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Evaluation of Coordinate Position Precision Using GNSS NEO SERIES and GSM SIM 7000E Modules

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Abstract

This study investigates the precision of coordinate positioning using Global Navigation Satellite System (GNSS) technology, focusing on GNSS Neo Series modules and the GSM SIM 7000E module. The research aims to address the lack of comparative studies evaluating these GNSS receivers simultaneously. A field test spanning 24 hours was conducted to collect data on satellite acquisition and Horizontal Dilution of Precision (HDOP). The GNSS systems were deployed in a controlled environment at the Class I Meteorological Station Hang Nadim, Batam. The system developed comprised GNSS modules (Neo 6M, Neo 7M, Neo 8M, and GSM SIM 7000E), an ESP32 microcontroller, Arduino UNO, and a Micro SD shield module. Data processing involved converting coordinates to meters and calculating longitude and latitude errors. Root Mean Square Error (RMSE) analysis and one-way ANOVA were performed to assess accuracy and compare the GNSS receivers. Results indicate that the GSM SIM 7000E demonstrated superior satellite acquisition, leading to higher accuracy in coordinate positioning compared to the Neo Series modules. The study also identified optimal data collection times for accurate dispersion. These findings provide valuable insights into selecting and deploying GNSS receivers, enhancing performance in location-based services and scientific applications.

Keywords: Coordinate Positioning, GNSS, Precision, Satellite Acquisition

1. Introduction

Global Navigation Satellite System (GNSS) is a satellite-based positioning system that provides users with their location on the Earth's surface. The most well-known GNSS today is the Global Positioning System (GPS), operated by the United States Department of Defense (Artini, 2014). GNSS can be used at any time and in any weather condition (Oo, 2019), even in adverse conditions such as rain or fog, both during the day and at night (Abidin, 2000).

GNSS is primarily utilized for geographic, civil, and military applications. GNSS navigation offers an accuracy range of 3-10 meters (Maulana, 2014). It determines the user's location coordinates, specifically latitude and longitude (Alfeno & Devi, 2017). A minimum of three satellites is required to determine a two-dimensional position (latitude and longitude), and at least four satellites are needed for a three-dimensional position (latitude, longitude, altitude). The greater the number of available satellites, the higher the obtained accuracy (Rudianto & Izman, 2011).

The Horizontal Dilution of Precision (HDOP) parameter in GNSS determines the accuracy of the horizontal position. A smaller HDOP value indicates better geometry, and therefore, to achieve an accurate position, a low HDOP value and a high number of satellites are essential (Ekawati, 2010). Errors in determining coordinates can have significant adverse effects, especially in navigation requiring high precision (Setiadi et al., 2023).

Position coordinates can be obtained using various GNSS receiver modules, such as the Ublox Neo 6M, Ublox Neo 7M, Ublox Neo 8M, and Simcom SIM7000E. Studies have shown that the accuracy level of the Ublox Neo 6M ranges from 3.86 meters to 4.5 meters (Ammarprawira et al., 2020; Permana et al., 2022). According to Ramadhani, (2022), the accuracy level of the Ublox Neo 7M is approximately

4.1 meters, while the Ublox Neo 8M has an accuracy level of 1.52 meters (Purwana et al., 2022).

Purbakawaca et al., (2022) used the GSM SIM 7000E module, but in their study, the role of GNSS was limited to displaying the device's location point without measuring the accuracy of the position coordinates. However, Khoeruman et al., (2022) reported that the GSM SIM 7000E module has a position accuracy of 1.7 meters.

No research has yet compared the three GNSS Neo Series modules and the GSM SIM 7000E simultaneously. Therefore, it is necessary to conduct simultaneous testing of the GNSS Neo 6M, Neo 7M, Neo 8M, and GSM SIM7000E. The position coordinate data from these four modules should be compared with a benchmark. A benchmark is a fixed point that serves as a reference in determining the position and altitude of surrounding points (Mutiara & Muhiddin, 2016; Ridwan & Anhar, 2022). The importance of using a benchmark lies in its known global coordinates.

2. Research Method

2.1 Time and Place of Research

The research was conducted from July 2023 to November 2023. The design and testing of the equipment for data collection were carried out in the Electrical Engineering Laboratory of Universitas Maritim Raja Ali Haji, Tanjungpinang. Data collection was conducted at the Class I Meteorological Station Hang Nadim, Batam. Data was collected continuously for 24 hours using the static method.

