IoT Public Transport Monitoring System for Bandung City

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***Abstract*— In order to address traffic congestion, the Bandung City government is working to expand public transit options, one of which is the Trans Metro Bandung (TMB) bus system. In general, fewer people utilize TMB buses than private vehicles. This is because consumers continue to rely on the system's schedules, which are frequently incorrect because of traffic congestion and other technical issues. The TMB application system still has limitations when compared to the Transjakarta bus system application facilities. One such limitation is the absence of information on estimated bus arrivals, which are impacted by traffic circumstances. Therefore, this research proposes applying the Internet of Things (IoT) concept to develop a tool that periodically delivers information about the present position of public transportation. This data will be collected using a global positioning system (GPS) device and reported to a server that offers the real-time information in a comprehensive manner via a Global System for Mobile Communications (GSM) device. In addition to the real-time position data, an integrated information service in the form of a website will display additional data, such as the projected time of arrival for the vehicle at the destination stop. Therefore, the purpose of this research is to provide consumers with a comprehensive information service that will enable them to have a better organized and enjoyable travel experience. In an effort to lessen traffic congestion throughout Indonesia, particularly in the city of Bandung, it is hoped that the outcomes of this study might encourage more potential passengers to select public transportation over private vehicles.**

Keywords—Public Transportation, IoT, Monitoring, Web-application

I. INTRODUCTION

Traffic congestion is a common occurrence everywhere in the world due to the large number of vehicles on the road [1]. Indonesia itself is the 30th country in terms of traffic congestion [2]. The Indonesian government is attempting to maximize community use of public transportation by enhancing its facilities and quality in an effort to lessen traffic congestion [3]. This has been carried out throughout Indonesia, particularly in major cities like Jakarta, Bandung, and others [4]. The Trans-Metro Bandung (TMB) bus in Bandung is one example of an urban environment where mobility is greatly impacted by improvements in the standard and amenities of public transportation [5]. Providing services with quick transit features, excellent comfort and security, and punctuality is the primary goal of TMB's existence. TMB Bus has an advantageous effect on connection, although it faces difficulties keeping up efficiency and punctuality [6].

As of right now, a TMB monitoring system is visible in the application that the government department has released. Still, the information is not comprehensive. In contrast, TransJakarta, the city's public transportation system, provides users with information on the bus's location, route, schedule, and map in addition to an expected arrival time. Each bus station has a display with information about several kinds of bus routes [6]. This information service is thought to be helpful for making it simpler for consumers to obtain information about public transportation in Jakarta because to its user-friendly structure and straightforward navigation [7].

Thus, this research suggests using the Internet of Things (IoT) concept to create a tool that can work to offer information regarding the position of public cars, which is updated frequently to receive the newest position. By using this tool, the position of the vehicle will be sent to a server, which will display current, accurate information along with estimations of when the vehicle will arrive at the closest bus stop. In this research, in addition to using hardware, we also use software in the form of web applications to develop an information service system.

Based on the existing issues, a hardware and software system was developed to provide more comprehensive monitoring of public vehicle real-time locations. By adopting an integrated IoT system and information services strategy, passengers on public transportation can determine the vehicle's current location and estimate when it will arrive at the stopping site. In hardware design, a single-board computer (SBC) is required as the primary device that links auxiliary modules, including the Global System for Mobile Communications (GSM) and the Global Positioning System (GPS) module [8]. While the GSM module's primary responsibility is to connect the SBC to the server and transmit data received from GPS, the GPS module's primary function is to collect the most recent location information based on several active satellites. The information gathered from the GPS module will all be stored on the server. Prospective passengers will be provided with this information through an integrated information service, which may be shown as a mobile application or website page. The goal of planning and executing vehicle arrival monitoring is to provide prospective

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passengers with thorough information for a more relaxed and well-organized travel experience. It is intended that the findings of this study may influence potential passengers decisions to use public transportation rather than a private vehicle.

