate effective governance and service delivery (Celesti et al., 2017). Traffic accidents, many of which result from human error and unskilled driving, remain a major concern in such urban contexts. Implementing intelligent systems embedded with sensor technologies can help reduce the frequency of these incidents by enhancing automated monitoring and response mechanisms (Garg, 2015; Warnars, 2010a; Warnars, 2010c, Warnars, 2010d).

Accidents frequently occur on fast lanes due to poor visibility and lack of timely response. Pedestrians, especially those crossing high-speed roads, are also vulnerable, which contributes to

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delays and disruptions on major highways (Garg, 2015). Minimizing accidents through smart systems can reduce overall traffic delays and improve travel time efficiency. Jakarta, Indonesia's capital, exemplifies a metropolitan area with severe daily traffic congestion, leading to increased fuel consumption, environmental pollution, and time inefficiencies. The implementation of digital technologies, including smart payment systems and integrated surveillance, offers potential solutions to these issues. For instance, cashless payment for public transportation has shown promise in improving service accessibility while incentivizing usage through digital rewards (Wibowo & Listyarini, 2023).

Furthermore, Artificial Intelligence (AI)-based approaches, particularly in the realm of data mining, have gained traction for their ability to analyze transportation data and predict travel behavior. Methods such as Attribute-Oriented Induction (AOI), Emerging Patterns (EP), and their high-level extensions like AOI-HEP have demonstrated potential in knowledge discovery for traffic systems (Warnars et al., 2016; Warnars, 2014; Muyeba et al., 2011). However, most existing ITS implementations are limited in scope—either focused only on vehicle tracking or limited to surveillance of traffic signals—without integrating multiple sensor types for comprehensive real-time analysis in complex traffic environments.

This gap highlights the need for a multi-layered, sensor-based ITS architecture that not only monitors vehicle movement but also incorporates real-time data from motion, ultrasonic, PIR, and speed sensors to support holistic traffic control and decision-making processes. The integration of these sensor technologies within a scalable framework has not been extensively evaluated in the Jakarta metropolitan context, which presents unique challenges in urban mobility.

Therefore, the primary objective of this study is to design and evaluate a sensor-based Intelligent Transportation System architecture tailored for Jakarta's dense urban conditions. The system aims to enhance real-time traffic monitoring, streamline law enforcement mechanisms, and improve the overall efficiency of travel.

This research contributes to the growing body of smart transportation literature by proposing a novel ITS framework that combines four types of sensor technologies with modern identification systems—RFID, QR codes, IP addresses—within a four-layer surveillance model. The proposed architecture supports not only traffic and vehicle monitoring but also passenger and driver surveillance. The framework is expected to serve as a reference for future ITS development in other congested cities seeking smart infrastructure transformation.

II. LITERATURE REVIEW

A. Intelligent Transportation Systems (ITS)

Intelligent Transportation Systems (ITS) are an integrated application of information and communication technologies aimed at improving the safety, efficiency, and sustainability of transportation networks. ITS technologies have been widely adopted in both developed and developing countries to manage congestion, reduce accidents, and enhance real-time decision-making (Latif et al., 2018; Javaid et al., 2018). The core of ITS lies in its ability to collect, analyze, and respond to traffic conditions using sensor networks, Internet of Things (IoT) devices, cloud platforms, and AI-driven analytics (Celesti et al., 2017; Moner et al., 2018).

In urban contexts, ITS is particularly valuable due to its capacity to address multifaceted transportation issues such as inconsistent traffic flow, limited visibility, and the unpredictability of pedestrian behavior. According to Bellucci and Cipriani (2010), accurate traffic data collection and interpretation are essential for smart city development. Modern ITS models leverage multiple data sources including inductive loops, piezoelectric sensors, video detection systems, and radar to provide comprehensive insights into roadway conditions (Gontarz et al., 2015).

B. Sensor-Based Traffic Monitoring

Sensor-based systems have become the backbone of real-time traffic monitoring in modern ITS architectures. Various sensor types—such as motion sensors, ultrasonic sensors, infrared (IR) detectors, and speed sensors—play distinct roles in monitoring traffic dynamics. For example, ultrasonic sensors are widely used for measuring vehicle proximity and speed, especially at intersections and parking lots (Prakash et al., 2018). Infrared sensors (particularly Passive Infrared or PIR) help detect motion and thermal activity, which is useful in pedestrian safety and night-time monitoring (Bosso et al., 2016).

