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DISTANCE-DEPENDENT ACCURACY OF GNSS BASELINE MEASUREMENTS: A COMPARATIVE STUDY OF GPS, GLONASS, AND INTEGRATED GPS/GLONASS SYSTEMS

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ABSTRACT

This study examines the accuracy of coordinate and baseline determinations using various satellite positioning methods—GPS, GLONASS, and integrated GPS/GLONASS—across increasing distances from a base station. Conducted along the Mansoura–Damietta Road in northern Egypt. The research focuses on static GNSS receiver operations under varying Position Dilution of Precision (PDOP) levels. Field data were collected using both satellite and traditional surveying techniques. Baseline measurements were taken between unknown stations using a total station, providing reference values for comparison. GNSS data from the base and rover stations were processed using Justin software. The results prove that the combined GPS/GLONASS system provides significantly higher accuracy in both coordinate and baseline measurements compared to either system used independently. The study found that baseline length measurements maintained an accuracy of 2–8 cm, with a correlation *coefficient of 96%, even at distances up to 10 km from the base station under favorable weather conditions.*

Keywords: Geodetic networks, GPS, GLONASS, Baseline length accuracy, PDOP, relative positioning technique

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1. Introduction

GNSS technology is applied in various fields across different sectors, including industry, farming, mapping, geographical information systems data acquisition, public protection, surveying, telecommunication, military, and transportation. GNSS technology has proven effective in civil engineering and survey applications, particularly in developing regions such as Egypt [1].

Now, it is quick and easy to receive accurate and precise coordinates anywhere using GNSS technology [2;3]. The low number of observable satellites could affect GPS functionality in canyons and in other difficult environments. This is, however, improved by combining multiple GNSS systems, which provides a larger number of observable satellites and higher accuracy [4]. In the technique used to solve positioning issues, mobile satellites are utilized. The position of the satellites can be computed with the required accuracy at any time. Dynamic triangulation is replaced by dynamic trilateration, which creates a three-dimensional system of linear measurements to compute the position of the identified points.

Several studies have been conducted to assess the accuracy of the GPS Static method, aiming to determine the optimal time window, DOP values, time intervals (epochs), and suitable elevation angles. research by [5] indicates the importance of almanac data files in determining the appropriate time for observation. Paper [6] also found that spending more time on observation does not necessarily lead to improved accuracy. However, it is essential to increase the number of satellites and lower the PDOP value settings to improve point coordinate accuracy. [7] Carried out a study on GPS-only and combined GPS and GLONASS precise point positioning. The study found that the availability of GLONASS satellites did not significantly influence positioning accuracy, as their availability was limited. The accuracy improved as more GLONASS satellites became accessible. The reference in a combined solution significantly improved compared to a GPS-only reference. [8] Present a new precise point positioning (PPP) model that incorporates GPS, GLONASS, GALILEO, and BEIDOU observation data. Their research demonstrated that the inclusion of BEIDOU, in addition to GPS, enhanced positioning accuracy compared to a GPS-only reference, and the combination of the GNSS systems further improved accuracy. The study is likely to involve data collection from GNSS receivers installed in the research stations, which receive signals from the GPS and GLONASS satellites. The data collected is then processed by specific algorithms and methodologies to determine the positions derived from each GNSS system, as well as positions obtained from the integrated GPS/GLONASS reference.

To compare the accuracy of the GNSS static technique, several parameters during both surveying and data processing affect the outcome. Some of the parameters are elevation angle, sample rate, baseline length, observation time, and the processing software [9]. To achieve a credible and accurate assessment, all parameters must be fixed and then changed alternately, e.g., the elapsed time per baseline, the baseline used, and the processing Ephemeris.

To calculate the coordinates of identified points, multiple measurements are conducted. The primary approach in geodetic practice relies on relative positioning, utilizing established terrestrial triangulation and polygonometry techniques. However, the methodologies applied are often inconsistent or poorly structured, as they frequently overlook critical factors such as the temporal and geometric configuration of satellite passes and the integration of different GNSS systems. Consequently, in many cases, the accuracy of geodetic determinations is not adequately justified by the distance from reference base stations.

