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Improving Transportation Management by Real-Time Bus Tracking using GPS

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Abstract: This study aims to present an innovative real-time bus tracking system using Global Positioning System (GPS) technology to enhance public transportation management. The research addresses current challenges faced by public transportation systems, such as traffic congestion and bus delays, and proposes a technological solution that improves service efficiency and passenger satisfaction. The proposed system includes modules for central management, individual bus tracking, and information display at bus stops, providing accurate data on bus location, speed, and estimated arrival times. The prototype was developed using the Waterfall Model methodology, focusing on modular design and effective client-server communication. Functional and usability testing results showed promising performance for the system, confirming its ability to improve passenger experience and reduce environmental pollution caused by congestion. The study recommends further development to include advanced security features and communication enhancements to improve the system's reliability and widespread applicability in smart cities.
Keywords: Passenger, Bus stops, Transportation, Improve, GPS

I. INTRODUCTION

Public transportation is the lifeline of modern cities, contributing significantly to economic and social development. However, current transportation systems face numerous challenges, most notably traffic congestion, bus delays, and a lack of accurate information available to passengers. These issues not only affect service efficiency but also reduce the attractiveness of public transportation, pushing individuals towards using private transportation, which in turn increases congestion and environmental pollution [1]. Historically, transportation systems relied on fixed schedules, which often failed to adapt to changing conditions such as congestion or unexpected breakdowns. This lack of flexibility leads to uncertainty for passengers, causing them to spend long periods waiting for buses without knowing their actual arrival time. In contrast, studies have shown that providing accurate and real-time information can enhance passenger confidence and encourage them to use public transportation [2]. This paper aims to address these challenges by developing an integrated real-time bus tracking system using Global Positioning System (GPS) technology. The proposed system aims to improve bus fleet management, provide accurate information to passengers about bus locations and estimated arrival times, thereby enhancing the efficiency of public transportation service and user satisfaction. The research focuses on designing and implementing a prototype capable of monitoring buses, processing data, and displaying it interactively for both officials and passengers. The main contribution of this study is to provide a comprehensive solution that combines real-time bus tracking, schedule management, and accurate information provision to passengers, with an emphasis on the technical aspects of developing a robust and scalable system. The relevant literature will be reviewed, the design and implementation methodology detailed, test results presented, and the implications of this system and recommendations for future research discussed.

II. LITERATURE REVIEW

Recent years have witnessed increasing interest in the development of Intelligent Transportation Systems (ITS) with the aim of improving the efficiency, safety, and sustainability of transportation networks. Real-time vehicle tracking systems are an integral part of these systems and have evolved significantly due to advancements in positioning and communication technologies. This review focuses on the literature related to real-time bus tracking, its impact on public transportation management, passenger experience, and the technologies used in this field.

A. Vehicle Tracking Systems and Their Applications in Public Transportation

Vehicle tracking systems primarily rely on Global Positioning System (GPS) technology to accurately determine the geographical location of a vehicle. This technology is widely used in fleet management, providing vital data on vehicle routes, speeds, and operational status [3]. In the context of public transportation, real-time bus tracking systems enable operators to monitor bus movements, respond quickly to any emergencies, and optimize schedules based on actual road conditions [4].

Historically, bus tracking systems relied on rudimentary technologies such as radio communication or terminal devices. With the advent of satellite communication and internet technologies, these systems have become more sophisticated and accurate [5]. For example, previous studies have shown that using GPS data can significantly improve the accuracy of bus arrival time estimation, which enhances passenger satisfaction and reduces waiting times at stops [6].

B. Impact of Real-Time Arrival Information on Passengers

Real-Time Arrival Information is a crucial factor in improving passenger experience and encouraging the use of public transportation. Instead of relying on fixed schedules that may not reflect reality due to congestion or weather conditions, these systems provide continuous updates on the arrival time of the next bus [7]. Research has shown that providing this information reduces anxiety and stress among passengers, increases their sense of control, and improves their perception of service quality [8].

Modern applications of these systems include display screens at bus stops, smartphone applications, and websites that provide instant information about bus locations and estimated arrival times. These applications not only benefit passengers but also help transportation operators manage passenger flow and allocate resources more efficiently [9].