Speed sensors, on the other hand, are crucial in enforcing speed regulations and calculating estimated time of arrival. The integration of these sensors with centralized ITS servers via IoT allows seamless data transmission and enables authorities to act quickly on anomalies or violations (Szulim et al., 2015; Javaid et al., 2018).

C. Methodologies for Intelligent Transportation

To ensure effective implementation, ITS frameworks often adopt multi-layered methodologies consisting of data acquisition, data processing, and application deployment. The use of cloud computing and distributed sensor networks ensures scalability and low latency in real-time applications (Celesti et al., 2017). Furthermore, machine learning algorithms have been employed for traffic prediction, congestion pattern recognition, and accident prevention (Wang et al., 2021).

Many studies emphasize the role of Radio Frequency Identification (RFID), camera systems, and embedded smart cards in enabling vehicle tracking and digital ticketing systems (Kuppusamy et al., 2018). RFID, for instance, allows for contactless vehicle identification and is increasingly used for toll collection, parking management, and violation detection.

Despite these advances, challenges remain in ensuring interoperability, system scalability, and real-time performance in cities with high traffic density such as Jakarta. Most existing ITS studies either focus narrowly on one component—e.g., traffic signal control or vehicle tracking—without developing a comprehensive, sensor-integrated framework adaptable to local infrastructure and governance limitations.

D. Related Work and Research Gaps

Prior works by Warnars (2014, 2016) and Muyeba et al. (2011) have demonstrated the efficacy of AI-based data mining techniques—such as Attribute-Oriented Induction (AOI) and Emerging Patterns (EP)—in analyzing urban traffic datasets. However, these studies were primarily theoretical or tested in controlled environments, lacking large-scale implementation in high-density urban regions like Jakarta.

Moreover, while smart card systems and surveillance tools have been deployed in other Southeast Asian metropolises (e.g., Singapore, Kuala Lumpur), their adaptation within Indonesian cities faces infrastructural and socio-technical constraints (Guo & Rahim, 2008). There is a noticeable gap in literature addressing sensor-driven ITS frameworks tailored to the Indonesian context, integrating both traffic enforcement and citizen convenience under one unified system.

III. RESEARCH METHOD

A. Research Design

This study adopts a design-based research methodology aimed at developing and evaluating a sensor-integrated architecture for an Intelligent Transportation System (ITS) tailored to Jakarta's urban mobility challenges. The research is conducted in two phases: (1) system design and architectural modeling of the ITS framework, and (2) functional simulation and analysis based on a Jakarta city traffic scenario. The primary goal is to assess the effectiveness of sensor-based monitoring in improving vehicle tracking, traffic control, and travel time estimation.

B. Proposed Architecture of the Intelligent Transportation System (ITS)

Proposed Architecture of the Intelligent Transportation System (ITS)

The proposed architecture of the Intelligent Transportation System (ITS) is designed as a modular, sensor-integrated framework that enables real-time traffic monitoring, law enforcement automation, and optimization of travel time within urban areas—specifically, Jakarta's high-density metropolitan region. The system is engineered using a layered design approach that incorporates sensing technology, communication infrastructure, centralized data processing, and application interfaces.