II. Literature Review

In Indonesia, many previous works of literature have suggested answers to this issue, particularly through the use of information technology like the Internet of Things (IoT) and the Global Positioning System (GPS). M. Dwiyaniti [9] proposed a bus monitoring application to track the real-time position of "yellow buses" on their route from Politeknik Negri Jakarta to Universitas Indonesia. Position, distance, speed, and time-related SMS data are received via the GPS and GSM modem. In order to monitor the bus's position, data is processed by a microcontroller and shown on a display. This display shows the route or map that the bus travels; the distance, bus speed, and time are shown on the display in LCD format, and each bus stop is denoted by an LED light. The research conducted by Ferdiansyah [10] discusses the development of a GPS and infrared car tracking and monitoring system that uses the NodeMCU ESP8266 microprocessor. Real-time tracking of the position, speed, and passenger count of the vehicle is performed by this system, and the data is subsequently saved in the Firebase database. Based on the research results, this system has an availability of 89.58% and a reliability of 88.37% at a 5cm distance. Next, Felia [11] presented regarding monitoring public transportation using GPS and an Arduino Uno R3 with an ATMega328 microprocessor. Based on the user's current location, this research utilizes the Haversine formula to find the closest bus stop. In order to give information about the distance and journey time between the bus and the bus stop, the program additionally makes use of Google Maps' distance matrix API.

On the other hand, research conducted in nations other than Indonesia, like Zhang's research [12], presented a real-time travel speed calculation model for public transportation which is based on GPS data. According to the findings of the error analysis, the line speed estimate model and the average travel speed between bus stops have accuracy rates of 97.9% and 88.4%, respectively. In conclusion, a strategy for optimizing the model is devised by preserving consistent high-frequency GPS data and altering the stopping point. This enhances the accuracy of travel speed estimation to 91.4%, satisfying the requirement for overseeing and assessing public transportation operations. Next, Hakeem [13] provides a basic Internet of Things (IoT) prototype that allows people to watch bus activity and allows authorities to keep an eye on it through a mobile application that shows the bus timetable, activities, and available seats. Wi-Fi communication is used by the NodeMCU ESP32 controller in the design prototype. The input sensors consist of a GPS module and an infrared sensor. The mobile apps' data analysis is presented using Blynk and cloud applications. The authorities may keep an eye on these operations, which benefits the bus transport services' timeliness, quality of service, and management. Lastly, Salih [14] proposed a system that would enable users of transportation to spend less time waiting at the bus terminal by providing information about the closest buses, their real-time location on a Google map, and their arrival time via a mobile application. With the help of an ESP32, GPS, and a mobile user interface provided by the Blynk IoT platform, the system was put into place utilizing IoT technology. The Haversine formula was used to determine the distance between the passengers and the bus location. The findings indicate that there is an average discrepancy of 177 meters, with a minimum inaccuracy of 8 meters, between the values computed by the Haversine equation and the data derived from the actual distance.

The majority of solutions are still concentrated on creating web or mobile applications to track the location of buses, as seen by the numerous earlier research mentioned above. There is an opportunity to boost productivity by implementing more creative and integrated solutions. The primary objective of this research is to offer a more comprehensive solution through the design and implementation of a monitoring system at bus stops. In addition to providing real-time bus arrival estimates, monitors at bus stops can provide more specific information, like the identification of arriving buses, the status of departing buses, and other pertinent data. This measure not only aims to improve the effectiveness of passenger wait times, but it also benefits public transportation infrastructure in general.

III. Proposed System

This research combines multiple IoT technology components. The GPS module on public transportation serves as the foundation for this system, which uses satellite signals to precisely identify and record geographic location before providing real-time coordinate data. The single board computer (SBC), which serves as a link between the GPS module and the internet infrastructure, receives this information after that (GSM). After that, the acquired data is delivered straight to the server's centralized database. This database plays a critical role as a location data storage container. It is configured to process and update incoming data on a regular basis, guaranteeing that the data displayed is accurate and up to date. A web-based application that maps the bus position in real time and offers other information like routes and predicted arrival times at the next stop is used to gather and validate vehicle location data. To achieve the final goal of this research, several stages of application use were carried out, as indicated in Fig. 1.