2.2 System Design

The GNSS position accuracy measuring instrument was designed using several main components: ESP32 microcontroller, Arduino UNO, GNSS modules Neo 6M, Neo 7M, Neo 8M, GSM SIM 7000E, and Micro SD shield module. The Neo series and GSM modules are used to obtain GNSS data. ESP32 and Arduino UNO process the data obtained from the GNSS modules, which is then stored on the Micro SD card. The system design diagram can be seen in Figure 1.

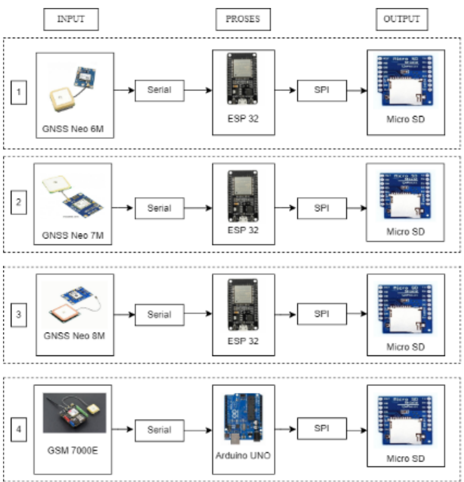

Fig 1. System Design Diagram

2.3 Data Processing and Analysis

The data processed includes GNSS receiver coordinates in degrees (latitude and longitude), the number of visible satellites, and Horizontal Dilution of Precision (HDOP). Before further analysis, coordinate data in degrees needs to be converted into meters. The conversion process utilizes the Transverse Mercator projection in the Universal Transverse Mercator (UTM) coordinate system. Once converted, longitude error and latitude error can be calculated as the difference between the GNSS receiver coordinates and the known benchmark coordinates. Longitude error (E-long) is calculated by subtracting the converted X coordinate of the receiver from the X coordinate of the benchmark. The calculation of longitude error can be seen in Equation 1:

$$\text{E-Long} = Xreceiver - Xbenchmark \quad (1)$$

Meanwhile, latitude error (E-Lat) is calculated by subtracting the converted Y coordinate of the receiver from the Y coordinate of the benchmark. The calculation of latitude error can be seen in Equation 2:

$$\text{E-Lat} = Yreceiver - Ybenchmark \quad (2)$$

After obtaining the longitude error and latitude error for each GNSS receiver, the Root Mean Square Error (RMSE) value is calculated as the square root of the:

$$RMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_{i-y_i})^2} \quad (3)$$

Where :

n = Number of values in the sample

x_i = Individual value

y_i = Mean value of treatments

Next, a one-way analysis of variance (ANOVA) is conducted to compare the accuracy between GNSS receivers. The parameters tested are HDOP and the number of satellites for each GNSS receiver. The confidence level used for the one-way variance analysis was $\alpha = 0.05$, equivalent to 95%. ANOVA testing will provide information on whether there are significant differences between GNSS receivers in terms of HDOP values and satellite counts. The hypotheses being tested are as follows:

H_0: There is no significant difference between HDOP and the number of satellites among GNSS receivers.

H_1: There is a significant difference between HDOP and the number of satellites among GNSS receivers.

$$H_0: \mu1: \mu2: \ldots : \mu k \quad (4)$$
$$H1: \mu1: \mu2 : \ldots : \mu k \quad (5)$$

If the research rejects H_0, then a Tukey post hoc test is needed to determine which pairs of GNSS receivers have significant differences in HDOP values and satellite counts. The Tukey post hoc test uses the following formula to calculate the Honestly Significant Difference (HSD). The formula can be seen in Equation 6 (Mendenhall et al., 2013):

$$HSD = q\sqrt{\frac{MSE}{n}} \quad (6)$$

Where :

q = Critical value for the Tukey distribution
MSE = Mean Square Error
n = Total number of data points

Each pair of GNSS receivers will be compared with the HSD value. If the average difference in HDOP and satellite counts is greater than the HSD, then that pair exhibits significant differences in accuracy. The results from RMSE analysis and ANOVA testing will be used to conclude on the accuracy of each GNSS receiver. Additionally, analysis of the positional error distribution patterns will provide insights into the characteristics of GNSS receivers in position measurement. Therefore, this study will provide valuable information for selecting GNSS receivers for related electrical engineering applications.