To assess measurement accuracy, seven geodetic network points were established along the Mansoura–Damietta Road in northern Egypt (see Fig. 1). Station ST.1 was designated as the base station. To evaluate the accuracy of GNSS data processing results obtained from different software packages, an open connected traverse was established using a Leica FlexLine TS09plus total station, which offers a high angular accuracy of 1 arcsecond. This instrument is equipped with advanced surveying applications, including the Travers POR program, which facilitates the creation of high-precision traverses. Fieldwork commenced at ST.1, where coordinates were predefined and the initial direction was assumed. Baseline lengths between each pair of stations were measured using the total station in both forward and backward directions. The objective of this study is to analyze the accuracy of baseline measurements under varying PDOP conditions using GPS and GLONASS systems in the static operational mode of GNSS receivers.

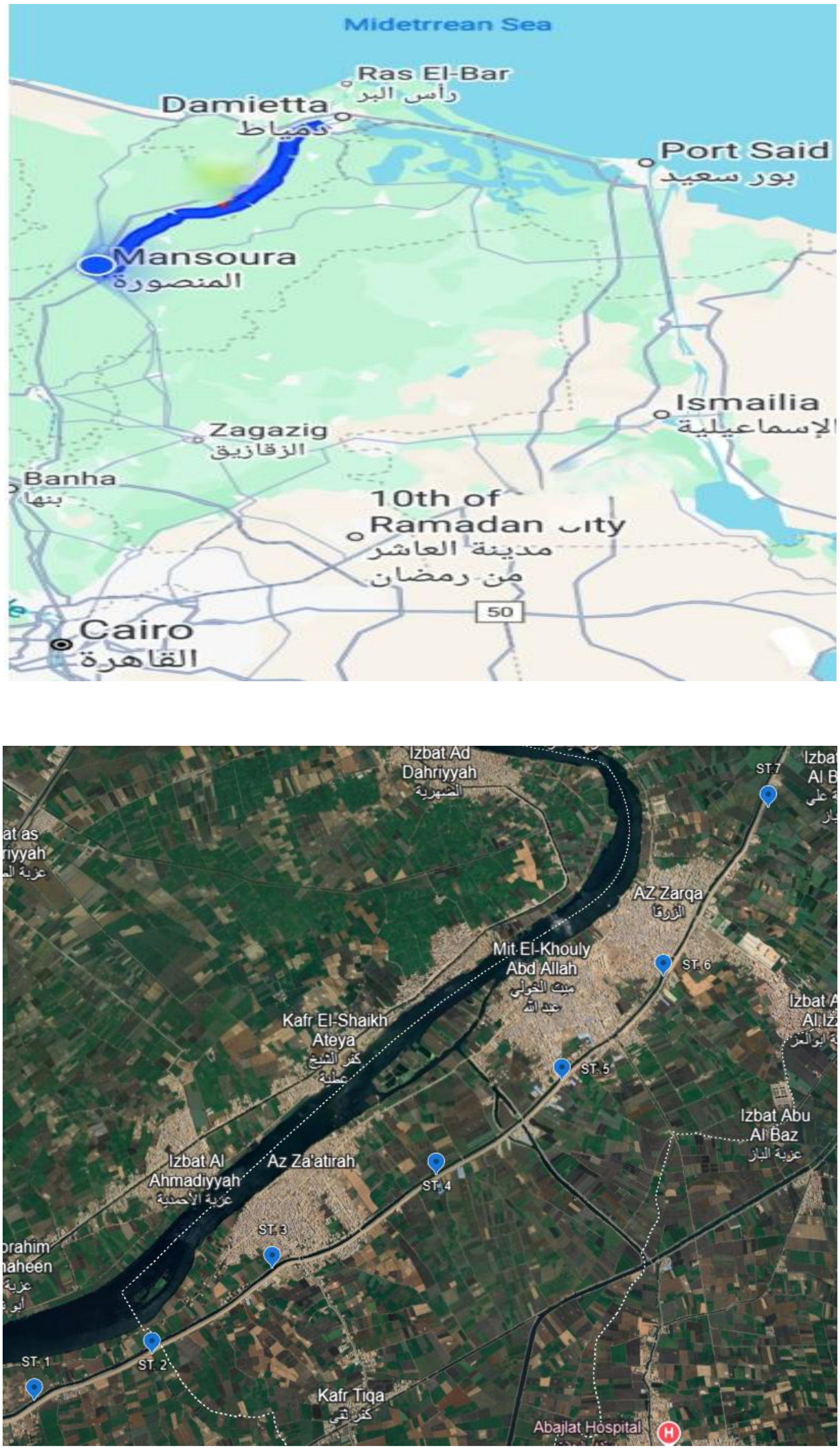

Fig. 1. Layout of the studied points of the geodetic network stations**.**

2. Experimental Work:

To achieve the goal of the current study, different types of data were employed. The GPS/GLONASS campaign, located north of the Nile Delta, includes seven points (from ST. 1 to ST. 7), which were established on the Mansoura – Damietta Road. The distances between these points range from 1 km to 10 km.

Coordinate and distance calculations were performed using MSC-61 software, pre-installed on the JAVAD Triumph-1 GNSS receiver, which was employed to survey all baselines. Observations were carried out with a 13° elevation mask and a sampling rate of 30 seconds. For comparison purposes, the coordinated values and inter-station distances obtained from the total station measurements were used as reference values, considered to represent the true positions. The results of the comparison, including graphical representations and summary tables, are presented below.

