تحسين دقة الإحداثيات المستنتجة بطريقة الرصد المطلقة باستخدام نظام تعيين المواضع الشامل GPS

د. محمد صادق عيسى*، د. عدنان أحمد محمد**، د. حنان كامل درويش***

الملخص العربي:

يتضمن هذا البحث مقارنة عملية لطرق تعيين مواضع النقاط الأرضية بناءً على بيانات مساحية من نظام تعيين المواضع الشامل GPS وذلك بطريقتين وهما الطريقة المطلقة والطريقة المطلقة الدقيقة وذلك بإنقاص أخطاء المدارات والميقاتيات باستخدام خدمة حساب الإحداثيات الدقيقة من شركة ترمبل TRX–PP. ومن ثم تم مقارنة النتائج مع مثيلاتها فيما لو تم الحساب والرصد بالطريقة النسبية باستخدام نقطة مرجعية معلومة. كما تم دراسة تأثير خطأ تعدد المسارات وتأثيره على الإحداثيات المحسوبة وذلك بمقارنة الإحداثيات الناتجة مع مثيلاتها بدون التأثير الإضافي لتعدد المسارت بوضع حاجز قريب من النقطة مما يسبب زيادة في خطأ تعدد المسارات وتأثيره على الإحداثيات المحسوبة.

وقد أظهرت نتائج المقارنة تحسناً كبيرا في إحداثيات النقاط المرصودة بالطريقة المطلقة عند استخدام خدمة المعالجة بالطريقة الدقيقة من شركة ترمبل. كما أظهرت قفزة نوعية في دقة النقاط عند معالجتها بالطريقة النسبية وربط النقطة المحسوبة بنقطة تحكم معلومة. بالنسبة للحاجز فقد أدى وجوده قرب نقطة الرصد إلى تأثير مباشر على كل من الإحداثيات الناتجة وعلى دقة هذه الإحداثيات لهذه النقطة.

الكلمات المفتاحية: طريقة الرصد المطلقة، التحديد الدقيق لموقع النقطة، PPP، RTK–PP.

*: مدرس في قسم الهندسة الطبوغرافية، كلية الهندسة، الجامعة اللبنانية الدولية في بيروت LIU, BIU

، *: أستاذ مساعد في قسم الهندسة الطبوغرافية، كلية الهندسة المدنية- جامعة البعث

Enhancing of GPS Absolute Point Positioning Determination

Dr. Mohamed S. Issa*, Dr. Adnan A. Mohammed, Dr. Hanan K. Darwishe*****

Abstract:

This research includes a practical comparison of the methods of locating ground points based on surveying data using GPS, in two ways, namely the absolute method and the absolute precise method, by decreasing the errors of orbits and clocks using the accurate coordinates calculation service from Trimble TRX-PP. And then the results were compared with their counterparts if the calculation and observation were done by the relative method using a known reference point. The effect of multipath error and its effect on the calculated coordinates was also studied by comparing the resulting coordinates with their counterparts without the additional effect of multipath by placing a barrier close to the point, which causes an increase in the multipath error and its effect on the calculated coordinates.

The results of the comparison showed a significant improvement in the coordinates of the points observed by the absolute method when using Trimble accurate service. It also showed a quantum leap in the accuracy of the points when they are treated by the relative method and linking the calculated point to a known control point. As for the barrier, its presence near the reference point had a direct impact on each of the resulting coordinates and on the accuracy of these coordinates for this point.

Keywords: *Absolute GPS positioning, Precise Point Position, PPP, RTX-PP.*

*: Assistant Professor, Surveying Engineering Department, Lebanese International University LIU , BIU University

, *: Associate professor, Topographic Department, Faculty of Civil Eng., Al-Baath university

Aim of the research:

This paper is based on comparing the resulted point's coordinates from two different positioning techniques. The first one is what known as point positioning absolute technique, whereas, the second one is the relative point positioning technique. Both techniques will be based on data collected using and without using a barrier which can generate additional multipath effect on the receiver antenna. Moreover, the point positioning mode will be processed using the precise Trimble RTX-PP technology. Accordingly, we will have four different cases with different coordinates for the same point.

The aim of this paper is to compare the resulted point coordinates from those four different cases and to analyze the accompanied coordinates accuracy. The comparison will guide us on the possibility of usage for each case and its field surveying applications and office processing precautions.

