Research Article

IoT-Based Real-Time Train Position Monitoring System Using GPS

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Abstract: In this modern era, the need for fast, efficient, and quality transportation is important, one of which is in the railway sector. Although trains have special tracks, accidents can still occur due to various factors, such as infrastructure damage and officer negligence. One of the accidents that occurred on January 5, 2024, between the Turangga train and the Bandung Commuter Line caused fatalities and injuries. To overcome this problem, a real-time train position monitoring system is needed. This research aims to design and develop a train position monitoring system using a GPS module. GPS (Global Positioning System) is widely used for tracking systems. This system monitors the position of trains and other information that can be accessed by station officers and the general public. By using the ESP32 microcontroller and NEO-6M GPS module, this system is expected to improve the safety of train travel, minimize the potential for accidents, and provide more accurate information about train arrival times at the station. This research also aims to test the performance of the monitoring system in real conditions. It is hoped that with this system, train accidents due to negligence can be minimized, and provide significant benefits for officers and the public who use train transportation.

Keywords: Monitoring System, Train Position, GPS, Transportation Security, Smartphone Application.

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1. Introduction

In this modern era, everything must be fast-paced and people are increasingly paying attention to everything related to time, including transportation. In addition to speed, quantity, and quality are also important factors in transportation. Transportation can also be associated with the service business process. Currently, the globalization of the transportation service business is progressing rapidly. This has led to increased competition among transportation service providers. As the transportation service business develops, service quality becomes increasingly important. Trains are one of the most popular means of transportation for the people of Indonesia. This is evidenced by the increase in special trains on various Android, iOS, and Windows Phone devices in Indonesia. These applications include Traveloka, Tiket.com, Pegipegi, Tokopedia, and the favorite application KAI Access (Setiawan & Novita, 2021).

Even though trains have dedicated tracks, accidents are not zero. They can occur due to various factors, including damage to assets and infrastructure. The railway system includes specialized equipment such as self-propelled locomotives for passenger transport, freight cars for freight transport, inspection trains/trucks, support cars, cranes, measuring carts, and track maintenance carts. Railroad infrastructure currently consists of tracks, stations, and railroad traffic facilities and infrastructure. One of the train accidents in Indonesia occurred between the Turangga train and the Bandung Commuter Line. This accident occurred on January 5, 2024. The accident left four people dead and 37 injured (Njatrijani et al., 2024).

One of the main factors that cause train accidents is the lack of infrastructure, especially in railroad crossings, and also the negligence of officers in carrying out their duties. Moreover, many motorists are impatient when the train passes so the chances of a train accident become greater (Hermawan et al., 2020).

Some of the factors that cause accidents in railways are due to human negligence, lack of infrastructure, the condition of railways can also affect the occurrence of accidents, human error, by mechanics and guards, lack of discipline of road users, policy-making factors, where the government is not serious in solving railway problems (Luth'v et al., 2022).

Some research on GPS or Navigation systems on Trains, development of train positioning systems and dead reckoning systems, prediction of road density using time series, energy saving optimization, use of Isolation Forest Algorithm for Abnormal GPS data on sanitation vehicles, generation of track images, combination of GPS and Lidar, development of inter-train communication and GPS Spoofing Attack Recognition, have been discussed in detail in previous studies. (S. Suakanto, et.al., 2024, W. Ongcunaruck, et.al., 2023, N. Seqip., et.al. 2023., Z. Yao., et.al.2022., F. Feng., et.al.2022., Y. Zhang, et.al., 2022, Z. Yang., et.al. 2021, M. Saki., et.al. 2022, D. She, et.al., 2025)

2. Theory

2.1 Train speed calculation

The calculation of train speed is using the speed equation where the change in distance is divided by the change in time. So if the train moves 1000 meters in 30 seconds then the speed is 1000 / 30 which is 33.33 m / s. The speed (m/s) formula can be shown in equation 1.

$$Speed\left(\frac{m}{s}\right) = \frac{\Delta Distance(m)}{\Delta Time(s)} \quad (1)$$

2.2 Parsing satellite data

The Neo 6M GPS module obtains latitude and longitude positions based on the satellites it receives. The data is sent in RX TX serial communication to the controller in this case the ESP32. The data parsing format is as follows:

```
$GPGGA,110617.00,41XX.XXXXX,N,00831.54761,W,1,05,2.68,129.0,M,50.1,M,,*42

$GPGSA,A,3,06,09,30,07,23,,,,,,,,4.43,2.68,3.53*02

$GPGSV,3,1,11,02,48,298,24,03,05,101,24,05,17,292,20,06,71,227,30*7C

$GPGSV,3,2,11,07,47,138,33,09,64,044,28,17,01,199,,19,13,214,*7C

$GPGSV,3,3,11,23,29,054,29,29,01,335,,30,29,167,33*4E

$GPGLL,41XX.XXXXX,N,00831.54761,W,110617.00,A,A*70

$GPRMC,110618.00,A,41XX.XXXXX,N,00831.54753,W,0.078,,030118,,,A*6A

$GPVTG,,T,,M,0.043,N,0.080,K,A*2C
```