Following the field observations, coordinates and distances were calculated from the base station (ST.1) to six other geodetic points. Data was collected during both favorable conditions (PDOP ≤ 3) and unfavorable conditions (PDOP > 3). All GNSS data from the base and rover stations were transferred to Justin software for post-processing. To ensure high measurement accuracy, several recommended best practices were followed throughout the survey and data processing phases:

• The almanac data file was consulted to determine the optimal observation times, favorable PDOP values, and appropriate satellite elevation angles for tracking, following the recommendations outlined by [5; 10].

• A station site was carefully selected to be free from obstructions near the receivers, minimizing the potential for multipath effects.

• To avoid signal interference, there should be no additional electrical sources close to the receivers.

• No vehicles or transportation are permitted near the receivers to ensure the safety of both the equipment and the surveyors.

• Survey baselines ranged from a few hundred meters up to 10 kilometers and were processed using broadcast ephemeris data

3. Results and Analysis:

To predict the best conditions for observing the satellite constellation and to identify the smallest PDOP errors, observations were carried out over 24 hours. The results of the errors in determining distances as they move away from the base station (ST.1) to each point are shown in Table 1 and are presented graphically in Fig. 2.

Table 1. Study of the Baseline length from the base station (St. 1) to other stations in a favorable condition (Period of PDOP ≤ 3).

Name of Station	Distance from ST. 1, (m)	Baseline Length using GPS/GLONASS, (m)	Measurement error, GPS/GLONASS (m)	Baseline Length using GPS, (m)	Measurement error GPS, (m)	Baseline Length using GLONASS, (m)	Measurement error, GLONASS, (m)
ST. 2	959.63	959.6138	0.0162	959.6036	0.0264	959.5988	0.0312
ST. 3	2085.22	2085.1879	0.0321	2085.1788	0.0412	2085.1765	0.0435
ST. 4	3561.91	3561.8675	0.0425	3561.8388	0.0712	3561.8426	0.0674
ST. 5	4881.79	4881.7218	0.0682	4881.7079	0.0821	4881.7024	0.0876
ST. 6	6170.54	6170..4719	0.0681	6170.4453	0.0947	6170.4413	0.0987
ST. 7	8016.04	8015.9538	0.0862	8015.9275	0.1125	8015.9157	0.1243