Methodology:

The adopted methodology during this study will consists of the following steps (explained in figure 1):

- Conducting the field observations for the tested two points (A and B) for four successive days without putting barrier near point B.
- Conducting the field observations for the tested two points (A and B) for four successive days while enforcing additional multipath effect by using barrier near point B.
- Processing the collected raw data for the single point (point B) absolute positioning with and without multipath from barrier using the precise Trimble RTX-PP technology.
- Processing the collected raw data for the single point (point B) relative to the known point A, also with and without multipath from the barrier.
- Comparing and analyzing the final resulted coordinates for point B from the resulted four different cases processing procedures.
- Drawing some comments and recommendations based on the previous analysis.

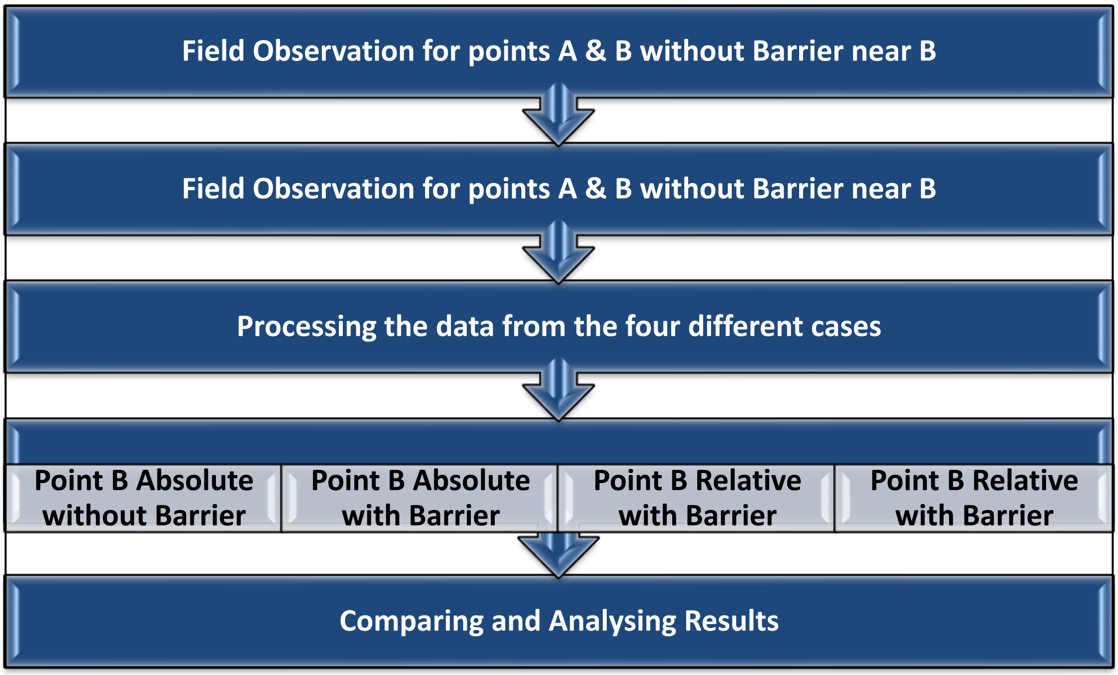


Figure (1): Flowchart depicting the adopted steps and methodology.

Absolute and Relative Positioning:

GPS positioning can be classified into two positioning techniques: absolute and relative positioning. The Absolute Point Positioning (APP) uses one unit receiver to determine the coordinate positioning, but due to the affecting errors, this mode has a bad accuracy. In the relative GPS Positioning (DGPS), two or more receivers are used to observe the same satellites at the same time, where one receiver occupies and the known point and the other receiver occupies the unknown point. The coordinates of the unknown points are determined relative to the coordinates of the base station; therefore, most of the errors can be eliminated or reduced through the differences. The accuracy of this method can reach to centimeters for baselines less than 20 km.

Absolute Point Positioning (APP) is much economic and easier than DGPS, because it uses one-unit receiver. It has two levels from positioning Service according to accuracy;

Standard Point Positioning (SPP) and Precise Point Positioning (PPP). The first technique, SPP, uses the broadcast ephemeris data in estimating the receiver position, where its accuracy about 40m. The second technique, PPP, was proposed for the first time in 1995 by Heroux and Kouba. It performs position determination by processing un-differentiated dual frequency code and carrier-phase measurements from a dual-frequency receiver coupled with precise GPS orbit and clock products. It has been widely demonstrated that it is capable of providing accurate position solutions at sub-decimeter level for kinematic positioning and at sub-centimeter level for static positioning. Figure (2) illustrates the differences between absolute, relative and PPP absolute observing techniques [**6**].

