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EVALUATION OF POST-PROCESSED KINEMATIC ACCURACY IN ENGINEERING PROJECTS

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ABSTRACT

The Global Positioning System (GPS) has become integral to numerous engineering applications, transforming fields such as construction, surveying, and agriculture. This research delves into the evaluation of post-processed kinematics (PPK) accuracy in engineering projects utilizing GPS technology, specifically comparing Fast Static (FS) with PPK coordinates across various session durations (SD). The study employs Trimble R4 GPS receivers at Al-Azhar University, Cairo, Egypt. The research explores two primary GPS positioning methods: static and kinematic. The focus is on PPK, a technique where data is processed after fieldwork, allowing for integration with precise ephemeris. The research compares PPK accuracy with FS across different SDs. The study area covers 0.129 km² with diverse features like trees and buildings. Three points on grass, asphalt, and sand surfaces are observed using FS for one hour. PPK is then applied with varying SDs (1 to 60 seconds). Statistical analyses, including ANOVA, assess the significance of differences in SDs at different locations. The results indicate that PPK accuracy improves with longer SDs, achieving a Root Mean Square Error (RMSE) of 1.7cm in 2D with a 60-second duration. Shorter SDs (1 to 30 seconds) exhibit significant differences, while longer durations (40 to 60 seconds) show no significant variation. The research underscores the importance of selecting appropriate SDs for optimal accuracy in precision-demanding GPS applications. This study provides valuable insights into optimizing GPS technology for engineering, emphasizing the significance of session duration selection for PPK accuracy. The findings contribute to the ongoing refinement of GPS technology in engineering projects.

KEYWORDS: Post-Processing Kinematic (PPK), Positioning, Accuracy, Evaluation, Session Duration.

تقييم دقة الرصد المتحرك بالحساب المكتبي في المشاريع الهندسية

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الملخص

أصبح نظام تحديد المواقع العالمي (GPS) جزءًا لا يتجزأ من العديد من التطبيقات الهندسية، مما أدى إلى إحداث تحول في مجالات مثل البناء والمسح والزراعة. يتعمق هذا البحث في تقييم دقة الرصد المتحرك بالحساب المكتبي (PPK) في المشاريع الهندسية التي تستخدم تقنية GPS، وتحديدًا مقارنة احداثيات الرصد الثابت السريع (FS) مع إحداثيات PPK عبر فترات الجلسات مختلفة لتقييم الدقة. استخدمت الدراسة أجهزة استقبال نظام تحديد المواقع Trimble R4 في جامعة الأزهر، القاهرة، مصر. يستكشف البحث طريقتين أساسيتين لتحديد المواقع عبر نظام تحديد المواقع العالمي (GPS): الثابت والحركي . وينصب التركيز

على PPK، وهي تقنية تتم فيها معالجة البيانات بعد العمل الميداني، مما يسمح بالتكامل مع التقويم الفلكي الدقيق. يقارن البحث دقة PPK مع FS عبر فترات الجلسات مختلفة، وتغطي منطقة الدراسة 0.129 كيلومتر مربع مع ميزات متنوعة مثل الأشجار والمباني. تم رصد ثلاث نقاط على السطح العشبي والإسفلتي والرملي باستخدام FS لمدة ساعة واحدة. يتم بعد ذلك تطبيق PPK بقيم فترات جلسات مختلفة (من 1 إلى 60 ثانية). تقوم التحليلات الإحصائية، بما في ذلك تحليل التباين (ANOVA)، بتقييم أهمية الاختلافات في الانحراف المعياري لفترات الجلسات في مواقع مختلفة. تشير النتائج إلى أن دقة PPK تتحسن مع فترات الجلسات الأطول، مما يحقق خطأ جذر متوسط مربع (RMSE) يبلغ 1.7 سم في ثنائي الأبعاد لمدة 60 ثانية. تظهر فترات الجلسات الأقصر (من 1 إلى 30 ثانية) اختلافات كبيرة، في حين لا تظهر فترات الجلسات الأطول (40 إلى 60 ثانية) أي اختلاف كبير. يؤكد البحث على أهمية اختيار فترات الجلسات المناسبة لتحقيق الدقة المثلى في تطبيقات الهندسية التي تتطلب الدقة. توفر هذه الدراسة رؤى قيمة لتحسين تقنية GPS للهندسة، مع التركيز على أهمية اختيار مدة الجلسة لدقة PPK. وتساهم النتائج في التحسين المستمر لتكنولوجيا نظام تحديد المواقع العالمي (GPS) في المشاريع الهندسية.