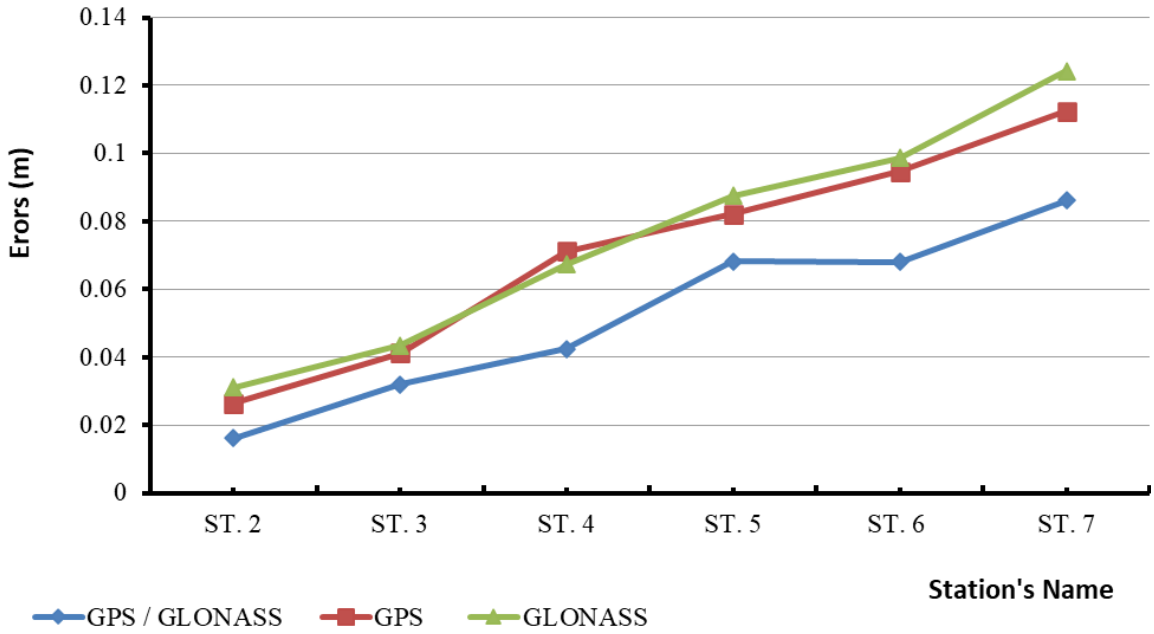

Fig. 2. Graph of the change in Baseline Length measurement error depending on the distance from the Base Station at PDOP<3.

Analysis of data in Tab. 1 and in Fig. 2 shows that the coordinates and distances obtained by using two GPS/GLONASS systems are much more accurate than when using each of them separately. The results of baseline measurements are shown, indicating that the accuracy of the distance measurements varies from 2 to 8 cm as they move away from the base station in case of using GPS/GLONASS systems and from 2 to 11 cm when using GPS observations only but when using GLONASS observations, errors vary from 2 to 13 cm.

The accuracy of calculating baseline length is affected by the PDOP values, both during favorable and unfavorable observation periods. The results of the errors in determining distances as they move away from the base station (ST.1) to each point are shown in Tab. 2 and are presented graphically in Fig. 3 for the period of PDOP > 3.

Table 2. Study of the Baseline length from the base station (St. 1) to other stations in a case of Period of PDOP > 3.

Name of Station	Distance from ST. 1, m	Baseline Length using GPS/GLONASS, (m)	Measurement error, GPS/GLONASS (m)	Baseline Length using GPS, (m)	Measurement error GPS, (m)	Baseline Length using GLONASS, (m)	Measurement error, GLONASS, (m)
ST. 2	959.63	959.6014	0.0286	959.5908	0.0392	959.5874	0.0426
ST. 3	2085.22	2085.1803	0.0397	2085.1688	0.0512	2085.1628	0.0572
ST. 4	3561.91	3561.8413	0.0687	3561.8279	0.0821	3561.8318	0.0782
ST. 5	4881.79	4881.7114	0.0786	4881.6977	0.0923	4881.6916	0.0984
ST. 6	6170.54	6170.4533	0.0867	6170.4114	0.1286	6170.4158	0.1242
ST. 7	8016.04	8015.9154	0.1246	8015.8975	0.1425	8015.8874	0.1526