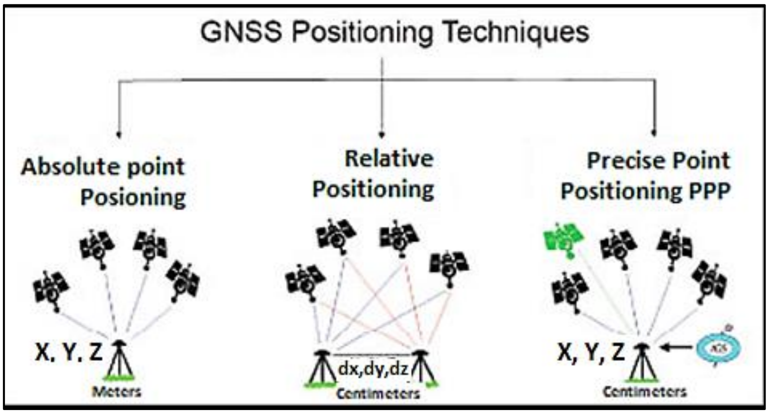


Figure (2): Illustration of the Absolute, Relative and the PPP Absolute positioning Techniques.

However, GNSS users prefer relative positioning method in surveying applications if high accuracy is needed. All GNSS methods depending on relative positioning principle require simultaneous observations collected at a number of stations at least one is a reference station whose coordinates are well known. Therefore, minimum two receivers should be used on surveys: the first one occupies the reference known point and the other occupies the unknown point whose coordinates will be determined. The primary factors for point positioning accuracy are the baseline length between two receivers and the observation duration. In this context, establishing Continuously Operating Reference Stations (CORS) networks has a significant contribution to the relative positioning [**1** and **7**].

The carrier phase measurement observed by the two receivers at a certain epoch can be written as [**6**]:

$$\emptyset_{b,k}^{i} = \lambda_k^{-1}\left(r_{b,k}^{i} - I_{b,k}^{i} + T_{b,k}^{i}\right) + f_k\left(\delta t_{b,k} - dt_k^{i}\right) + N_{b,k}^{i} + \varepsilon_{b,k}^{i}$$

where ϕ is the carrier phase measurement (unit: cycle), λ is the carrier wavelength (unit: m), *r* represents the true geographical distance between the satellite and the receiver (unit: m), I is the ionospheric delay (unit: m), T is the tropospheric delay (unit: m), *f* is the carrier frequency (unit: Hz), δt is the receiver clock error (unit: s), *dt* is the satellite clock error (unit: s), N is the integer ambiguity (unit: cycle) and ε is the residual errors mainly including carrier phase noise and multipath (unit: cycle). Subscripts b and r respectively represent the base and the rover receiver. Subscript k is the identifier for different frequencies, and $k \in 1, 2$ for dual frequency case. Superscript *i* represents the satellite #*i*.

PPP method is the particular case of traditional absolute point positioning approach that became widespread after the establishment of global GNSS networks with permanent stations. For a worldwide positioning in sub-meter level, an accurate determination of corrections of satellite orbits and clocks is possible using data of a global GNSS network. Data collection with a dual frequency receiver at the point, whose coordinates will be computed accurately, is enough in PPP method for determining high accurate position. So, by using code and carrier phase observations with a double frequency receiver that are utilized by the un-differenced and ionosphere-free combinations, decimeter to centimeter level point positioning accuracies may be achieved due to observation durations [**12**, **5**, **4**, and **7**].

The accuracies of orbit and clock correction products and error models to be used in determination have significant importance on the point positioning accuracies to be achieved in PPP method [**2**].

The study Area:

The study case is located in LIU university, Rayak campus, Lebanon. This campus is located between Zahle and Baalbek cities, as shown in Figure (3).

Figure (3): Location of the tested points, LIU Rayak Campus, Lebanon.

The reference point A is a known control point with geocentric coordinates in the Global WGS84 datum, as listed in Table (1).

Table (1): Coordinates of reference known control point (A)

Point	X (m)	Y (m)	Z (m)
Point (A) Rayak Campus	4289177.7361	3117087.7490	3534865.1596

Field Observations:

The field observations were conducted using two dual frequency multi GNSS systems, that are: two Topcon Hyper-V GPS receivers. The collection of raw data was conducted on eight successive days' sessions, as explained in the table (2):

Table (2): Details of the observation sessions for points A and B.