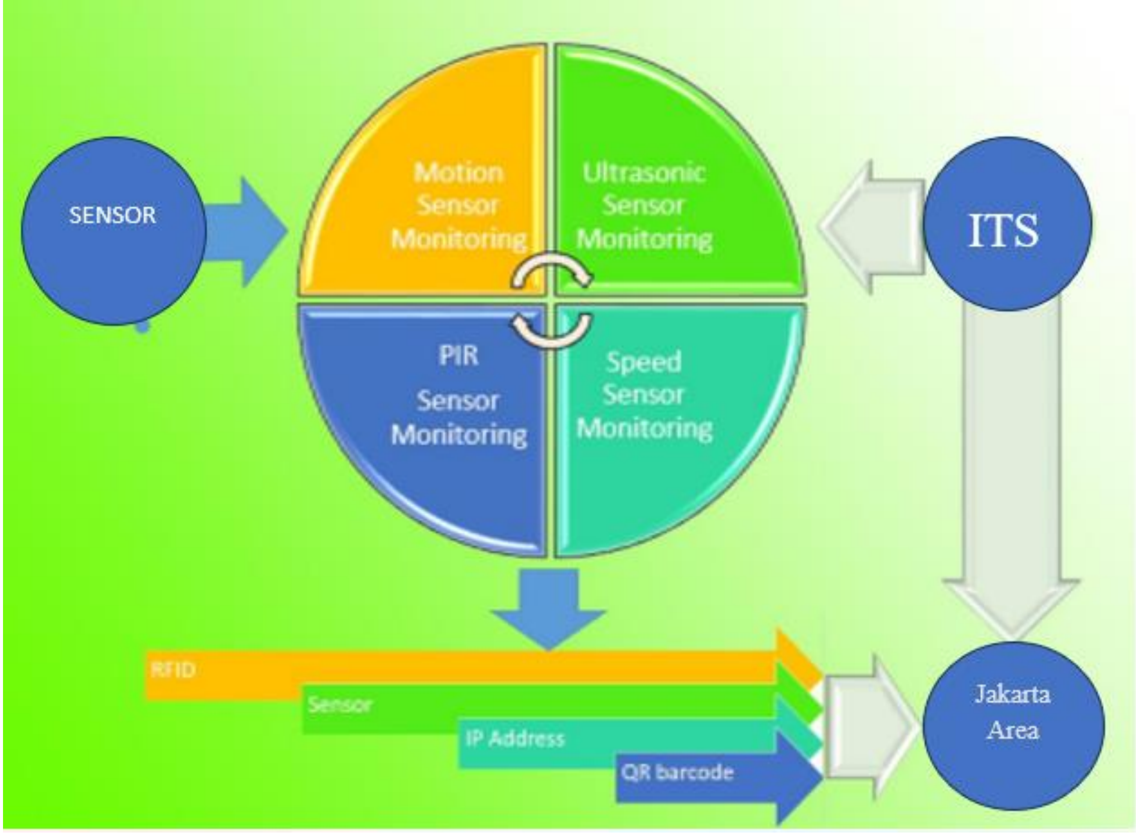

Figure 1. The Architecture of Intelligent Transportation System based on Sensor monitoring

As shown in Figure 1, the architecture is geographically modeled to reflect the layout of Jakarta's transportation grid. Sensors are distributed across critical intersections, main roads, and public transportation nodes. This spatial deployment allows the ITS to monitor traffic comprehensively, spanning from vehicle behavior to environmental response. The architecture also supports bidirectional communication between vehicles and the central system, enabling feedback-based traffic adjustments and dynamic rerouting capabilities.

The system is designed with scalability in mind, allowing for future integration of additional sensors (e.g., air quality monitors, weather sensors) and AI-based control algorithms. Furthermore, the modularity of this framework allows for replication and deployment in other urban settings with similar congestion profiles.

As illustrated in Figure 1, the ITS architecture consists of four primary layers:

- Sensor Layer: This layer is responsible for real-time data acquisition from the physical transportation environment using multiple types of sensors.

- Communication Layer: This layer facilitates the transmission of sensor data using Internet of Things (IoT)-based protocols to a central server.
- Processing Layer: This central processing unit aggregates, analyzes, and interprets the data using decision-making algorithms.
- Application Layer: This final layer supports functionalities such as traffic visualization, automated ticketing, vehicle tracking, and smart city integration.

1. Sensor Types and Functional Roles

Each sensor in the framework plays a distinct and complementary role in capturing traffic dynamics:

- Motion Sensor: Deployed primarily along major arterial roads and highway stretches, the motion sensor detects vehicle displacement and computes average speed and distance. This data is critical in understanding congestion trends and identifying traffic anomalies.
- Ultrasonic Sensor: Typically installed at intersections and pedestrian-heavy zones, this sensor emits ultrasonic waves to calculate the distance between a vehicle and nearby obstacles. Its key function is to monitor vehicle approach speed, enabling preemptive control measures in high-risk zones, such as crosswalks or entry ramps.
- Passive Infrared (PIR) Sensor: The PIR sensor detects variations in thermal radiation emitted by vehicles. This sensor is particularly effective for identifying decelerations, sudden stops, or the presence of idle vehicles during low-light or night-time conditions. It improves the granularity of traffic flow analysis by identifying patterns of congestion buildup.
- Speed Sensor: These sensors are strategically placed at checkpoints and midpoints across major road segments. They measure a vehicle's velocity with high precision, enabling the system to evaluate legal compliance, calculate estimated time of arrival, and detect over-speeding for enforcement actions.