C. Modern Technologies in Intelligent Transportation Systems

Modern Intelligent Transportation Systems rely on a wide range of advanced technologies, including the Internet of Things (IoT), Artificial Intelligence (AI), and big data analytics. These technologies enable the collection of vast amounts of data from various sources (such as GPS devices, sensors, and cameras) and their analysis to extract valuable insights that support decision-making [10].

In the context of bus tracking, IoT devices are used to collect location and speed data from buses and transmit it to central servers for processing. AI algorithms, such as machine learning, are applied to analyze this data and predict arrival times with higher accuracy, taking into account factors such as traffic congestion, weather conditions, and unexpected events [11]. Communication technologies such as GPRS and TCP/IP are also used to ensure reliable and efficient data transfer between buses, servers, and display screens at stops [12].

Recent literature indicates that integrating these technologies can lead to the development of more responsive, efficient, and sustainable public transportation systems, contributing to the achievement of smart city goals and reducing the carbon footprint [13].

III. METHODOLOGY

To develop the real-time bus tracking system, the Waterfall Model software development methodology was adopted due to its linear and structured nature, ensuring the completion of each phase before moving to the next. This methodology consists of sequential phases: Planning, Analysis, Design, Coding, Testing, and Maintenance and Documentation [14].

A. Planning Phase

In this initial phase, the main objectives of the system and the project scope were defined. The focus was on developing a software system that provides real-time bus tracking functionalities, displays arrival information to passengers, and manages the bus fleet for administrators. Preliminary research was conducted to identify suitable technologies, such as using GPS for positioning, client-server communication protocols (TCP/IP), and relational databases for data storage. It was emphasized that the system should be scalable and efficient to handle a large number of buses and passengers in an urban environment.

B. Analysis Phase

The analysis phase involved gathering detailed system requirements. User requirements (passengers, drivers, administrators) and functional and non-functional system requirements were identified. For example, functional requirements included: accurately tracking bus location, calculating estimated arrival times, displaying information on station screens and user applications, and managing buses, routes, and stations. Non-functional requirements included: performance (fast response time), reliability (service continuity), scalability, and security (data protection). Similar available systems (e.g., Google Transit) were analyzed to understand best practices and identify gaps that the proposed system could fill.

C. Design Phase

In this phase, the system's architectural design, database design, and user interface design were developed. The system was divided into main modules: the central server unit, the bus unit (client), and the bus stop unit (client).

The database was designed to store information about buses, stations, routes, and drivers, with an emphasis on optimizing relationships between tables to ensure efficient data retrieval and modification. UML diagrams (such as use case diagrams and sequence diagrams) were used to illustrate system interactions and data flow between different components.
The user interface for administrators was designed to be user-friendly, allowing them to manage buses, define routes, and monitor system status. Information display interfaces for passengers at stations and smartphone applications were also designed to be clear and direct, focusing on providing accurate and real-time information.

D. Coding Phase

The system was implemented using the Java programming language, given its cross-platform nature and robust environment for developing complex applications. NetBeans IDE was used as the integrated development environment. Client-server communication was built using the TCP/IP protocol to ensure reliable data transfer. The Google Maps API was integrated to visually display bus and station locations on maps.

E. Testing Phase

Comprehensive tests were conducted to ensure system functionality and performance. These tests included: Unit testing for each system component (e.g., bus management unit, real-time communication unit, tracking unit), Integration Testing to ensure that units work together correctly, and System Testing to evaluate the overall system performance against specified requirements. Usability Testing was also conducted to assess the ease of use of the system by end-users (passengers and administrators).

F. Maintenance and Documentation Phase

This phase involved preparing detailed system documentation, including a user manual, a developer manual, and design documents. A future maintenance plan was also developed to ensure the system's continued operation and updates in line with technological advancements and user needs.

IV. PRACTICAL APPLICATION OF THE SYSTEM

This section discusses the details of the design and practical application of the proposed real-time bus tracking system, focusing on the main components, database structure, client-server communication design, and a presentation of some system interfaces.