الكلمات المفتاحية : الرصد المتحرك بالحساب المكتبي، المكانية، الدقة، تقييم، مدة الجلسة.

1. INTRODUCTION

Recently, the Global Positioning System (GPS) has become an indispensable tool across a multitude of engineering applications, revolutionizing fields such as construction, land surveying, infrastructure development, and precision agriculture [6].The ability to precisely determine and track locations has greatly improved the efficiency and accuracy of various engineering projects[18].

Therefore, there exist two primary methods for ascertaining positions: point positioning and relative positioning [8]. Point positioning typically entails determining its location within a clearly defined coordinate system, often represented by three coordinate values. Conversely, relative positioning entails the determination of coordinates in relation to another designated reference point, thereby establishing a local coordinate system's origin [2]. Relative positioning stands out as the most precise GPS technique, leveraging variations in code or carrier phase ranges to mitigate errors[11]. Surveying applications employ an array of relative positioning techniques, including static, post-processing kinematic, and real-time kinematic methods [16].

The static techniques of GPS surveying eliminate several systematic errors when high-precision positioning is needed. These methods involve establishing baselines through the collection of data between stationary GPS devices over an extended duration to account for fluctuations in the satellite's geometry [17]. Each receiver in this system continuously records data for a predefined period at each location. Similar to static GPS surveys are brief—between 15 and 30 minutes [1]. Using the static technique, the GNSS receiver pairs are installed on stations with known and unknown positions. Most of the time, one of the receivers is located at a known place (they have moved forward like a traverse). The second receiver can also be set up in an arbitrary place with arbitrary coordinates. The coordinates of the second receiver are required for this technique.

Kinematics is the most effective way of working on a satellite. It uses techniques of relativistic positioning with carrier phase [15]. When the receiver is moving or fixed in one location, these surveys can offer snapshots of the point coordinates [7]. It's usually less accurate than what is obtained through static, but most are sufficient for survey form. It has applications in many fields of research, such as mapping, border, construction have been successfully used to locate drilling ships during hydrographic studies and to position aerial cameras during photogrammetric work. Used to guide machine controlled digging in large construction projects. Useful for non-research applications such as high precision agriculture. The difference between static and kinematic measurement techniques is the duration of each session. When the static method is utilized to establish control points, it requires notably longer sessions in contrast to the shorter sessions typically utilized in kinematic methods [10].

During post-processing kinematics (PPK) data gathered tasks are stored in the controller or receiver until fieldwork concludes. Subsequently, the data is processed in the office using the same software and processing techniques employed in static surveys. Data latency isn't a concern in PPK surveys since the data is processed afterward [13]. Another benefit of PPK research is the ability to integrate sensitive ephemeris with observational data, addressing any data removal failures in their publication ephemeris, and determining the base station coordinates once fieldwork is completed. Therefore, there's no need to know the base station's coordinates before the survey begins. The combination of data latency and precise ephemeris has resulted in a slight improvement in PPK, slightly surpassing RTK. RTK's research enables the immediate detection of measurements while conducting a field study. The key benefits of using RTK surveys include the reduction of time spent in the office and the ability to validate field surveillance. With RTK, data can be promptly transferred to a GIS system or integrated into an existing measurement project [14]. In recent years, there has been interest in the non-differential technique called Precise Point Positioning [9]. has been steadily increasing. The technique requires only one receiver and is very suitable for measurements in remote areas beyond the range of established GNSS reference stations. It can be seen as an advanced variant of standard autonomous technique where precise products with satellite ephemerides and satellite clock error corrections replace the broadcast navigation message and advanced models, and approaches are used for elimination of various effects and errors. Numerical least-squares approach is being used for an estimation of unknown parameters including receiver’s position[5].Integer ambiguity resolution in PPP is problematic compared to differential techniques due to uncalibrated phase delays[12]. However, with the availability of high-quality precise products, such as those offered by the International GNSS Service (IGS), and the utilization of a GPS receiver, it becomes feasible to obtain centimeter-level positioning accuracy in static mode and the decimeter level in kinematic mode [4].

The objective of this research is to evaluate the accuracy of post-processed kinematics (PPK) in engineering projects using GPS technology. The study compares Fast Static (FS) with PPK coordinates across various session durations (SD) using Trimble R4 GPS receivers. statistical tests were applied to validate the results and the importance of selecting appropriate session durations for optimal accuracy in location determination.