Day	Observation Day	Observations Start and Stop time	Details
First 4 Days	May/15/ 2019	5:00 **to** 6:00 **PM**	Point A on fixed tripod (h= 1.641 m) Point B on fixed Tribrach (h= 0.216 m) Without Barrier near B
	May/16/ 2019	4:56 **to** 5:56 **PM**	
	May/17/ 2019	4:52 **to** 5:52 **PM**	
	May/18/ 2019	4:48 **to** 5:48 **PM**	
Second 4 Days	May/19/ 2019	4:44 **to** 5:44 **PM**	Point A on fixed tripod (h= 1.641 m) Point B on fixed Tribrach (h= 0.216 m) With Barrier near B
	May/20/ 2019	4:40 **to** 5:40 **PM**	
	May/21/ 2019	5:36 **to** 4:36 **PM**	
	May/22/ 2019	5:32 **to** 4:32 **PM**	

During the field observations preparation, the receiver on point A was leveled and centered with fixed height by tripod, whereas, the receiver on point B was adjusted and leveled on fixed handmade tribrach, as shown in Figure (4).

Fixed Tribrach with antenna oriented North installed on unknown Point B

Tripod with antenna oriented North installed on known Point A

Figure (4): Setup of points A and B, Rayak Campus, Lebanon.

The field observations were collected during 8 successive days with almost the same atmospheric conditions. It should be noted that, during these observation days, the first four days were done without the barrier near point B, whilst, it was used in the later four days. The used barrier is a metal plate with dimensions 1.3*1.3 meter, which was fixed one meter apart from point B on the same edge of the wall with an inclination angle equals to 30 degrees. The two antennas for the two receivers were made by the same manufacturer and model and both were oriented to the north during observations. The distance between the reference point A and the unknown point B is small and approximately equals to 106 meters. By these precautions, and using the double difference processing technique for relative observations, most of the common errors between the two receivers are eliminated or at least minimized.

Planning stage:

In order to obtain the most accurate position for point (B) and to study the effect of satellites positions on point coordinates determination, a careful planning should be made. Therefore, and since all observations were shifted by the 4 minutes amount from day to day, the same satellite and constellation should be observed during the one-hour session period and almost same DOP values affect the point B each day. The observed satellites are shown in figures 5 and 6.

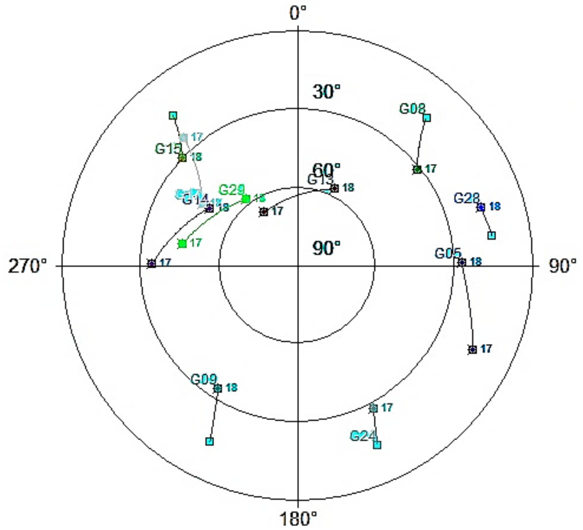


Figure (5): Sky plot for the observed satellites in each day during the 1-hour observation period.

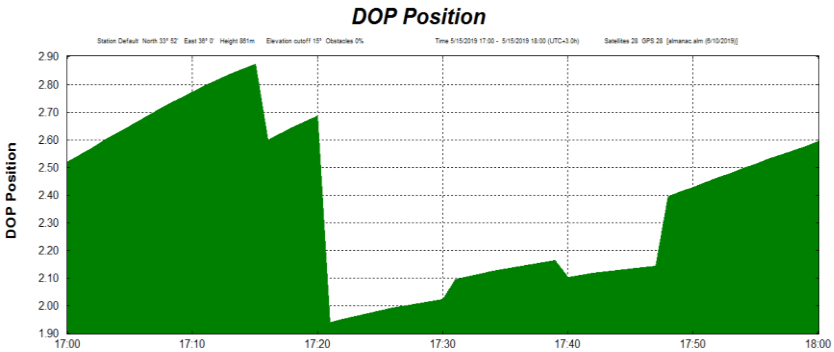


Figure (6): PDOP Values during the 1-hour session period in each observation day

From figures (5 and 6) we can deduce that the value for the PDOP ranges from 1.95 to 2.85 which are accepted values. Concerning the sky plot, we can notice that some satellites located in the Northern-East location such as SVs: G05, G28, G08, and G13 may affect the position determination because of the barrier that may cause additional multipath which is located in the Western-South location of the point B during the second stage of observations.