A. Database Design

The database is a vital component of any bus tracking system, as it stores and manages all data related to buses, stations, routes, and drivers. The database was carefully designed to ensure efficiency, reliability, and scalability, while adhering to normalization rules to reduce data redundancy and improve its integrity [15]. The database consists of four main tables:

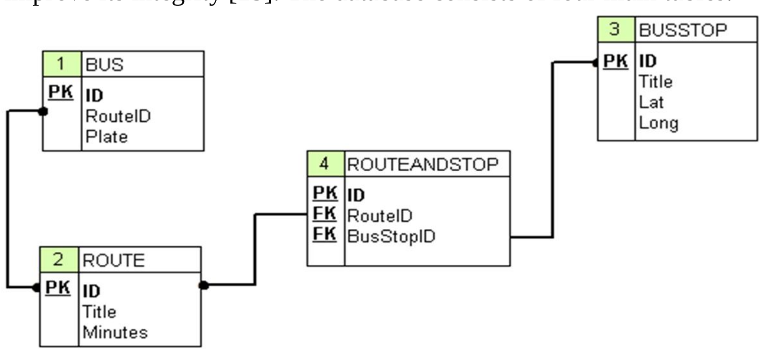

Fig. 1 Database Table Relations

- BusStop: Stores bus stop information, including a unique ID, and latitude and longitude for precise geographical location of each stop.
- Route: Stores route information, where each route represents an ordered set of bus stops.
- Route And Stop: An intermediate table linking routes and stops, allowing the order of stops on each route to be defined.
- Bus: Stores bus information, including a unique license plate number, operational status, and its assigned route.
- Relationships between these tables were designed using Primary Keys and Foreign Keys to ensure referential integrity and facilitate efficient data retrieval and modification.

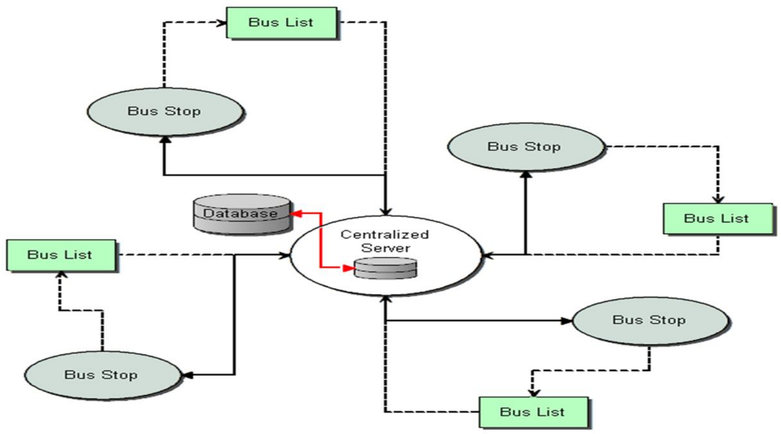

Fig. 2 Overall Concept Diagram

B. System Architectural Design

The proposed system is based on a Client-Server Architecture to ensure efficient and reliable communication between different components. The system consists of three main components:

- Main Server System: Represents the brain of the system, processing all signals and communications from buses and bus stops. The server handles tasks such as: database management, GPS data processing, calculating estimated arrival times, and sending updates to bus stops and user applications. The server was designed to handle a large number of concurrent connections.
- Bus Unit: Represents the client running inside each bus. This unit collects location and speed data from the GPS device installed in the bus and periodically sends it to the central server. It also allows drivers to send emergency signals or traffic status updates to the server.
- Bus Stop Unit: Represents the client running at bus stops equipped with display screens. This unit receives data from the central server about incoming buses, their estimated arrival times, and traffic status, and displays it to passengers in real-time.

Communication between the server and clients is done via the TCP/IP protocol, ensuring reliable data transfer. A custom communication protocol was designed for exchanging messages between the server and clients, where each message contains a unique code identifying its type and content.