2. Test Site and Data Used

The study area is located at Al-Azhar University in Cairo, Egypt, with coordinates at N30°03'22" latitude and E31°18'54" longitude. Were used a Trimble R4 GPS system geographic (dual frequency) to gather GPS data and employed Trimble Business Center 2.2 for processing the observations. The study site covers an area of 0.129 km2, as shown in **Fig. 1**. This site includes various features such as trees and university buildings. Notably, reference point is will know in the study area [M1], positioned above the roof of the College of Civil Engineering, and there are 3 points as a known from fast static which played a crucial role in our research. To ensure reliable satellite signal reception and optimal sky visibility, a Mask Angle of 15° elevation was maintained using GPS controllers. We took precautions to avoid signal interference by ensuring there were no reflective surfaces or nearby electrical installations. Additionally, no transportation besides the receivers to protect points and the surveyors.

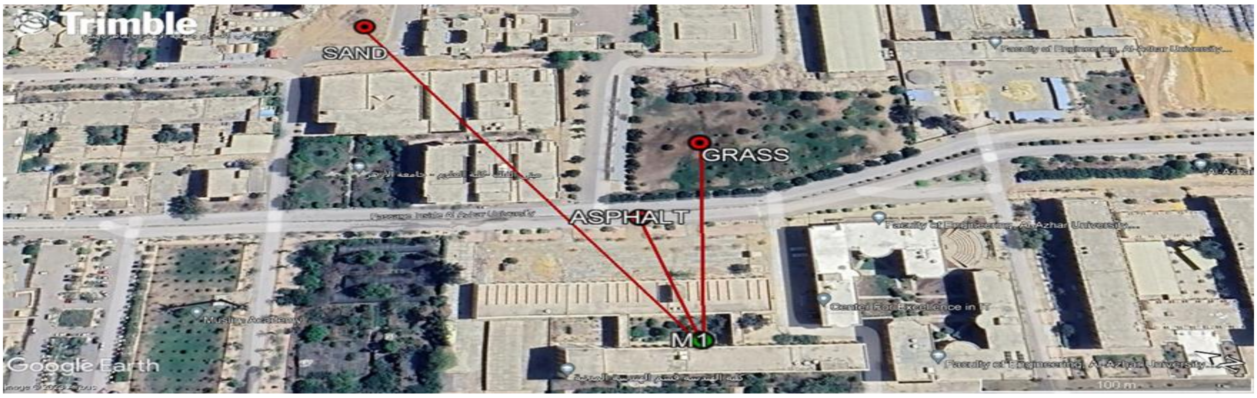

Fig. 1: Study Area in Al-Azhar University.

3. Research Methodology

The methodology employed in this study for evaluating PPK will comprise the following three stages as shown in **Fig. 2**.

The first stage involved obtaining coordinates for three points using the fast static method, with each observation session duration of one hour at the different place (Grass, asphalt, and sand). After that, the identification of the three points was achieved through the post-kinetic processing (PPK) method, utilizing distinct session durations for each point: 1 second, 5 seconds, 10 seconds, 20 seconds, 30 seconds, 40 seconds, 50 seconds, and 60 seconds. A reference point with known coordinates, designated as M1, served as a reference station. Following this, all recorded observations underwent scrupulous correction using the software Trimble Business Center (TBC).

In the second stage after processing the data, was extracted the PPK (Post-Processed Kinematic) coordinates and the fast static coordinates. Subsequently, various statistical and mathematical operations were performed. It will determine the accuracy of location, compare the differences between them and evaluate the result.

In the third stage, was conducted a significance test to compare the session durations at different locations using ANOVA: Single Factor analysis. The purpose of this test was to determine whether the three samples were drawn from the same normal population with equal variances or from three distinct normal populations with equal variances. To assess the significance of the differences in session durations among various locations, the ANOVA: Single Factor test was carried out with a confidence level (β) set at 0.05. The study focused on three specific points: grass, asphalt, and sand. The selection of these points was primarily based on specific criteria, particularly the variations in session duration observed at these different locations. Using the sample data, was aimed to determine whether the differences in population standard deviations between the three groups were statistically significant [3].

Ho : $\mu_1 = \mu_2$

H_1 : $\mu_1 \neq \mu_2$

$\sigma_c{}^2 = \frac{SSc}{Vc}$, $\sigma_r{}^2 = \frac{SSr}{Vr}$

$F = \frac{\sigma_c{}^2}{\sigma_r{}^2}$

Required Sample Data:

$\sigma_c{}^2$ variances between ground type

$\sigma_r{}^2$ variances between coordinates

Vr,Vc degree of freedom

SSc sum of squares between the ground type

SSr sum of squares between the coordinates

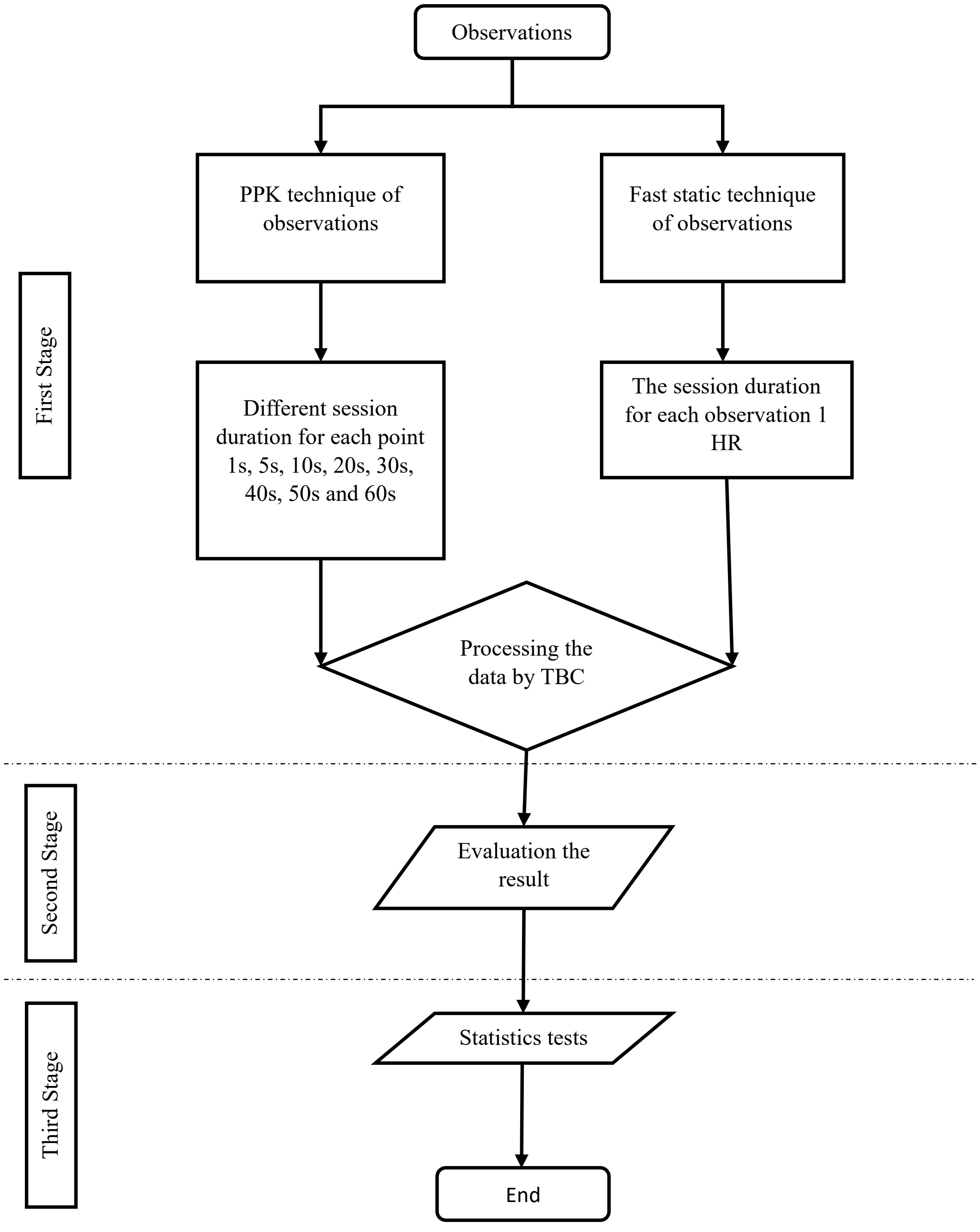

Fig. 2: Workflow of research methodology.

4. Results and Discussion

4.1 Establishment control points

The fast-static technique was used to gather three observations at different locations, specifically on grass, asphalt, and sand surfaces. Two dual-frequency Trimble R4 GPS receivers were employed to capture these observations. Subsequent to data collection, the coordinates were processed using the Trimble Business Center software, incorporating both the UTM Zone 36 and WGS 84 coordinate systems.

The data collection process commenced with connecting the three points to a known coordinate point known as M1. Both GPS receivers operated concurrently, with one receiver stationed at the known coordinate point M1 (base), and the second receiver positioned at the unknown points (rove). Each observation session conducted using the fast-static technique had duration of 1 hour.

Prior to obtaining processed coordinates, a correction process was performed for these points, and the corrections were subtracted from the unprocessed data. The difference that were obtained during this process are detailed in **Table 1.** These coordinates will serve as a reference point for evaluations conducted by PPK.