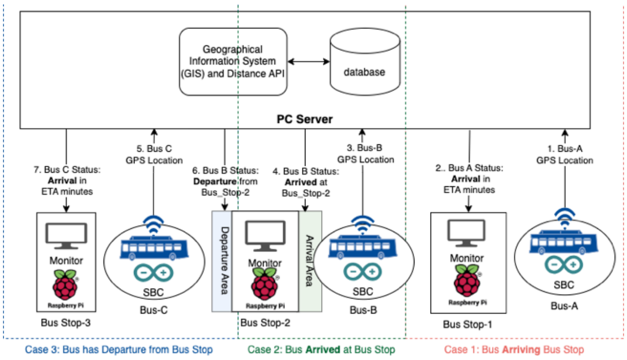

Fig. 1. Proposed System Architecture

The SBC devices have an ESP32 that provides broad Wi-Fi and Bluetooth connection, making it simple for the device to connect to and interact with the internet or other devices. Sending and receiving real-time location data which is essential for tracking and navigation applications requires this connectivity. The ESP32 can handle demanding data processing operations while maintaining effective network connectivity thanks to the dual-core Tensilica LX6 processor, which is essential for IoT development to guarantee system responsiveness and dependability. Furthermore, the NEO-6M GPS Module offers tracking sensitivity and positioning precision of up to 2.5 meters, which is essential for applications like asset tracking and vehicle navigation that demand exact location. The module may save crucial configuration and location data thanks to extra capabilities like EEPROM and battery backup, which guarantees faster and more accurate system startup following shutdown or reset. The integration of the ESP32 with the NEO-6M GPS necessitates careful consideration of power management, memory usage, and communication protocol parameters. Receiving NMEA data from the NEO-6M GPS is possible with the ESP32's support of serial communication. The ESP32 can extract and use this location data, with the right settings, to do tasks like estimating arrival time and calculating distances between coordinates.

Once the vehicle position data has been successfully recorded on the server, the estimation time arrival (ETA) calculation program begins to operate. Based on the bus's previous position and the next bus stop, the estimated vehicle arrival calculation results are obtained. These outcomes are also shown in an information system that provides potential passengers with the computation's results. The arrival of busses as a mode of public transportation is the main topic of this research, with a focus on the use of IoT technology to track and monitor the position and arrival time of buses in real time. As illustrated in Fig. 2, a number of stages of work were completed in order to meet the research's ultimate goal. To ensure that this research yields a prototype that satisfies the goals, there are multiple requirements namely (1) public transportation monitoring; (2) public transportation arrival status.

Fig. 2. Proposed System Flowchart

In general, public vehicle monitoring specifications include the ability to obtain the location of public vehicles using the GPS module embedded in the SBC. However, the proposed system must be able to compute, through road segment modifications, the difference in distance between the current coordinates of public transportation and the bus stops to be reached in order to satisfy the second specifications. In addition, the bus's arrival status from the closest bus stop must be created by the system. It is anticipated that the server would get real-time updates on the whereabouts of public transportation vehicles. Based on two primary modules, GPS-based position tracking tools and GSM-based communication tools, the specifications outline a suggested method to address location uncertainty in real time, particularly in scenarios with varying environmental constraints.

High levels of location accuracy, quick signal locking times, and adaptability to different environmental circumstances are essential features for GPS-based position monitoring devices. This module's purpose is to deliver precise and trustworthy vehicle position data, especially in challenging circumstances and environments. In the meantime, the communication module needs to have quantifiable resource availability, rapid and dependable connectivity, and effective data processing capabilities. Fig. 3 shows the schematic design of the proposed system.

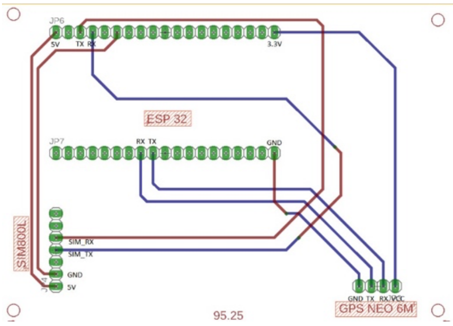

Fig. 3. Schematic Design.

IV. Implementation and Testing

In order to enhance the functionality and dependability of monitoring systems, particularly with regard to connectivity and data processing, the two modules' individual standards have been established. Several actors, including users or potential passengers, SBC, servers, and the monitoring system, are accountable for executing their roles in this suggested public transportation arrival monitoring system in order to meet the research's primary objective. It is the responsibility of potential passengers to choose their desired route of travel and to find out the current state of the public transportation they want to utilize.