Furthermore, of the 8 sets of data sent, the data format with the prefix $GPGGA is used. $GPGGA is the shortest GPS message to get the location. The parsing information of $GPGGA is:

$GPGGA,110617.00,41XX.XXXXX,N,00831.54761,W,1,05,2.68,129.0,M,50.1,M,,*42

- 110617 - is the time the location was obtained, 11:06:17 UTC
- 41XX.XXXXX, N - Latitude 41 deg XX.XXXXX' N

- 00831.54761, W - Longitude 008 deg 31.54761' W

- 1 - fixed quality (0 = invalid; 1 = GPS fix; 2 = DGPS fix; 3 = PPS fix; 4 = Real Time Kinematic; 5 = Float RTK; 6 = estimation (direct calculation); 7 = manual input mode; 8 = simulation mode)

- 05 - number of satellites tracked
- 2.68 - Horizontal position dilution
- 129.0, M - Altitude, in meters above sea level
- 50.1, M - Geoid (mean sea level) height over the WGS84 ellipsoid
- empty field - time in seconds since the last DGPS update
- empty field - DGPS station ID number
- *42 - checksum data, always prefixed with *

2.3 Addable automation system

1) Automation with railway crossings: One of the automation systems that can be applied to this device is the automation of railroad crossing bars. With the addition of a receiver device placed on the crossing bar, if the train approaches the crossing bar either from a distance or an estimation of passing, the device on the crossing bar will activate the alarm and can close the bar automatically.
2) Automation with train travel arrangements: For integration with train travel is currently not possible, because the GPS module used has a delay of a few seconds, a module that has a very fast response is needed so that the safety level of train travel can be guaranteed. In addition, it is also necessary to consider the stability of the internet network to be able to manage train travel directly.
3) Automation of monitoring at each train station: For the monitor, it is easy to use a kind of tablet so that it only changes a little from the application used, but it does not rule out the possibility of using gadgets such as laptops or computers.

3. Method

This research uses an experimental method to design, implement, and test a train tracking system using GPS and WiFi modules. The following are the steps of the methodology applied in this research.

3.1 System Design

1) Components: In this research, ESP32 microcontroller is used as the main controller, Neo 6M GPS Module to obtain GPS position, and LCD display for visual display. In this research, a special PCB for GPS tracker is used.
2) Integration of GPS tracking system with Firebase and MIT App Inventor: This system uses a real-time database from Firebase for storing location data from trains and MIT App Inventor for creating smartphone monitoring applications.

3.2 System Implementation

1) PCB Manufacturing and ESP32 Programming: The ESP32 is mounted on a PCB made specifically for this research and programmed using the Arduino IDE. The program processes the location data input from the Neo 6M GPS module.
2) Configuration of Firebase real-time database and Smartphone Application: The real-time database is set up so that it can receive train location data sent from the ESP32. The smartphone application is used with the help of the MIT App Inventor web which adds a map feature to make it easier for users to track trains.
3) System testing: After the integration of hardware and software is complete, testing is done to ensure all components function as designed. Testing includes time response testing, accuracy testing, train tracker system testing, and remote train tracker system testing. In detail, Figures 1, 2, and 3 illustrate the Flowchart of the system built.