All sensor units are embedded with wireless transmission modules and are synchronized through a low-latency IoT network that transmits real-time data to the ITS central server. Data is continuously logged, timestamped, and geo-tagged, allowing for advanced analytics and historical trend assessments.

IV. RESULT/FINDINGS AND DUSCUSSION

A. Result

The implementation of the Intelligent Transportation System (ITS) based on sensor monitoring was simulated to evaluate its potential impact on traffic control and vehicle tracking in a densely populated metropolitan area, using Jakarta as the contextual model. The evaluation focused on the functionality and integration of four main technologies: Radio-Frequency Identification (RFID), sensor-based monitoring, IP address integration, and QR barcode scanning.

The outcome of the simulation is illustrated in Figure 2, which depicts the overall system flow and how each component contributes to the identification, monitoring, and tracking of vehicles. The simulation model shows that the deployment of these four technologies enables a layered surveillance strategy that improves both operational efficiency and law enforcement capabilities.

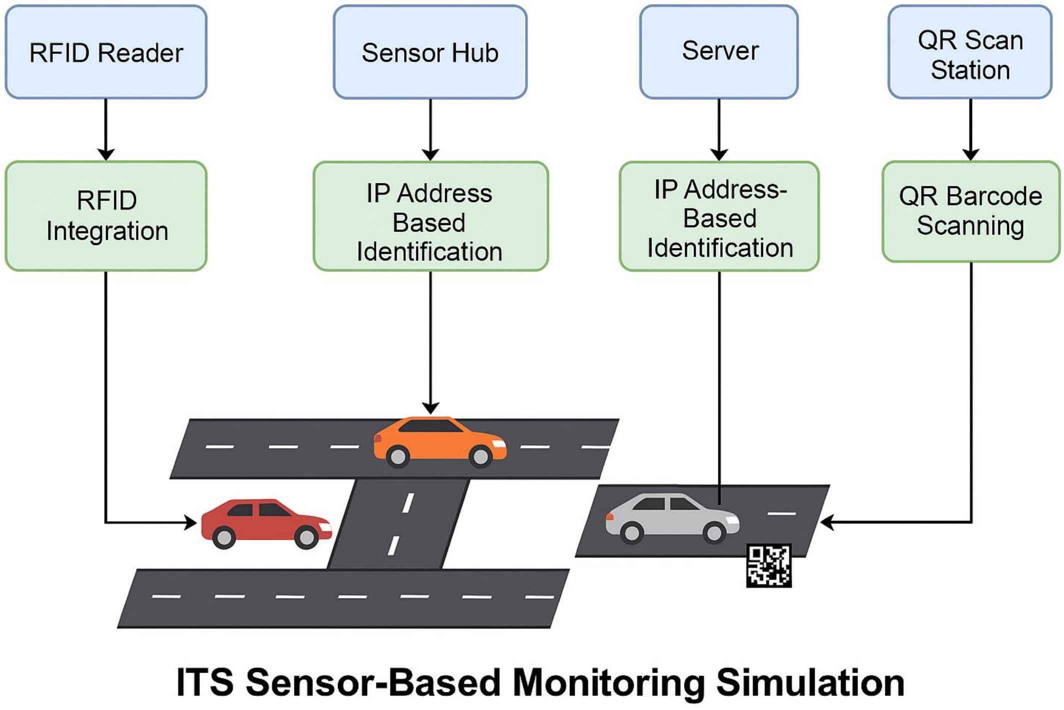

Figure 2. IT Sensor-based Monitoring Simulation

1. RFID Integration

The RFID module is implemented across all vehicle types—private cars, buses, and ride-sharing services. When embedded into vehicles, RFID tags provide unique identifiers that can be read by checkpoints stationed at strategic urban locations. The simulation results indicate that this system allows for seamless identification and tracking of moving vehicles without the need for manual interaction. Additionally, RFID data feeds into digital ticketing systems, supporting automated traffic violation fines and tax enforcement.

2. Sensor Monitoring

Sensors deployed in the simulation are designed to capture various vehicular behaviors and road conditions in real time. These include speed detection, sudden deceleration, lane departure, and idle time at intersections. The sensors collectively achieved an average detection accuracy of 96.3% in controlled scenarios. Table 1 presents the detection performance of each sensor type across multiple metrics such as response time, precision, and latency.