The SBC will be responsible for initializing the system as a whole, periodically obtaining coordinates from GPS, and transmitting data from the GSM module to the server via the internet network. GPS-generated location data is subsequently transmitted to Firebase database. Upon receiving data from the SBC, the server will calculate the distance between the bus's current location and the stops it will make based on its route. This calculation's output will be shown in the information system, which serves as the proposed research's front end.

Based on the schematic, the system reads GPS data from two sources, the GPS NEO-6M module and the SIM800L module, and sends this data to Firebase Firestore. During the setup phase, the system first attempts to connect to Wi-Fi; if it fails, the internet connection using the SIM800L is initialized. The SIM800L connection requires APN configuration and opening the GPRS context. Once the internet connection is established, Firebase is initialized and connected. In the main loop, GPS data is read from both modules, and if the data is valid, information such as latitude, longitude, and speed is sent to Firebase. The time information is adjusted to the GMT+7 time zone and formatted in ISO 8601 standard. The logic for checking and sending GPS data is repeated continuously to ensure accurate real-time data is sent to Firestore. The pin connections are as follows: for the GPS NEO-6M, RX NEO-6M is connected to TX ESP32 (GPIO 17) and TX NEO-6M is connected to RX ESP32 (GPIO 16); for the SIM800L, RX SIM800L is connected to TX ESP32 (GPIO 10) and TX SIM800L is connected to RX ESP32 (GPIO 9). Fig. 4 shows the implementation of the proposed system using the modules that previously explained.

Fig. 4. Prototype Implementation

The GPS device coordinate data will be compared to the real position data based on Google Maps. The Haversine formula will be used to determine the difference between the GPS coordinates and the real coordinates. A program on the system server has the ability to determine both the ETA and the separation between two coordinate points. The program will use each point's latitude and longitude information that is saved in the Firebase database to determine the GPS accuracy. Thus, the sample of the test's outcomes from GPS coordinates in Firebase, are shown in Table I.

TABLE I. DISTANCE ACCURACY OF GPS COORDINATES TEST RESULTS

Real Coordinates	GPS Coordinate	Distance Accuracy (m)
-6.979235, 107.631279	-6.978447, 107.631333	±100
-6.979235, 107.631279	-6.979065, 107.631543	±18
-6.972754, 107.636131	-6.979054, 107.630911	±31
-6.972753, 107.636125	-6.972759, 107.635966	±29
-6.968409, 107.637249	-6.968728, 107.637681	±32
-6.968389, 107.637201	-6.968423, 107.637465	±10
-6.968392, 107.637185	-6.968612, 107.637028	±34
-6.968389, 107.637201	-6.968457, 107.637311	±16

After the system has determined the bus location point in real time, the following step is to calculate the bus's estimated arrival at the destination point. The system has a program that makes use of the Google Cloud API, more precisely, the distance matrix API, to determine the estimated time of arrival. Every minute, the system's program will retrieve the most recent bus coordinate data in real time from Firebase. The coordinate data will then be loaded into the API distance matrix to determine the estimated time of arrival. Firebase receives each buses coordinate that the GPS generated and the its ETA from the system. Secure protocols are used during communication between the GPS device and Firebase via the internet to prevent unwanted parties from accessing sensitive data. The web page that appears on the monitor screen at every bus stop will retrieve the data for additional processing once it has been stored in Firebase. This website converts raw data into meaningful information, like the location of the bus, the travel distance, and a real-time estimate of arrival time. Users can do this to view the bus's current location and estimate when it will arrive at their bus stop. Fig. 5 shows the implementation of website monitoring for the public transport. Meanwhile, as shown in Fig. 6, the detailed information of the public transport monitoring is shown. As in the bottom-left, the movement progress of the buses is shown and in the bottom-right side the information of its next destination, completed with the distances and its estimated time arrival.