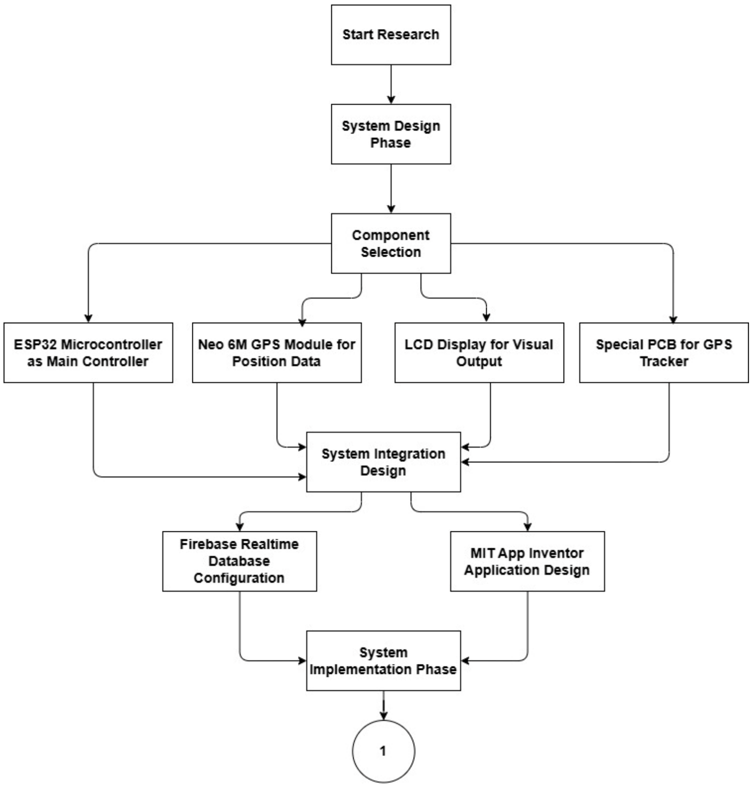

Figure 1. The flowchart in this system

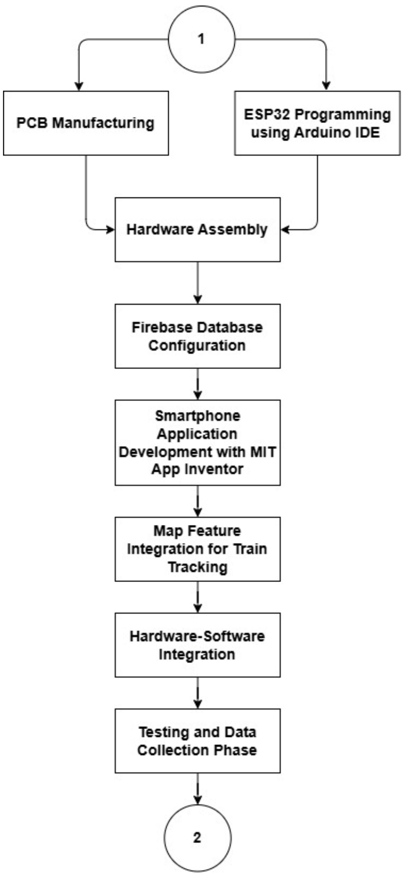

Figure 2. The Flowchart in this system step 2

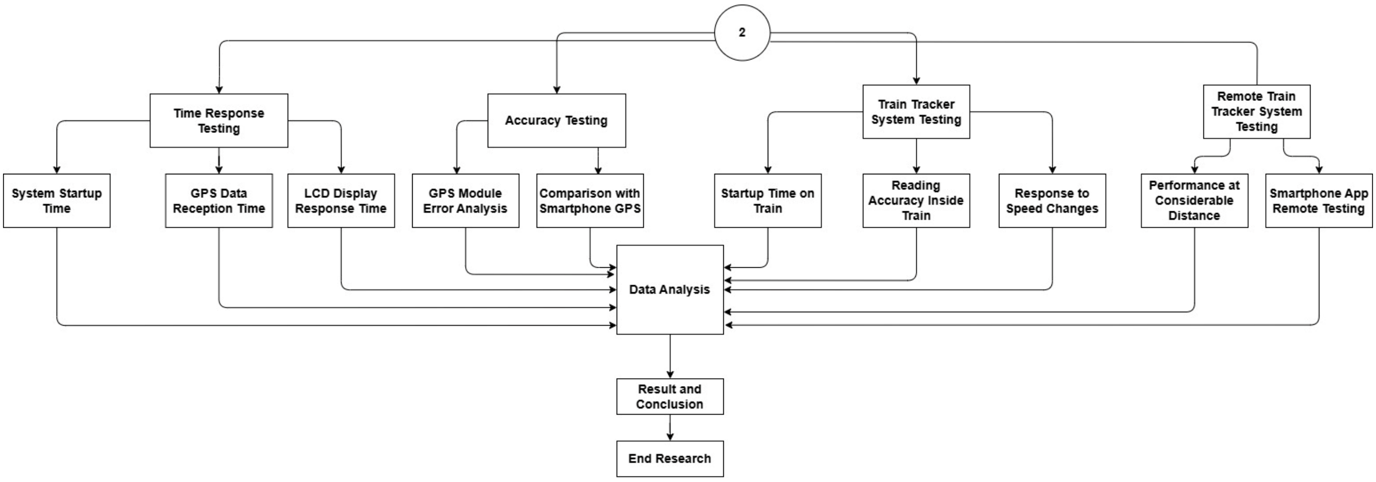

Figure 3. The Flowchart in this system step 3

3.3 Testing and Data Collection Phase

1) Time response testing: This test aims to determine how long it takes for the system to start up, receive GPS data, and display the coordinate readings on the LCD layer.
2) Accuracy testing: This test aims to determine how far the error or inaccuracy of the GPS module used is compared to the GPS module reading from the smartphone.
4) Train Tracker system testing: This test is conducted to determine the performance of the device when used or installed on a train. In this test, it is also the time required when the device is first turned on on the train, the accuracy of the readings from inside the train, and how the device responds to the changing train speed.
5) Testing the remote Train Tracker system: This test was carried out to test the performance of the device with the Train Tracker smartphone application under the condition that the train and the device have a considerable distance.