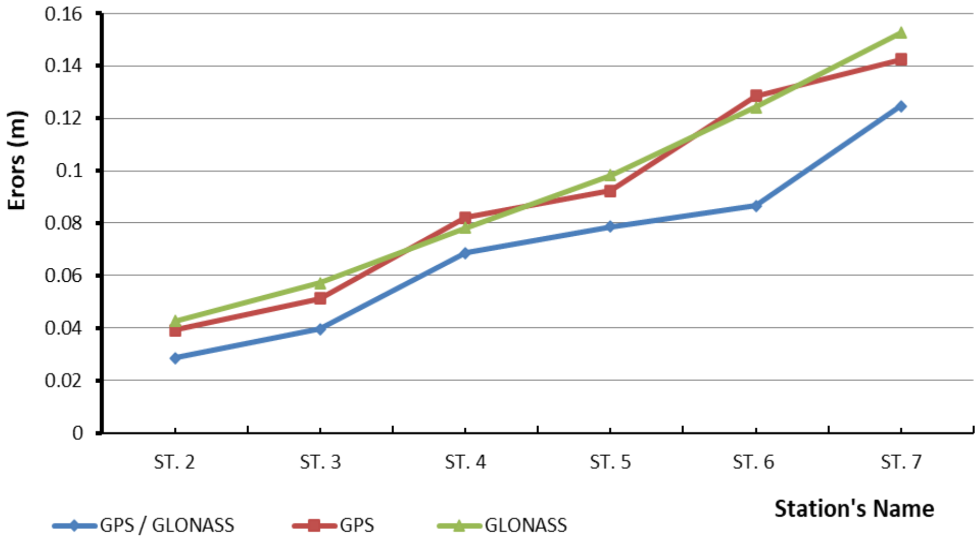

Fig. 3. Graph of the change in the Baseline Length measurement error depending on the distance from the Base Station at PDOP>3.

Analysis of the data presented in the tables and figures indicates that PDOP values significantly influence the accuracy of coordinates and distances obtained using GNSS. Baseline length errors measured with the combined GPS/GLONASS system are notably smaller during periods when PDOP ≤ 3 compared to periods when PDOP > 3. Specifically, during periods of low PDOP (≤ 3), errors range from 2 to 8 cm, whereas during periods of higher PDOP (> 3), errors increase to between 3 and 13 cm.

Based on the data presented in the tables and figures, graphs were generated to illustrate the relationship between the baseline length, from the base station (ST.1) to the rover station, and the corresponding measurement errors using GPS/GLONASS systems. Figures 4 and 5 depict these relationships for periods with PDOP ≤ 3 and PDOP > 3, respectively.

Figs. 4 and 5 show that baseline length measurement errors increase as the distance from the base station to the rover station increases for the GPS/GLONASS system, under different PDOP conditions. Each figure includes the regression equation representing the relationship between error and baseline length, along with the corresponding correlation coefficient for the respective PDOP periods. where,

r is the measurement error of baseline length.

L is the baseline length from the base station to each other station.

R^2 is the correlation coefficient.

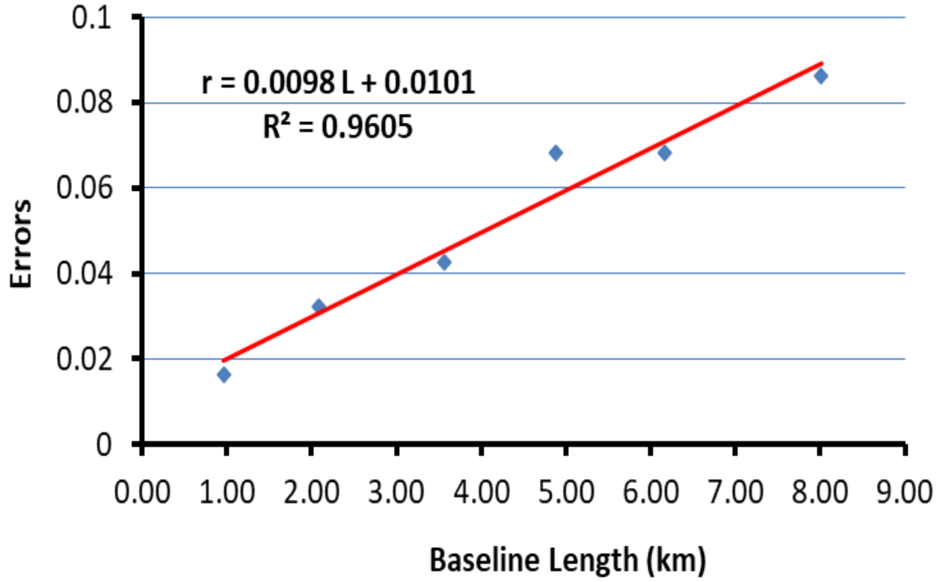

Fig. 4. Relationship between measurement errors and baseline length using GPS/GLONASS systems at PDOP<3.