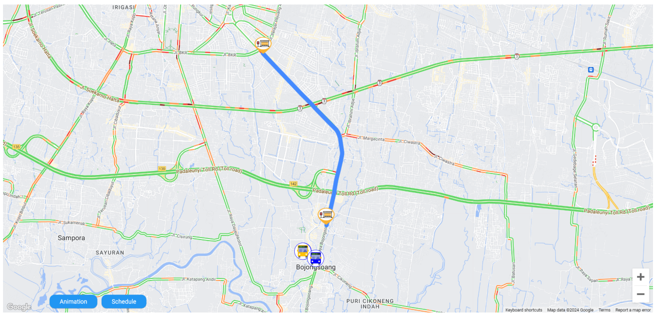

Fig. 5. Website Monitoring

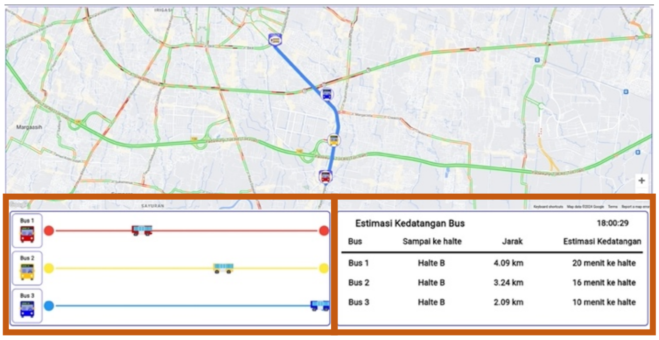

Fig. 6. Bus stop route monitoring

The system's website integrates both practical and aesthetically pleasing elements in its interface design. The website was developed to offer a user-friendly, educational, and effective experience. Visual clarity was taken into consideration when designing this interface, making sure that the information is displayed in a way that is simple to understand right away.

Every bus current location is shown on the website. In addition, the progress of the bus's journey from its starting position is displayed. The three buses have just begun to move from their starting place, as seen in the picture. The expected arrival of cars at a certain stop is displayed on the bottom right side of the interface, providing information on the arrival of public transportation. Additionally, there is a mode designed for smaller LCD screens that utilizes two buttons, each serving a function to display bus information. This design ensures that the desired information can be easily viewed by the user when in smaller screen mode.

Table II shows the GPS testing for resolving the position of the buses. During the Cold Start test, the GPS NEO-6M and SIM800L devices are in a state where they have never been connected to a power source before. This process begins by connecting the devices to a power source for the first time. In this condition, the GPS NEO-6M requires time to download almanac and ephemeris data from the satellites to determine its position. The indicator light on the GPS NEO-6M module will light up when the signal from the satellites is successfully received and the position can be determined. If the light on the GPS NEO-6M module does not light up, it means that the device has not yet received a signal from the satellites.

TABLE II. EXAMPLE OF GPS TEST RESULTS ON

Trial No	Cold Start (min.)	Warm Start (min.)
1	45	7
2	17	10
3	22	4
4	18	9
5	19	10
6	15	8
7	17	7
8	20	9
9	14	10
10	16	7

In the Warm Start test, the GPS NEO-6M and SIM800L devices have previously been connected and obtained satellite signals. This process begins by temporarily disconnecting the power source from the devices and then reconnecting it. In this condition, the GPS NEO-6M device only needs part of the previously downloaded data to re-establish its position. The time required for the device to reconnect to the satellites and obtain the location is recorded. The light on the GPS NEO-6M module will light up more quickly compared to the Cold Start, indicating that the device has received the satellite signal and determined its position.

V. CONCLUSION

This research on the bus monitoring system highlights significant advancements in utilizing GPS technology and real-time data processing to improve public transportation. By integrating the Google Cloud API, especially the Distance Matrix API, the system efficiently calculates estimated bus arrival times, providing valuable information to passengers. This integration ensures real-time updates of bus coordinates from Firebase, displaying current locations and estimated arrival times on a user-friendly website.

The website showcases bus progress and arrival estimates at specific stops, balancing practicality with aesthetic appeal. Secure communication protocols between GPS devices and Firebase enhance data protection, reliability, and security. This system's real-time, accurate information can improve the travel experience, making public transportation more predictable and convenient.

The findings indicate that applying IoT and GPS technologies can reduce uncertainty and waiting times in bus travel, potentially encouraging more public transportation use, reducing traffic congestion, and improving urban mobility. Overall, this research emphasizes the importance of technological integration in modernizing public transportation, offering a model that can be adapted globally to enhance services.

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