4. Result and Discussion

The results of this measurement are divided into four according to the four testing processes carried out. The flow for the device to communicate to the smartphone is as follows:

The Neo-6M GPS module will send the coordinate position it gets via serial communication to the ESP32 microcontroller. The accuracy and speed of response from the GPS module depend on the antenna installed. Then the coordinate position obtained will be sent to the smartphone via Firebase. The GPS Tracker device position results will be compared with the position reading results by the GPS sensor on the smartphone.

4.1 Time response measurement results

When the device is turned on from a dead condition, the device will initialize the GPS module, connect to WiFi, and, send the position value obtained to the smartphone via GPS. If successful, the Latitude and Longitude position data of the device can be seen on the smartphone. The time response is measured from the first time the device is turned on until it successfully sends the GPS tracker position value to the smartphone. As for the time-measuring instrument, a stopwatch application is used. Time Response measurement can be seen in Figure 4.

Figure 4. Time response measurement

4.2 Accuracy measurement results

After the device successfully reads and sends the Latitude and Longitude positions to the smartphone application. In the smartphone application, the GPS sensor can be activated on the smartphone device so that if the smartphone and GPS Tracker device are brought closer, it can be used as a measurement of the accuracy of the device. Figure 5 is the Device Accuracy Measurement. Table 1 is Measurement Result Accuracy. The latitude accuracy measurement graph, Longitude accuracy measurement graph, and Accuracy measurement error graph are shown in Figures 6, 7, dan 8.

Figure 5. Device accuracy measurement

Table 1. Measuring Result Accuracy

No	Device		Smartphone		Error	
	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
1	-6.90651	107.63585	-6.90642	107.63585	0.00009	0
2	-6.90649	107.6359	-6.90646	107.63587	0.00003	0.00003
3	-6.90649	107.6359	-6.90644	107.63588	0.00005	0.00002
4	-6.90649	107.6359	-6.90654	107.63584	0.00005	0.00006
5	-6.90649	107.6359	-6.90649	107.63576	0	0.00014
Average					**0.000044**	**0.00005**