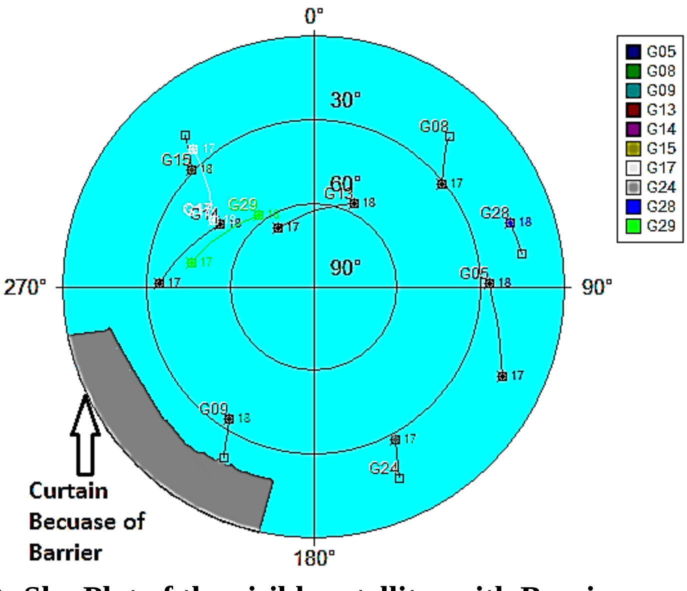


Figure (7): Sky Plot of the visible satellites with Barrier near B during the 1-hour session observation period

This barrier has an inclination angle equals to 30 degrees and, since the height of antenna equals to 0.216 m and the dimensions of the barrier equal to 1.3*1.3 meter, the angle at antenna for the remaining part of antenna will equals to 15 degrees. This remaining part equals to the mask angle at the antenna and, therefore, it will not block any signal, and, accordingly, this make it useful for testing the additional multipath effect from the observed satellites, as illustrated in figure (8).

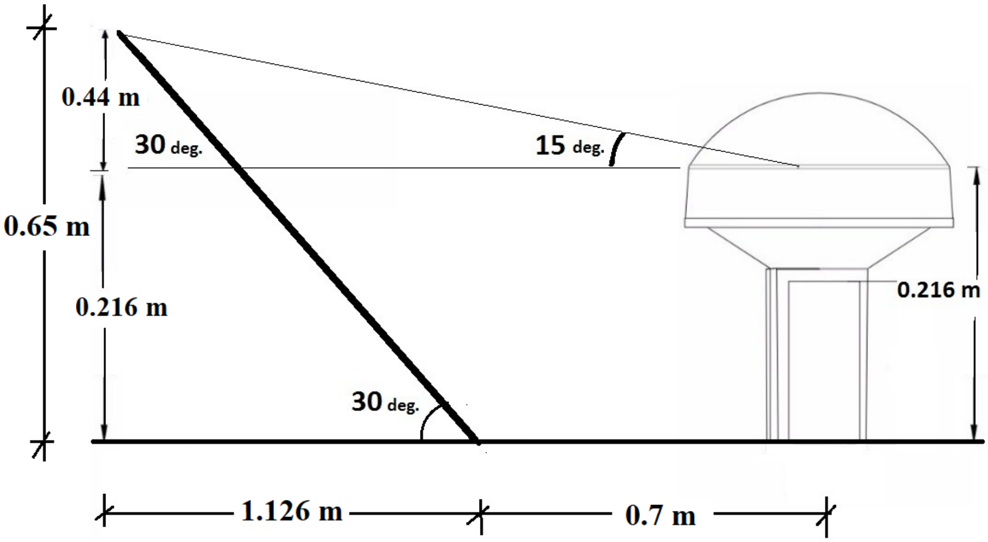


Figure (8): Sketch Explaining the position and inclination of Barrier with respect to the Antenna near point B.

Processing results:

After collecting the required field data according to the scheduled table, the raw data provided us with four different groups of coordinates for the same unknown point B. The raw data were converted to RINEX 2.11 format (with only GPS data). Taking into consideration that only GPS data were used in the processing since these are the only similar observations during each day sessions. Each group has multiple (four) different determination of coordinates.

The raw data were processed using the service of Trimble RTX online service which relies on the generation of precise orbit and clock information for GPS and GLONASS satellites in real-time [**2**]. It is based on a Trimble owned orbit and clock solution for the satellites which is derived from a global tracking network of more than 100 reference stations equipped with Trimble NetR5, NetR8 and NetR9 receivers. At the processing centers the observations are used by multiple redundant servers to compute precise orbit and clock estimates which are then transmitted to users worldwide. In addition, the servers store the parameter estimates in a compressed data format with 1Hz clock updates. This data is used as input for the RTX Post-Processing service.

Table (3) lists the obtained coordinates from the first stage which is Absolute positioning for point B without the effect of barrier.

Table (3): Sample of the resulted coordinates for PPP B (Without Barrier) along with the resulted Standard Deviation (S.D.).