C. System Interfaces and Functions

Multiple user interfaces were developed to meet the needs of different users:

1) Administrator Role

The administrator interface enables administrators to manage the system comprehensively, including:

- Bus Management: Adding new buses, modifying existing bus information, and deleting buses from the system. Each bus is identified by a unique license plate number.
- Bus Stop Management: Adding new bus stops by specifying latitude and longitude, and displaying bus stop locations on Google Maps to verify their accuracy.
- Route Management: Creating new routes by defining the sequence of bus stops, and assigning routes to buses.
- Real-time Monitoring: Displaying currently connected buses, tracking their locations on the map, and monitoring their operational status (e.g., emergency signals).

2) Bus *Role*

The bus interface displays vital information to drivers and enables them to interact with the system. Key functions include:

- Location and Speed: Displaying the bus's current location and speed based on GPS data.
- Next Destination: Showing the next stop on the bus's assigned route.
- Accuracy Alerts: Informing drivers about their adherence to the schedule (on time, late, and early).
- Emergency Signals: Sending an emergency signal to the central server in case of breakdowns or accidents which alerts administrators.
- Traffic Congestion Status: Enabling drivers to report traffic congestion status (smooth, normal, congested) to update passenger information at stops.

3) Bus Stop Role

The bus stop interface displays accurate and real-time information to passengers. Key features include:

- Bus Location on Map: Displaying the current location of incoming buses on a Google Map.

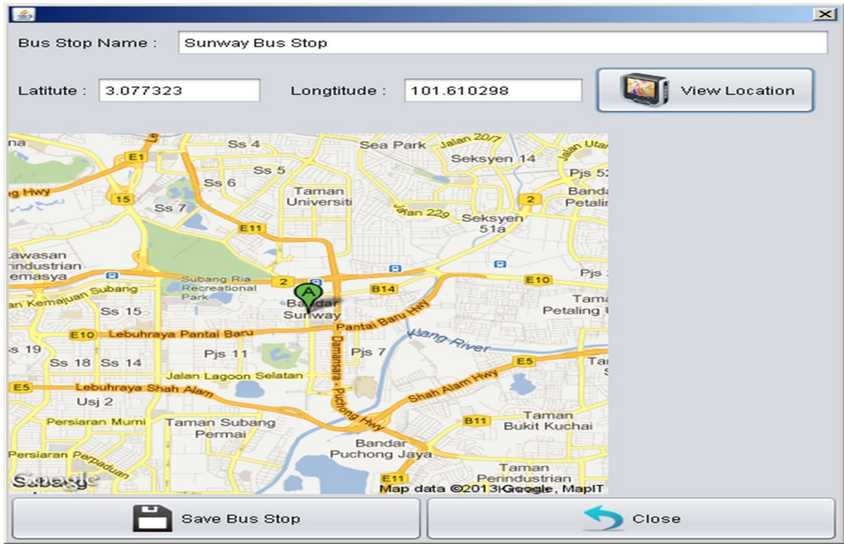

Fig. 3 Bus Stop Location Verification

- Estimated Arrival Times: Estimating bus arrival times at the stop based on GPS data and traffic status.
- List of Incoming Buses: Displaying a list of buses that will stop at the station, with information about each bus's route and next destination.
- Traffic Status: Displaying traffic status reported by drivers.

4) Communication Implementation

Communication between the server and clients was designed to be efficient and reliable. Both client applications (bus and bus stop) continuously listen for new messages from the server. Similarly, the server listens for incoming connections from all connected clients. Messages are encoded with unique codes to identify the message type, allowing the server and clients to take appropriate actions. For example, when a new bus is added, a registration request is sent to the server, which in turn verifies the bus's license plate number and grants it access to the system.

V. TESTING AND RESULTS

To ensure the quality and reliability of the proposed system, comprehensive tests were conducted in two main phases: Unit Testing and Usability Testing. These tests aimed to verify the system's functional performance and its adherence to user requirements.