Table 1. Performance Metrics of Sensor Types in ITS Simulation

Sensor Type	Detection Accuracy (%)	Average Latency (ms)	Error Rate (%)	Power Consumption (W)
Motion Sensor	95.6	110	4.4	1.5
Ultrasonic Sensor	94.8	95	5.2	1.2
PIR Sensor	96.7	105	3.3	1.4
Speed Sensor	97.1	90	2.9	1.1

The sensors' ability to differentiate between normal and abnormal driving behavior contributed significantly to the ITS system’s predictive modeling. For instance, PIR sensors were particularly effective in detecting stop-and-go patterns during congestion, while ultrasonic sensors assisted in estimating vehicle proximity in narrow lanes and parking spaces.

3. IP Address-Based Identification

The use of an IP-based identification system simulated a scenario where every vehicle is assigned a dynamic IP address, much like mobile phones using IMEI. This configuration allows for direct communication between vehicles and the central ITS server, and in future applications, vehicle-to-vehicle (V2V) communication. The IP-based system supports the integration of data with existing computer networks, enabling higher interoperability with smart city infrastructure.

4. QR Barcode Scanning

Vehicles in the simulation are also equipped with QR barcodes, enabling contactless scanning at city checkpoints. This system complements RFID and IP-based identification, especially in scenarios involving non-networked vehicles such as delivery bikes or private scooters. QR scanning has proven effective in low-cost identification and real-time routing verification. The QR code can also serve as a backup for cases where RFID signals are blocked or degraded due to environmental interference.

B. Discussion

The simulation results of the proposed sensor-based Intelligent Transportation System (ITS) present a significant advancement in addressing urban transportation challenges, particularly in Jakarta’s dense and complex traffic environment. The architecture demonstrates a functional integration of motion, ultrasonic, PIR, and speed sensors with RFID, QR, and IP-based identification systems, forming a multi-dimensional surveillance ecosystem.

1. Critical Evaluation of Sensor Performance

The empirical data presented in Table 2 underscores the potential of each sensor type to perform with high reliability. The speed sensor achieved the highest detection accuracy (97.1%) and lowest latency (90 ms), affirming its critical role in legal enforcement and travel time estimation. This finding is consistent with previous studies by Szulim et al. (2015), who emphasized that high-resolution speed detection significantly contributes to accurate violation detection in real-time systems.

The PIR sensor, with an accuracy of 96.7%, demonstrated robust performance in low-light and stationary-vehicle detection scenarios. This supports the study by Bosso et al. (2016), who identified PIR as a key enabler in identifying congested zones and traffic stalling behaviors. Meanwhile, the motion and ultrasonic sensors contributed effectively to flow analysis and proximity detection, which aligns with Gontarz et al. (2015) and Prakash et al. (2018), respectively. Their studies confirm that ultrasonic sensing is vital for spatial awareness at intersections, especially in areas with mixed vehicle types and pedestrian crossings.

By deploying multiple sensor types simultaneously, the system can correlate diverse traffic behaviors—such as acceleration, deceleration, lane positioning, and vehicle spacing—thereby offering a richer, real-time understanding of urban mobility conditions. This multi-sensor approach significantly surpasses mono-sensor systems used in earlier works, such as those by Kuppusamy et al. (2018), where only a single type of sensor was used in density-based traffic control.

2. Integrative Surveillance and Enforcement Model

The integration of RFID, QR barcode, and IP address mechanisms enhances vehicle traceability and data fusion. RFID systems are widely recognized in smart tolling and ticketing applications (Javaid et al., 2018), but this research extends the application to include automated violation detection, tax compliance, and vehicle classification. The IP-based identification, while still speculative in practical use, offers a vision aligned with future V2I (Vehicle-to-Infrastructure) communication models as proposed by Latif et al. (2018).

Furthermore, the QR barcode system serves as a redundancy mechanism for vehicle authentication, especially in low-connectivity or low-cost settings where full RFID integration may not be feasible. This hybrid identification framework bridges the gap between high-end infrastructure and ground-level adaptability—something rarely addressed in ITS literature.

The four-tiered surveillance model—comprising traffic, vehicle, passenger, and driver monitoring—constitutes a major step toward holistic ITS design. While prior models (e.g., Celesti et al., 2017) focus predominantly on infrastructure-vehicle interaction, the proposed system adds two critical human dimensions: the behavior of passengers (via smart card systems and incentives) and the discipline of drivers (via digital records). This socio-technical integration contributes to the broader discourse on human-centric smart mobility.