3. Results and Discussion

The field test was conducted for 24 hours starting from September 22, 2023 (10:00 AM WIB) to September 23, 2023 (10:00 AM WIB). The GNSS components were placed on the benchmark located at the BMKG instrument park in Batam. The actual benchmark coordinates are latitude 1.119031° and longitude 104.113677°. GNSS data was collected every second continuously for 24 hours. The BMKG benchmark can be seen in Figure 2, while the GNSS components can be seen in Figure 3.

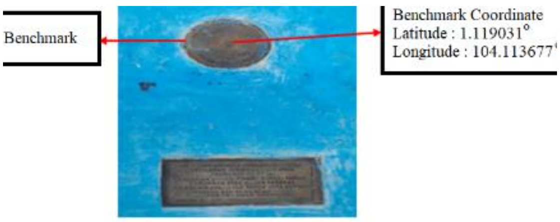

Fig 2. Benchmark

Fig 3. GNSS components

The results of the 24-hour field test for each GNSS Neo Series and GSM SIM 7000E consist of satellite data and HDOP values. Satellite values include data directly transmitted by satellites to the GNSS receiver, such as time, satellite positions, and other information. The satellite values read are influenced by local weather conditions and the strategic placement of GNSS devices, sometimes resulting in noise affecting satellite value readings. The more satellites acquired by each GNSS receiver, the more accurate the GNSS device tends to be. The GSM SIM 7000E acquires the highest average number of satellites, with an average of 18 satellites. In contrast, the Neo 6M has the lowest average number of satellites at 10. The average number of satellites for each GNSS receiver can be seen in Table 2. Graphs showing the satellite data for each GNSS receiver are depicted in Figure 4.

Table 2. Average number of satellites for GNSS receiver

GNSS *Receiver*	Satellite Count
Neo 6M	10
Neo 7M	11
Neo 8M	12
GSM SIM 7000E	18

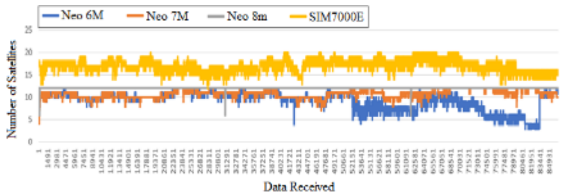

Fig 4. Satellite Graph

HDOP or Horizontal Dilution of Precision is a value error caused by the relative positions of satellites. The HDOP values obtained from each GNSS receiver vary because of factors such as atmospheric conditions, the number of visible satellites, topographic conditions, and GNSS antenna quality. At times, GNSS experiences noise during HDOP readings, with values peaking at 99.99, causing significant spikes in the graph. The best average HDOP value is found in Neo 8M at 0.58. Meanwhile, the least favorable average HDOP value is in Neo 6M at 1.07. The average HDOP values obtained for each GNSS receiver can be seen in Table 3. The HDOP graph is shown in Figure 5.

Table 3. Average HDOP Values for GNSS Receivers

GNSS Receiver	HDOP Value
Neo 6M	1.07
Neo 7M	0.7
Neo 8M	0.58
GSM SIM 700 E	0.69

The HDOP values obtained from each GNSS receiver have different levels of accuracy. Referring to Table 4, the GNSS receivers Neo 7M, Neo 8M, and GSM SIM 7000E fall into the ideal category (high accuracy level). On the other hand, the HDOP value for the GNSS Neo 6M falls into the Excellent category (still accurate positioning).

Table 4. DOP value rating

DOP	Rating	Explanation
0-1	*Ideal*	Ideal accuracy level is high
1-2	*Excellent*	Position is still accurate
2-5	*Good*	Minimum level of accuracy
5-10	*Moderate*	Measurement is not
10-20	*Fair*	Not accurate
>20	*Poor*	Not reliable

The validation of coordinates from each GNSS receiver over 24 hours against benchmark coordinates aims to determine the accuracy of each GNSS receiver's coordinates compared to the actual coordinates. The highest accuracy over 24 hours was achieved by the GSM SIM 7000E, with a latitude accuracy of 0.75 m and a longitude accuracy of 2.44 m. In contrast, the lowest accuracy was observed with the Neo 6M, with a latitude accuracy of 7.76 m and a longitude accuracy of 71 m.