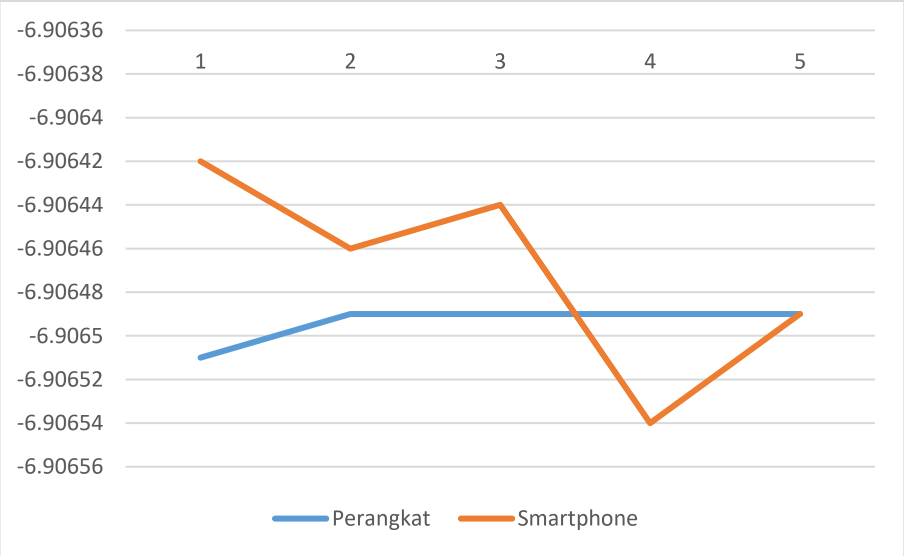

Figure 6. Latitude accuracy measurement graph

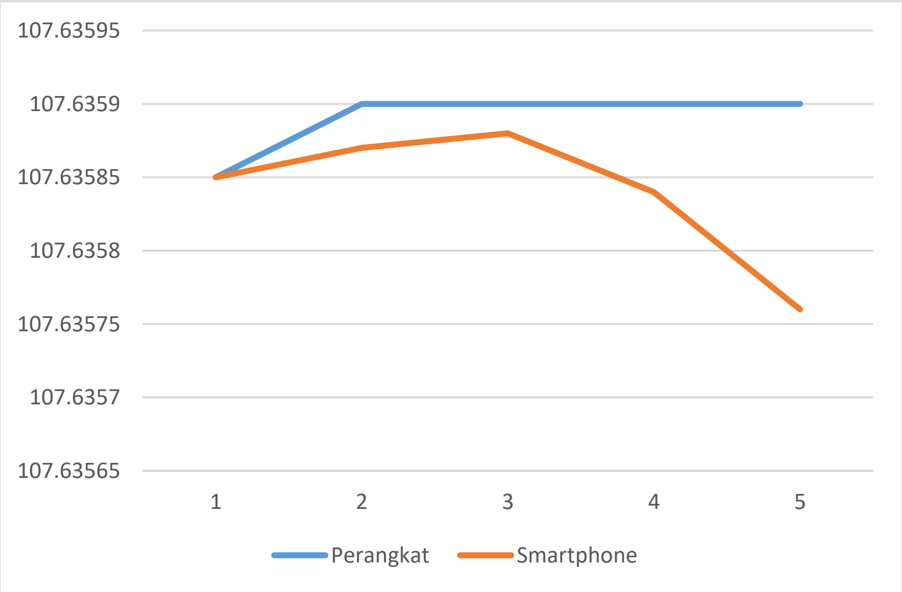

Figure 7. Longitude accuracy measurement graph

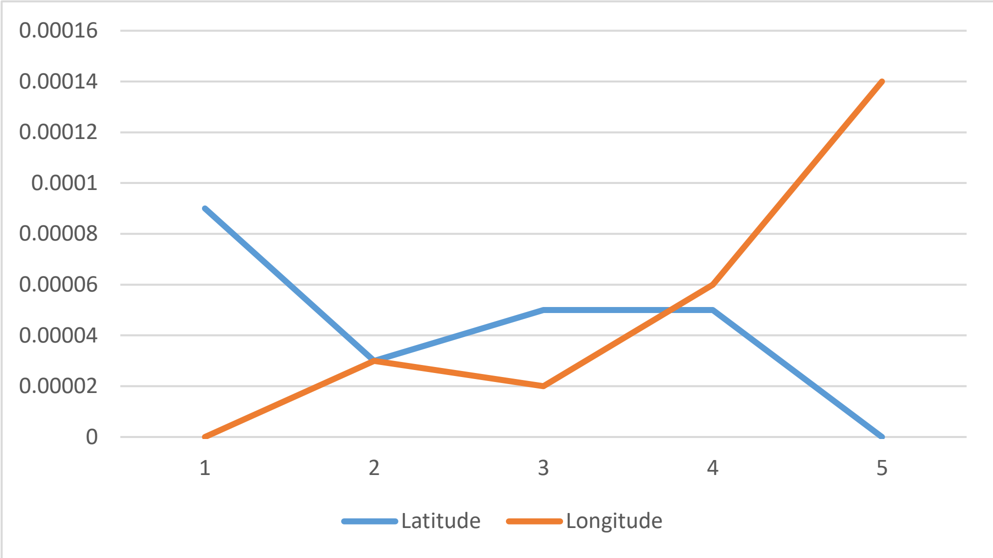

Figure 8. Accuracy measurement error graph

4.3 Measurement results of the Train Tracker system

Train Tracker system testing is done by activating the device on the train. Because the speed of the train cannot be known, the method used is to take data on the position of the train with the device and smartphone as in measurement 3.2 continuously with an interval of approximately 2 minutes each time. This has the aim of ensuring that the readings from the device during the train journey work properly. Figure 9 is the Train Tracking System Measurement. While Table 2 shows the Accuracy Measurement results. The latitude measurement graph of the Train Tracker, latitude measurement graph of the Train Tracker and measurement error graph of the Train Tracker are shown in Figures 10, 11, and 12.