Observation Session	WGS84 X (m)	S.D (Cm)	WGS84 Y (m)	S.D. (Cm)	WGS84 Z (m)	S.D. (Cm)
Day1 B	4289256.239	5.5	3117041.621	1.17	3534811.778	3.7
DAY2 B	4289256.221	5.5	3117041.635	1.16	3534811.749	3.7
DAY3 B	4289256.239	5.5	3117041.610	1.17	3534811.763	3.7
DAY4 B	4289256.246	5.5	3117041.673	1.17	3534810.533	3.7
Average	**4289256.236**	**5.5**	**3117041.635**	**1.17**	**3534811.768**	**3.7**

From table (3) we can notice that the same resulted accuracy for point B coordinates were obtained. This is logically expected since the same parameters, same satellites configuration, and same precautions were used in each observation's day. Moreover, the standard deviation for each coordinate's component resulted at the centimeters level which is considered a great improvement compared to meters level for absolute poisoning in the original data.

Comparison between Absolute and PPP results for Point B:

Table (4) lists, after calculation of position of average point determined from each session, the calculated distance from this average point and the remaining points for the same session, along with the statistical indicators. The table lists three different cases. The first case is the results of RTX-PP processing and listed in first column, whereas, in the second column, the results of processing of original absolute positioning raw data without RTX-PP technique. The third column lists the difference in location of point B between the previous two processing modes. This was repeated for the case using barrier near B.

Table (4): Obtained coordinates for point B resulted from various processing techniques.

Statistical Values	Without Additional Multipath			With Additional Multipath		
	Distance of PPP B from Average Cm	Distance of B from Average Cm	Distance from Raw and PPP RTX Values point (m)	Distance of PPP B from Average Cm	Distance of B from Average Cm	Distance from Raw and PPP RTX Values point (m)
	1.74	38.90	4.063	5.56	41.74	4.265
	2.42	142.16	3.148	3.03	63.75	5.003
	2.54	95.82	4.811	3.05	67.50	5.124
	4.16	56.90	4.721	1.42	99.47	3.781
Average	**2.71**	**83.44**	**4.186**	**3.266**	**68.115**	**4.543**
Minimum	**1.74**	**38.90**	3.148	**1.42**	**41.74**	3.781
Maximum	**4.16**	**142.16**	4.811	**5.56**	**99.47**	5.124
St.-Dev.	**1.03**	**45.79**	0.77	**1.71**	**23.79**	0.63

From table (4) we can notice that the discrepancies between average point and each position determination as determined by original raw data ranged from 39 cm to about 142 cm for normal absolute positioning, whereas, for the PPP determination, the discrepancies ranged from 1.4 cm to about 5.5 cm. Accordingly, we can conclude some important assertions:

- The effect of the additional multipath raised the discrepancies between point B locations by about 20 %.
- The discrepancies between each position determination was in meters range using the raw data, whereas, it was in the cm range for the PPP determination using the RTX service.
- The position determination using the RTX service raised the precision of point determination by about 95 % for both cases either using barrier or without the barrier usage.
- The distance between original position from absolute positioning and the PPP positioning were in meters levels whether using or without using the barrier near point B, as listed in the third and sixth columns.

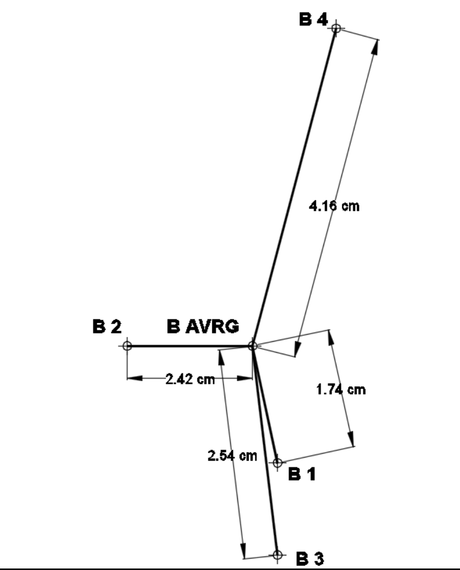
Comparison between Absolute and Relative determination of Point B:

The collected data for the first four days were processed using the TBC (Trimble Business Center) software, in which the point A was considered as a control point with known fixed coordinates (as listed in table 1) and the coordinates for the point B were obtained for the four observations days. This procedure was repeated for the second four days where the barrier was used near B. Table (5) lists the results obtained from the Absolute and Relative processing operations.