An analysis was also conducted to determine the optimal time for the dispersion of accurate points on the GNSS. The best dispersion of coordinate points was obtained after 2 hours of data collection to acquire coordinates from the GNSS receiver. The highest accuracy was observed with the GSM SIM 7000E, with a latitude accuracy of 0.33 m and a longitude accuracy of 0.38 m. Conversely, the lowest accuracy was observed with the Neo 7M, with a latitude accuracy of 1 m and a longitude accuracy of 3.72 m. The results of the accurate points from the GNSS receivers can be seen in Table 5.

Table 5. GNSS Receivers Accuracy Over 2 Hours

GNSS	Accurate Points (2 Hours)	
	Latitude	Longitude
Neo 6M	2.25 m	0.68 m
Neo 7M	1 m	3.72 m
Neo 8M	1.27 m	0.57 m
GSM SIM 7000E	0.33 m	0.38 m

The farthest coordinates read on the GNSS Neo series have exceeded the standard set by astronavigation (International Hydrographic Organization, 2008) of 5 meters. This is caused by the frequent rain that occurred during data collection, which resulted in a decrease in the accuracy of coordinate readings from GNSS (Ikbal et al., 2017). The best coordinate points were obtained after 2 hours of data collection with the farthest point on latitude being 2.25 meters for GNSS Neo 6M. The farthest point on longitude is for Neo 7M with a distance of 3.72 meters. These farthest coordinates are still in the good category because they have not exceeded the limit set by astronavigation of 5 meters (International Hydrographic Organization, 2008).

A one-way variance analysis (ANOVA) was conducted on the HDOP and satellite data from the GNSS receivers. The number of treatments involved four different GNSS receivers. The repeated HDOP and satellite data per second were collected, amounting to 86,400 GNSS data points. The ANOVA results for HDOP are presented in Table 6. The ANOVA results for the satellite data are presented in Table 7.

Table 6. Results of One-Way ANOVA for HDOP

Source of Variation	SS	df	MS	F	F crit
Between Groups	11,720.71	3	3,906.9	41,799	2.6
Within Groups	32,302.80	345,600	0.09		
Total	44,023.51	345,603			

Table 7. Results of One-Way ANOVA for Satellites

Source of Variation	SS	df	MS	F	F crit
Between Groups	3,329,090	3	1,109,697	610,863	2.6
Within Groups	627,818	345,600	1,82		
Total	3,956,908	345,603			

Based on the results of the one-way analysis of variance (ANOVA) conducted on HDOP and satellite data, it was found that the calculated F-value is greater than the F-table value for both HDOP (41799.0193 > 2.604935) and satellite data (610863.104 > 2.60493). This indicates that there are significant differences in HDOP and satellite data among the four GNSS receivers used. The one-way ANOVA shows that there are differences among the four GNSS receivers, but it does not specify which GNSS receiver's data differs from the others. Therefore, Tukey tests are necessary following the one-way ANOVA to identify the specific differences between the GNSS receivers.

The Tukey test requires the Honestly Significant Difference (HSD) value as a threshold to determine whether the GNSS receivers are significantly different. The HSD value for HDOP is 0.004, and the HSD value for the satellite data is 0.017. These values serve as the thresholds for comparing the differences between each pair of GNSS receivers. Based on Tukey test, HDOP values and the number of satellites from GNSS receivers differ from each other.

The best HDOP is owned by Neo 8M with a value of 0.58 and the worst is owned by Neo 6M with a value of 1.07. Meanwhile, the highest number of satellites is owned by GSM SIM 7000E with 18 satellites and the lowest is owned by Neo 6M with 10 satellites. The difference in the number of satellites is influenced by the type of satellites received. The more satellites received, the smaller the HDOP value (Ekawati, 2010). However, according to research conducted by Liu, (2002), other factors that affect the HDOP value are satellite orbit errors, satellite clock errors, ionospheric effects, and receiver errors. This could be the reason why the HDOP value of GSM SIM 7000E is slightly larger than that of Neo 8M.

4. Conclusion

Based on the research that has been conducted, it can be concluded that this study has thoroughly assessed the coordinate position precision of GNSS Neo Series modules and the GSM SIM 7000E module. Through comprehensive field tests and meticulous data analysis, notable differences were observed among the GNSS receivers in terms of satellite acquisition and Horizontal Dilution of Precision (HDOP). The GSM SIM 7000E demonstrated higher satellite acquisition, resulting in increased accuracy in coordinate positioning compared to the Neo Series modules. These findings provide valuable insights for selecting and deploying GNSS receivers adapted to specific application needs, ultimately enhancing performance and efficiency in location-based services and scientific pursuits.

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