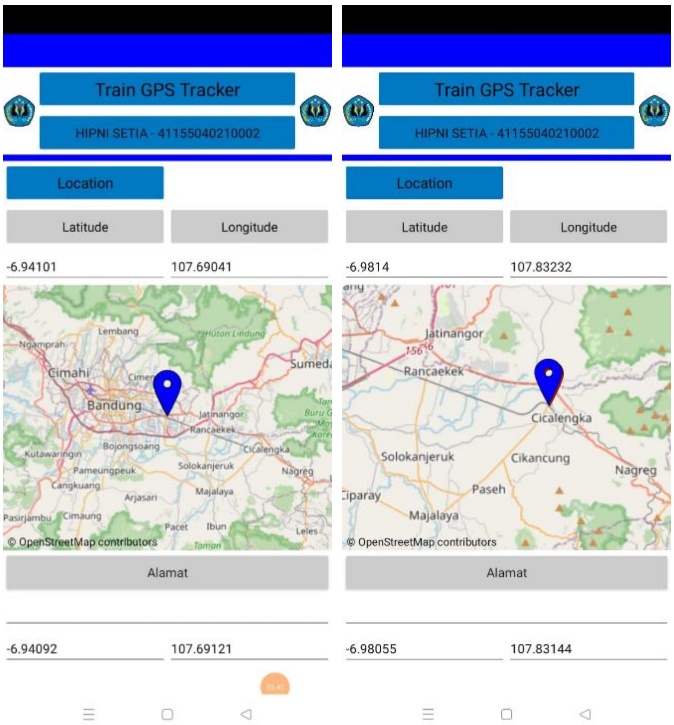

Figure 9. Train Tracker system measurement

Table 2. Accuracy Measurement Results

No	Device		Smartphone		Error	
	Latitude	*Longitude*	*Latitude*	*Longitude*	*Latitude*	*Longitude*
1	-6.94101	107.69041	-6.94092	107.69121	0.00009	0.00080
2	-6.94133	107.69118	-6.9441	107.69831	0.00277	0.00713
3	-6.94472	107.70051	-6.94685	107.70642	0.00213	0.00591
4	-6.94904	107.71255	-6.94858	107.71479	0.00046	0.00224
5	-6.94964	107.71403	-6.95252	107.72195	0.00288	0.00792
6	-6.95407	107.72622	-6.95981	107.74113	0.00574	0.01491
7	-6.95407	107.72775	-6.95981	107.74113	0.00574	0.01338
8	-6.95695	107.7342	-6.95981	107.74113	0.00286	0.00693
9	-6.96529	107.75706	-6.96542	107.75778	0.00013	0.00072
10	-6.96554	107.75776	-6.97425	107.77592	0.00871	0.01816
11	-6.96976	107.76945	-6.97416	107.78182	0.00440	0.01237
12	-6.97635	107.7875	-6.97944	107.79605	0.00309	0.00855
13	-6.9806	107.79928	-6.9805	107.79915	0.00010	0.00013
14	-6.98062	107.79936	-6.98215	107.80305	0.00153	0.00369
15	-6.9821	107.80349	-6.98362	107.80758	0.00152	0.00409
16	-6.98376	107.808	-6.98353	107.82606	0.00023	0.01806
17	-6.9814	107.83232	-6.98055	107.83144	0.00085	0.00088
18	-6.97841	107.82755	-6.98222	107.82237	0.00381	0.00518
19	-6.97843	107.8273	-6.98154	107.82274	0.00311	0.00456
20	-6.98554	107.81648	-6.98185	107.8041	0.00369	0.01238
	Average				**0.00269**	**0.00740**
	Biggest error				**0.00871**	**0.01816**