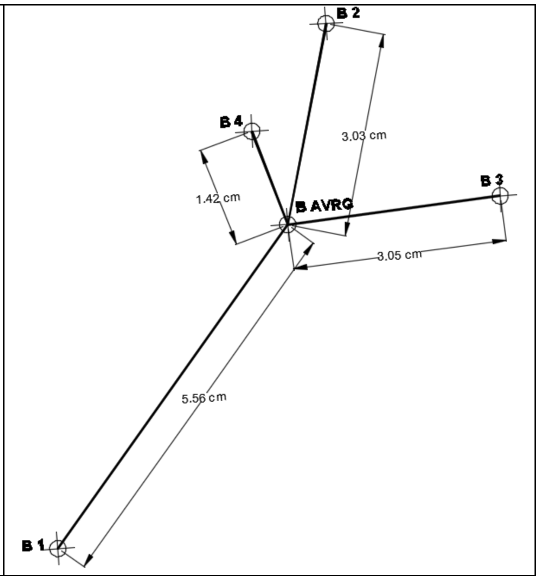
Table (5): Comparison for the obtained resulted coordinates for point B from the four processing sessions

	Distance between Average point (B AVRG.) to the determined 4 different positions for each observing case (Cm)			
Statistics	B Absolute without barrier PPP	B Relative without barrier	B Absolute with barrier PPP	B Relative with barrier
	1.74	0.25	5.56	0.35
	2.42	0.18	3.03	0.31
	2.54	0.17	3.05	0.30
	4.16	0.52	1.42	0.37
Average	**2.71**	**0.28**	**3.27**	**0.334**
Standard Deviation	**1.03**	**0.16**	**1.712**	**0.03**

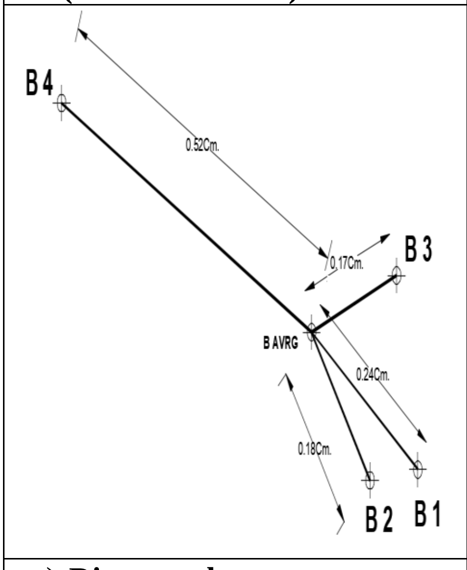
From Table (5), one can notice that, in both cases using or without using the barrier, the use of known control point in relative mode reduces the discrepancies by about 90 percent. Moreover, the discrepancies decreased from centimeters level to millimeters level, which is clearly demonstrated in figure (9).



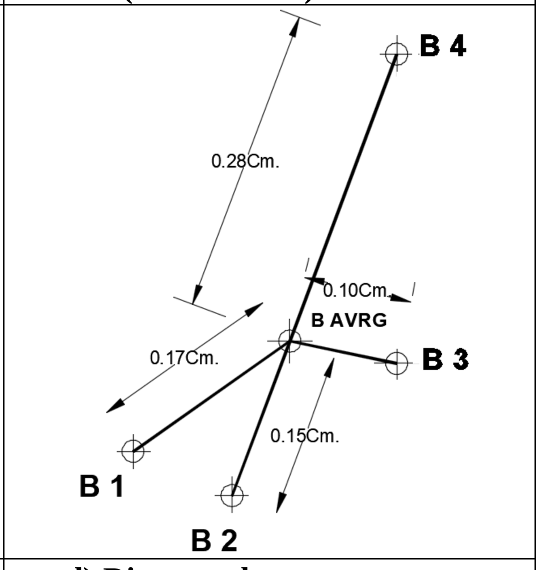
a) Distances between average position for B and the 4 determined absolute positions (without Barrier) Cm units



b) Distances between average position for B and the 4 determined absolute positions (with Barrier) Cm units



c) **Distances between average position for B and the 4 determined relative positions (without Barrier) Cm units**



d) Distances between average position for B and the 4 determined relative positions (with Barrier) Cm units

Figure (9): Sketch Explaining the position difference between Each determined Position for B and its corresponding Average Position (Cm Units)

By analyzing the results presented in Figure (9), it is clear that the mean 3D positioning errors were large when measuring on absolute base, whereas, these errors decreases when using the PPP service (Figure 9: a and b). Moreover, it reaches its minimum values when it calculated relative to fixed known point (Figure 9: c and d). However, the measurement session duration as well as the post-processing type observations (L1 or L1+L2) have a larger impact on accuracy.