A. Unit Testing

The system was divided into smaller units, and each unit was tested independently to ensure its correct operation. The tested units included:

- Bus Management Unit: Testing the functions of adding, deleting, modifying, and displaying bus information. The results showed that all functions worked correctly, ensuring efficient management of the bus fleet.
- Bus Stop Management Unit: Testing the functions of adding and deleting bus stops. It was confirmed that the system correctly handles the relationships between stops and routes, and that any changes to stops are correctly reflected in the system.
- Real-Time Communication Unit: This unit is crucial for system performance. The server's ability to handle multiple, simultaneous connections from buses and bus stops was tested. Tests showed that the system is capable of effectively receiving and sending messages, with a response time of less than one second for 20 simultaneous connections at an internet speed of 2.0 Mbps, confirming communication efficiency.

TABLE I
UNIT TESTING FOR REAL-TIME COMMUNICATION MODULE

Performed Task	Result
Detection of New Client Connection	Passed
Receive Client Messages Simultaneously	Passed
Reply Client Messages Simultaneously	Passed
Authentication of Client Connections	Passed
Client Database Record Management	Passed
Client Message Response Latency	Passed
Overall	Passed

- Real-Time Tracking Unit: The accuracy of tracking bus location and speed using GPS data was tested. It was confirmed that the system accurately displays locations on Google Maps and that speed data is calculated correctly. This unit is essential for security and monitoring purposes.

Table II
UNIT TESTING FOR REAL-TIME TRACKING MODULE

Performed Task	Result
Maximum Feed Delay Time	Passed
GPS Feed Delivery	Passed
Accuracy of GPS Coordinates	Passed
Integration of Google Maps for Positioning	Passed
Overall	Passed

Routing Module: Testing the correctness of linking bus stops and routes to buses. The results showed that all links worked correctly, ensuring buses are routed according to specified paths.

Table III
UNIT TESTING FOR ROUTING MODULE

Performed Task	Result
Correctness of Data Linkage Operations	Passed
Reliability of Bus-Server-Bus Stop Communication	Passed
Creation of Bus Routes	Passed
Overall	Passed

- Bus System Unit: The bus's ability to send location and speed data, emergency signals, and traffic status updates to the server was tested. Its ability to receive messages from the server and display information to drivers. Although GPS testing was simulated in this study, the results were positive.
- Bus Stop System Unit: Testing the bus stop's ability to receive and display information about incoming buses and estimated arrival times. It was confirmed that information is displayed correctly and in a timely manner to passengers.

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Table IV
UNIT TESTING FOR BUS STOP SYSTEM MODULE

Performed Task	Result
Receiving Real-Time Data on Time	Passed
Integration of Google Maps	Passed
Displaying Correct Information	Passed
Overall	Passed

Overall, unit tests showed that all system components work correctly and meet the specified functional requirements.

B. Usability Testing

Unlike unit testing which focuses on technical aspects. Usability testing aims to evaluate the ease and effectiveness of use of the system by end users. Since the proposed system is not directly interactive with passengers (but rather provides information), a questionnaire was used to collect feedback from 30 participants on usability and performance aspects. The questionnaire was divided into two main sections:

- Usability Metric: This section focused on user satisfaction with the provided service. The results showed that the majority of participants (21 out of 30) provided very positive feedback, indicating high user acceptance of the system. This acceptance is crucial, especially since the system introduces a new concept in public transportation.

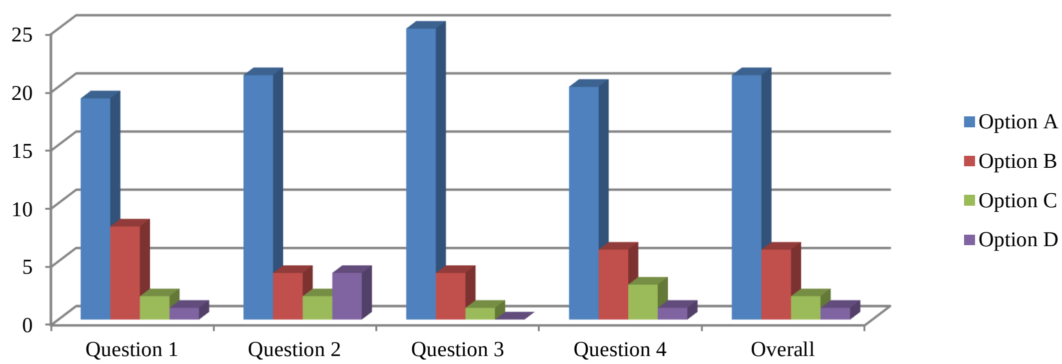

Fig. 4 Usability Testing for User Acceptance

- Performance Metric: This section focused on the accuracy and reliability of the information provided by the system. Although the system is still a prototype, the results were better than expected, with most participants giving high performance ratings. However, a few users noted some issues, emphasizing the need for further improvements and updates in future versions.