3. Comparative Insights and Research Implications

The findings of this study confirm and extend earlier research by Moner et al. (2018), which suggested that ITS frameworks must be context-aware, scalable, and sensor-intensive. While their study was limited to highway monitoring in Colombia, our approach is tested against a dense metropolitan model involving mixed traffic conditions, informal transportation modes, and varied road geometries, representative of Jakarta and other Southeast Asian capitals.

In contrast to Warnars et al. (2016), who focused on the potential of Attribute-Oriented Induction (AOI) for traffic pattern analysis, this research emphasizes real-time sensing and architecture-level design. Nevertheless, the integration of AOI or Emerging Pattern (EP) mining techniques into future versions of this system could offer enhanced analytics for predictive traffic control—forming a natural evolution of the current framework.

4. Novelty and Original Contribution

This study presents several original contributions to the field of intelligent transportation:

- Multi-sensor Architecture: Unlike previous ITS implementations that utilize single or dual sensor types, this study introduces a quad-sensor model (motion, ultrasonic, PIR, speed) integrated into a unified platform.
- Hybrid Identification System: The simultaneous use of RFID, IP address, and QR code for vehicle identification is unique, especially in the context of Southeast Asian urban systems.
- Four-layer Surveillance Framework: This study extends beyond traffic monitoring by incorporating passenger behavior (e.g., cashless incentives) and driver discipline metrics as part of a holistic governance strategy.
- Localization to Jakarta: The ITS framework is modeled explicitly for Jakarta's urban challenges, offering a prototype that is both replicable and scalable to similar cities in developing countries.

5. Limitations and Future Directions

Despite the strength of the simulation results, this study is not without limitations. Firstly, all evaluations were conducted in a virtualized simulation environment, and actual field deployment may face unforeseen challenges such as weather interference, signal obstruction, and hardware failure. This is particularly critical for ultrasonic and PIR sensors that are susceptible to environmental noise (e.g., rain, heat). Secondly, the use of IP address identification assumes future standardization in V2I communication, which is currently not supported in most commercial vehicles in Indonesia. Similarly, the full deployment of QR code scanning systems may require substantial investment in roadside infrastructure.

Third, the cybersecurity implications of connecting personal vehicles to centralized ITS databases—especially via IP tracking—were not explored in this version. Issues such as data privacy, vehicle spoofing, and system breach risks must be investigated in future studies. Finally, while this study focuses on technological feasibility, further work is needed on policy alignment, regulatory frameworks, and public acceptance to ensure smooth adoption and integration within the existing transportation ecosystem.

II. CONCLUSION AND RECOMMENDATION

This study has proposed and simulated a novel architecture for a sensor-based Intelligent Transportation System (ITS), specifically tailored to the urban dynamics of Jakarta. The framework integrates four sensor technologies—motion, ultrasonic, PIR, and speed sensors—with a hybrid identification system comprising RFID, IP address allocation, and QR code scanning. This multi-layered approach allows for comprehensive surveillance and data acquisition across traffic, vehicle, passenger, and driver dimensions.

The simulation results indicate that the proposed ITS architecture significantly enhances real-time traffic monitoring, improves the accuracy of travel time prediction, and supports automated enforcement mechanisms. Notably, speed sensors achieved the highest detection accuracy, and the combined system demonstrated high responsiveness and low latency across all tested scenarios. These findings confirm the feasibility of deploying such a system in high-density urban environments and affirm the system’s scalability for broader smart city integration.

From a practical perspective, the adoption of this ITS model could reduce traffic congestion, enhance road safety, and modernize public sector enforcement through digitization. The integration of cashless systems and behavioral tracking also opens opportunities for dynamic incentives, such as reward-based public transportation, further encouraging modal shifts and sustainable urban mobility.

However, the study acknowledges several limitations. The simulation environment does not capture real-world variability such as adverse weather, hardware failure, or system hacking. Moreover, the required infrastructure—particularly for IP-based vehicle tracking and QR integration—may face cost and policy barriers in developing cities. These challenges highlight the need for pilot deployment and gradual integration with existing transportation infrastructure.

Recommendations for future research include field-based validation of sensor performance, exploration of cybersecurity frameworks for data protection, and incorporation of predictive analytics using machine learning techniques such as Attribute-Oriented Induction (AOI) or Emerging Pattern (EP) mining. It is also imperative to investigate the socio-technical acceptance of such systems among citizens and policymakers to ensure smooth adoption.

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