From figure (9), we can see that the positioning determination discrepancies ranges between 1.74 cm to about 4.16 cm for the four determined positions taken with the same precautions and observation conditions and processed with precise orbit and clock parameters, whereas, for the determination with additional multipath effect, the positioning determination accuracy ranges between 1.42 cm to about 5.56 cm for the four determined positions. Since all errors and effects are the same for the repeated 4 days observations, this indicates the effect of the additional multipath on the absolute determination of point position decreased the accuracy by about 20 percent.

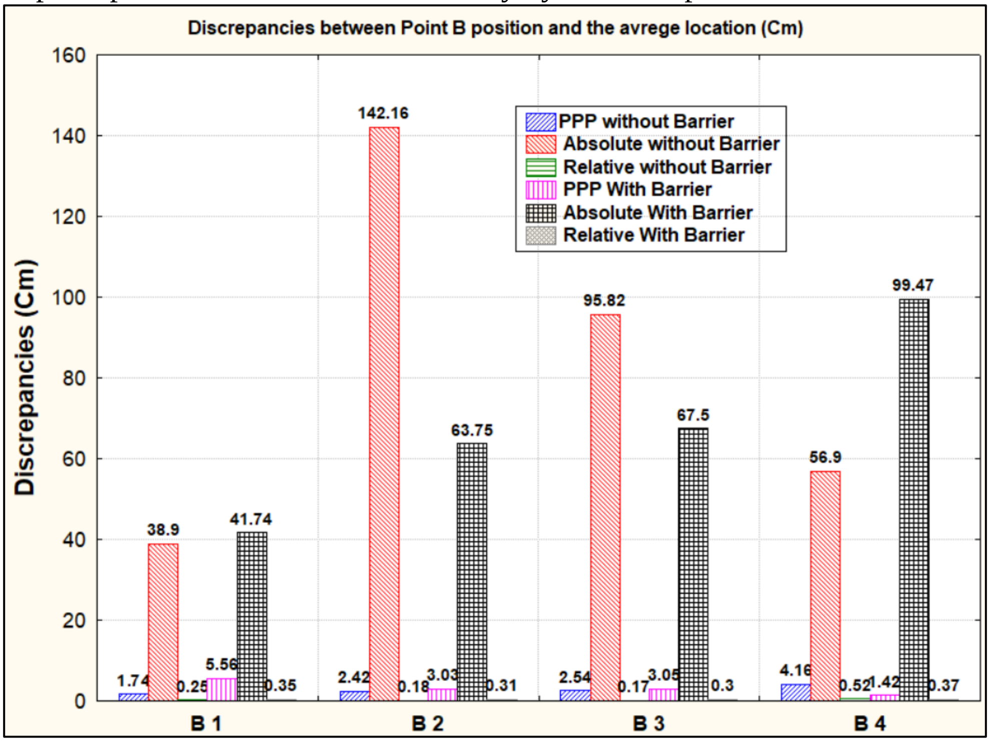


Figure (10): Graph illustrating the discrepancies between each determined position for B (Absolute and Relative) and its corresponding average position (Cm Units) the eight different days

On the other hand, and as concluding remarks (as depicted in figure 10), we can summarize that the position discrepancies were the largest for absolute positioning (meters level) and smaller for the PPP calculated positions (centimeters level) and became the smallest (millimeters level) when calculated in the relative mode using fixed known control point. This is valid for the first group of observations (without barrier) and the second group (with barrier).

Conclusions and Recommendations:

In this study two groups of observations were tested to determine the position of single point position. The first one is the absolute positioning mode and the second was the absolute positioning with additional multipath effect on point observations. In both cases the position was calculated first from the raw data and secondly using the PPP mode. Then, all calculations and position determination was repeated in the relative mode using known reference point.

From the comparison between the obtained results, we can conclude that:

The absolute positioning mode can be used for exploration applications and search for known points. The accuracy of the absolute determination of points using GNSS system can be greatly improved using the PPP processing technique where the accuracy improved from meter level to centimeter level, and accordingly, the point positioning can be used for most of surveying and mapping applications such as reference point for topographic surveys and likewise applications. If high accuracy is needed, where millimeter range is required, the processing can be done using the relative mode where known control point must be available.

However, these improved results as estimated by Trimble-RTX, using PPP solution and its own satellite ephemerides products were related to use of single satellite constellation, which is the GPS system and with same satellites positions. These results should be checked if multi constellation of GNSS were used, with the same observation circumstances, along with same receivers and parameters, can give better position accuracy. In addition, the relative mode, and since the baseline length was short and equals to about one hundred meters, the improvement of position determination can be checked for longer distance between the known reference point and the unknown point.

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