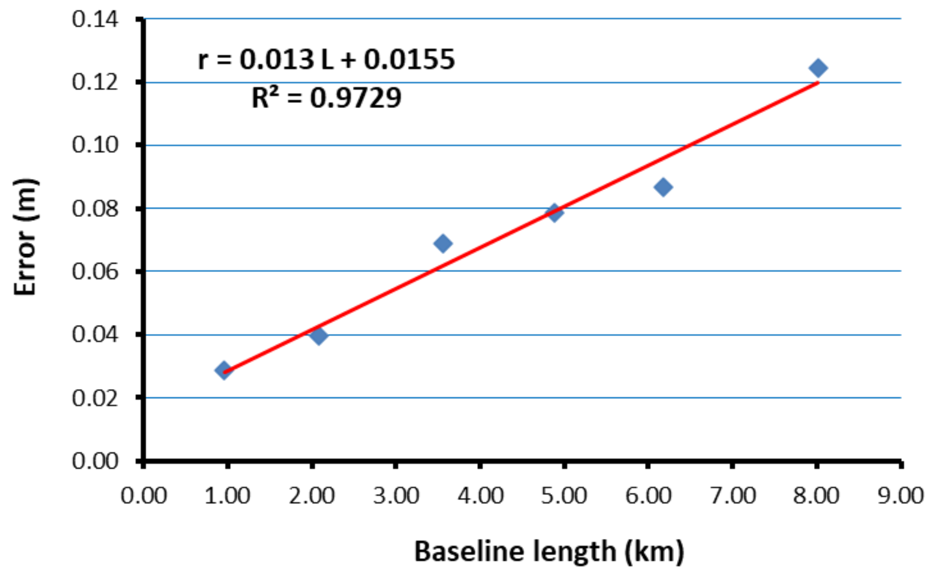

Fig. 5. Relationship between measurement errors and baseline length using GPS/GLONASS systems at PDOP>3.

Based on the research results, the following recommendations are proposed to enhance the quality of geodetic surveys using satellite-based coordinate determination methods, thereby improving the accuracy of coordinates and distances:

- Conduct observations during favorable weather conditions whenever possible.
- In unfavorable weather conditions, extend observation time to at least 20 minutes.

- Schedule observations to coincide with periods of minimum PDOP values.
- Use a satellite elevation cutoff mask angle of 10° or higher to reduce multipath errors and improve coordinate accuracy.
- Perform an initial quality check of collected data at the observation site. If significant errors are detected, either conduct additional observation sessions or postpone data collection to a more suitable time.
- Utilize dual-frequency, dual-system GNSS receivers to enhance signal quality and reliability.
- Employ combined GPS/GLONASS systems for observations and calculations to improve positioning accuracy.

4. Conclusion:

According to the research results in this study, GPS/GLONASS configurations demonstrate evident improvements compared to using GPS or GLONASS alone in terms of solution availability and accuracy, which are typically seen as crucial factors in urban environments

The experimental results show that the measurement error of baseline length increases with increasing distance from the base station to the rover station.

Analysis of the data in this study indicates that PDOP values significantly affect the accuracy of coordinates and distances obtained using GNSS. The study demonstrates that, during periods when PDOP ≤ 3, baseline length measurements maintain an accuracy ranging from 2 to 8 cm, with a correlation coefficient of 96%, even at distances up to 10 km from the base station.

5. Data Availability Statement:

All data generated or analyzed during this study are included in this published article.

6. Acknowledgments

The authors express gratitude to members of the civil engineering department of the Higher Future Institute for Engineering and Technology in Mansoura for helping in collecting and analyzing data.

7. Conflict of interest:

The authors declare there are no conflicts of interest regarding the publication of this article.

8. Author Contribution:

- Sobhy Abdel Monem Younes: Conceptualization, analysis of data, writing, reviewing, and editing.
- Sobhy Abdel Monem Younes and Aya Mohsen Handousa: Methodology, experimental part, writing- original draft preparation.

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