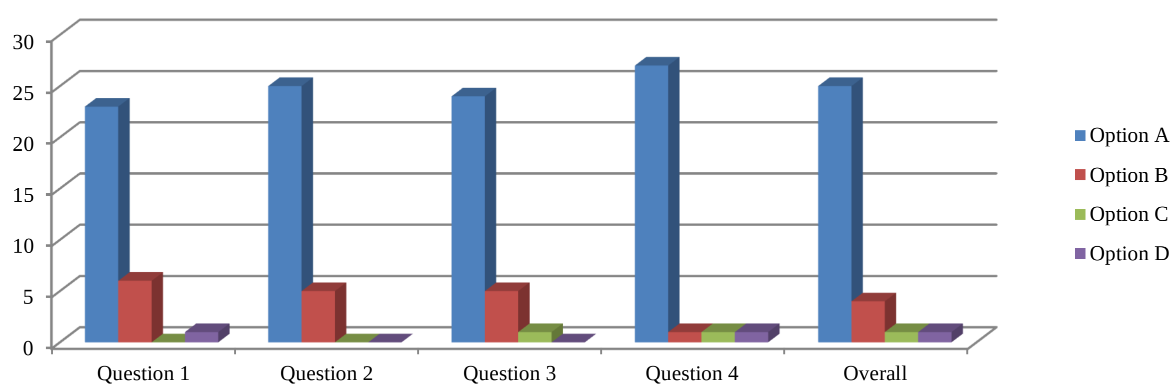

Fig. **Error! No text of specified style in document.** Usability Testing for Performance Measurements

These results show that the proposed system has good user acceptance and strong functional performance, paving the way for further development and wider application.

VI. CONCLUSION AND FUTURE RECOMMENDATIONS

This study aimed to analyze, design, and implement a prototype of an automated public transportation management system, focusing on real-time bus tracking using GPS technology. A structured software development methodology was followed, starting from requirements definition, through design and implementation, to testing and evaluation. The results showed that the proposed system is capable of providing accurate and reliable information about bus locations and estimated arrival times, contributing to improved public transportation service efficiency and passenger satisfaction.

The main contributions of this study are the provision of a comprehensive architectural design for a real-time bus tracking system and a practical implementation demonstrating how to integrate GPS, TCP/IP, and Google Maps technologies to provide an integrated solution. The system's effectiveness was also verified through unit and usability tests, which showed strong functional performance and good user acceptance.

Despite the promising results, there are several areas that can be improved and developed in the future:

1) Communication and Security Enhancements: It is recommended to include advanced communication and security features, such as voice or video calls between the server and drivers in emergencies. System security should also be enhanced, especially in display units at bus stops, to prevent theft or damage, in addition to implementing secure login modules for administrators.
2) Integration of Advanced AI Technologies: More complex machine learning algorithms can be used to improve the accuracy of arrival time predictions, taking into account additional factors such as historical traffic patterns, special events, and sudden changes in conditions.
3) System Expansion: The system can be expanded to include other types of public transportation (e.g., trains or taxis) and integrated with other smart city systems for more comprehensive transportation management.
4) User Interface and Passenger Experience Improvement: Developing more interactive smartphone applications for passengers, with personalized features and instant alerts.
5) Economic Feasibility Studies: Conducting economic feasibility studies to assess the costs and benefits of implementing the system on a large scale in different cities.

Through these improvements, the proposed system can become a powerful and sustainable solution for public transportation management in smart cities, contributing to the creation of more efficient, environmentally friendly, and convenient urban environments for citizens.

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