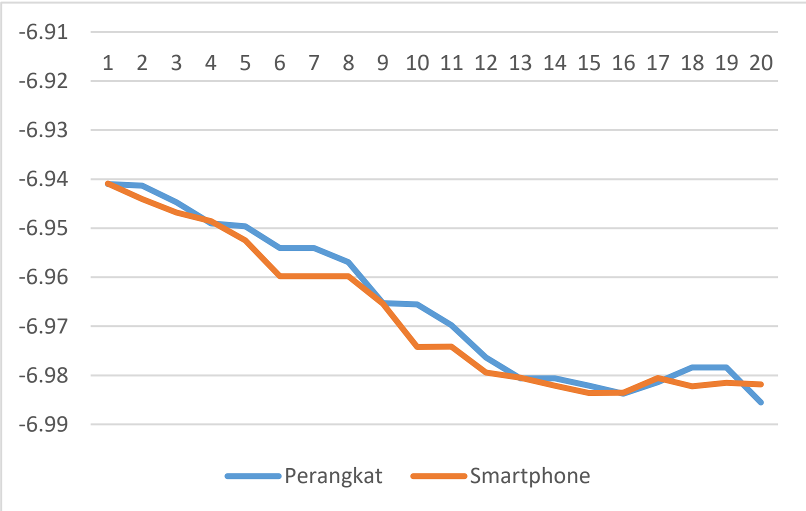

Figure 10. Latitude measurement graph of Train Tracker

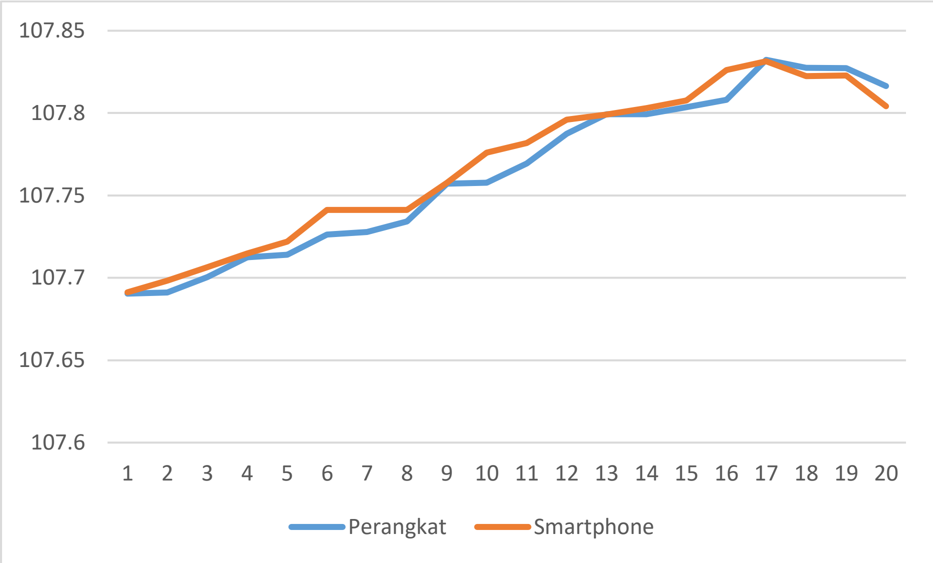

Figure 11. Latitude measurement graph of Train Tracker

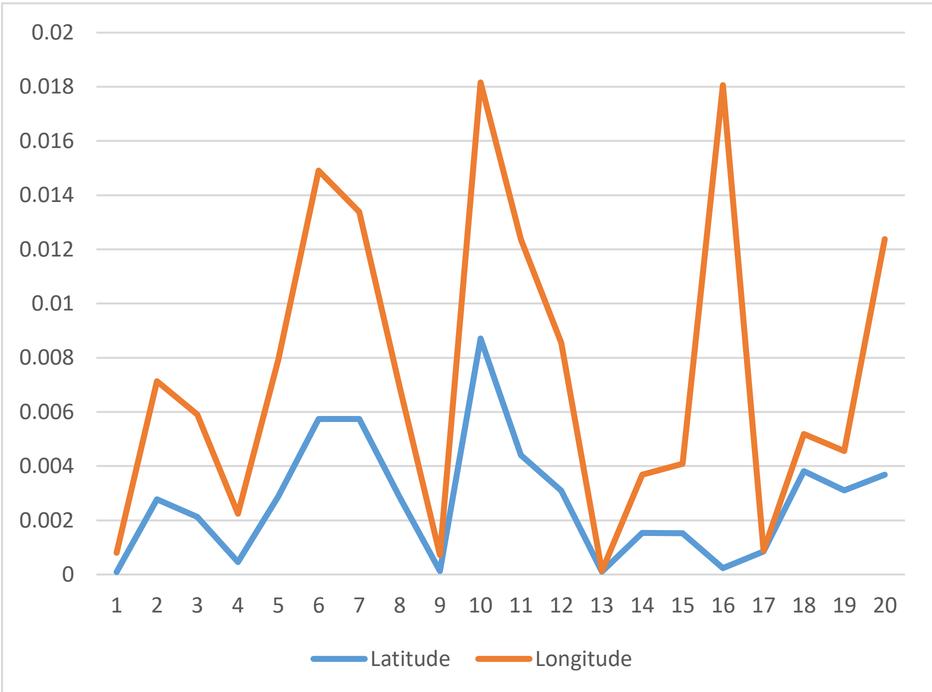

Figure 12. Train Tracker measurement error graph

4.4 Remote Train Tracker system testing

In this test, only monitoring the position of the train using the Train Tracker application is carried out where the position of the smartphone used is in a location far from the train to ensure that the Train Tracker can be accessed regardless of location. Figure 13 is a Remote Train Tracker system testing.

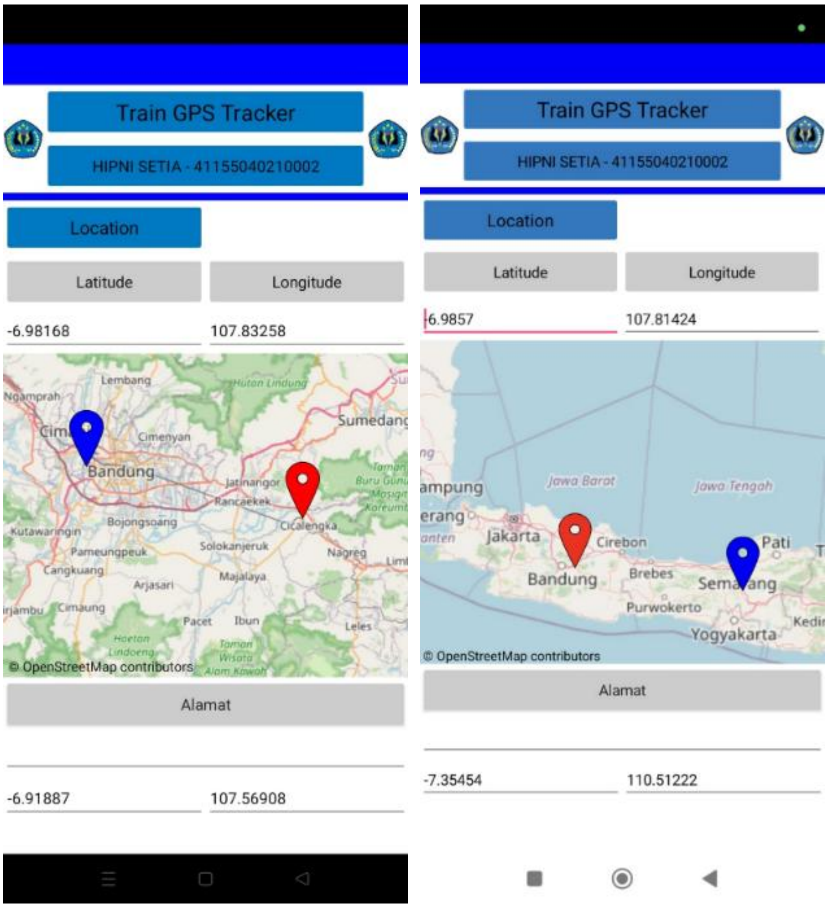

Figure 13. Remote Train Tracker system testing

4.5 Comparison with commercial GPS Tracker

The two main advantages of this research GPS Tracker are customization: The homemade GPS Tracker has advantages in terms of customization, such as additional monitors of the temperature and humidity conditions on the train, and fuel levels. And easy to integrate: The main drawback of the GPS Tracker on the market is that it is difficult to integrate into the applicable system, in general, the market GPS Tracker can only track the position of 1 tracker device. In addition, there is rarely a market GPS Tracker that can be modified. Table 3 is a Comparison of GPS Tracker with commercial GPS.

Table 3. Comparison of GPS Tracker with commercial GPS

Features	**GPS Tracker GT06**	**GPS Tracker VT-15**	**GPS103AB**	**GPS Tracker made**
Connectivity	GPRS (SIM)	GPRS (SIM)	GPRS (SIM)	WiFi
Accuracy	10m	10m	5m	2.5m (PDF) 5.555m (Testing accuracy accuracy 4.2.2)
Initialization time Cold start	45-90s	-	45s	27s (PDF) 3:46s
Hot start	15s	-	1s	1s (PDF)

Features	GPS Tracker GT06	GPS Tracker VT-15	GPS103AB	GPS Tracker made
				18s
GPS Tracking	SMS by sending a message first	SMS by sending a message first	SMS with additional interval messaging features	Smartphone apps at intervals
Number of GPS Trackers	1	1	1	Can do unlimited trackers according to the number of devices used
Development	-	-	-	System development is possible as needed, including automation.
Development	-	-	-	System development is possible as needed, including automation.

5. Conclusion

After doing the research, several conclusions were drawn. The Railway GPS Tracker system using the Neo 6M GPS sensor was successfully carried out to detect the position of the train with a fairly low average error value obtained, namely 0.00296 for latitude or 0.0074 for longitude. ESP 32 successfully connects to WiFi and sends train position data from the GPS sensor to the GPS Tracker Smartphone Application via the Firebase server. The performance of the Railway GPS Tracker system using the Neo 6M GPS sensor with a smartphone application was successfully implemented. Several suggestions are useful in developing further research: Adding the number of Train GPS Tracker systems so that many trains can be tracked. Adding a train speed monitoring feature. Adding a train arrival time estimation feature based on train speed and train distance from the user.

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Availability of data and Materials: All data are available from the authors.

Conflicts of Interest: The authors declare no conflict of interest.
Additional Information: No Additional Information from the authors.

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