Table 1: The difference between the three points before and after processing.

Point		Difference(cm)
Grass	E	33.5
	N	186.1
	Z	94.9
Asphalt	E	78.4
	N	575
	Z	348.7
Sand	E	51.4
	N	54
	Z	315.2

From the **Table 1.** was find that the average error is in the easting 54.4cm, northing 271.7cm and the height 253cm**.**

4.2 Evaluation of PPK Results

A post-processing kinetics (PPK) technique was employed for initializing the device during a 10-minute period. Subsequently, the same three points were observed using PPK methods, varying the session duration from 1 second to 60 seconds. Following data collection, the Trimble Business Center software facilitated post-processing. The precise coordinates were extracted, and the PPK coordinates were subtracted from the fast static coordinates to identify resultant errors.

These errors were found to be affected by variations in session duration. The influence of changing session duration on these errors is visually represented in **Fig. 3.** These figures provide a clear illustration of how the duration of the observation sessions correlates with the observed errors in the coordinates obtained through the PPK technique. Observing reveals that the accuracy was lower during the initial second of the session. However, as the sitting duration increased, the accuracy improved significantly. Specifically, the accuracy values were as follows: 1 second = 8cm, 5 seconds = 5.5cm, 10 seconds = 4.5cm, 20 seconds = 4cm, 30 seconds = 3.2cm, 40 seconds = 2.6cm, 50 seconds = 2.7cm, and 60 seconds = 1.7cm. Consequently, the accuracy notably increases during the second 60 seconds of the session duration.

In **Fig. 4.** it is evident that accuracy in elevation exhibits a proportional increase relative to variations in session durations. Specifically, the accuracy at 60 seconds attains 1.5cm, with a subsequent decline in acuracy as the time period diminishes. At 50 seconds, the accuracy is noted at 2.3m, while at 40 seconds and 30 seconds, it remains at 2.3cm and 2.5cm, respectively. Further reductions in time, such as 20 seconds, result in an accuracy of 3cm, followed by 4.1cm at 10 seconds and 5 seconds. The trend continues with a minimal increase to 4.2cm at at the session duration of 1 second. This is when the session duration increases, the improvement in the elevation accuracy is obtained.

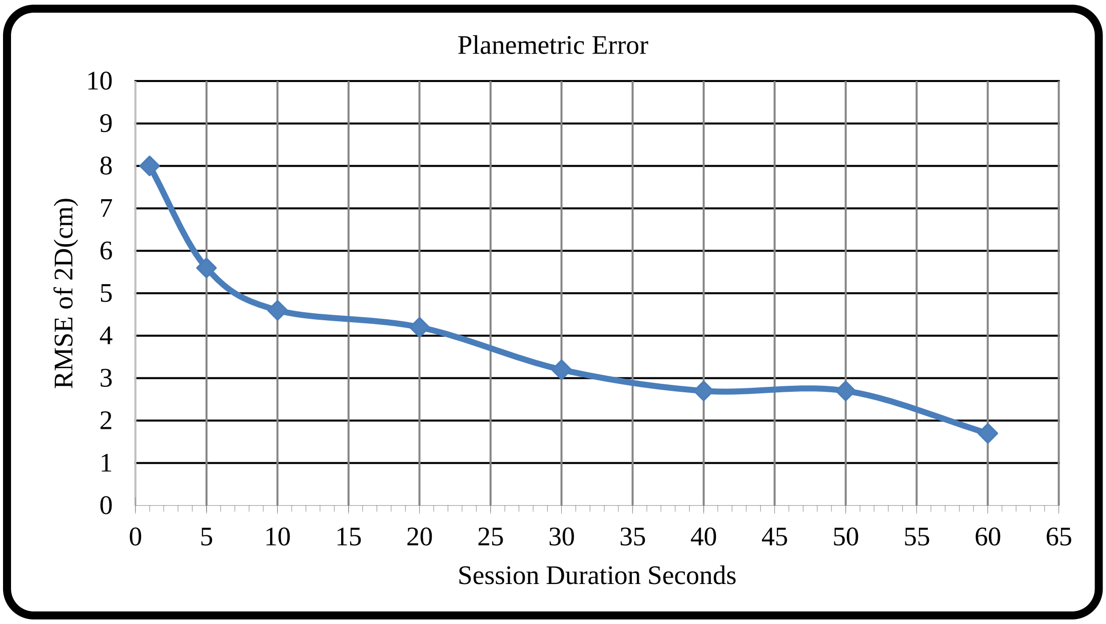

Fig. 3: 2D Error from easting, and northing, for three points with different session duration.

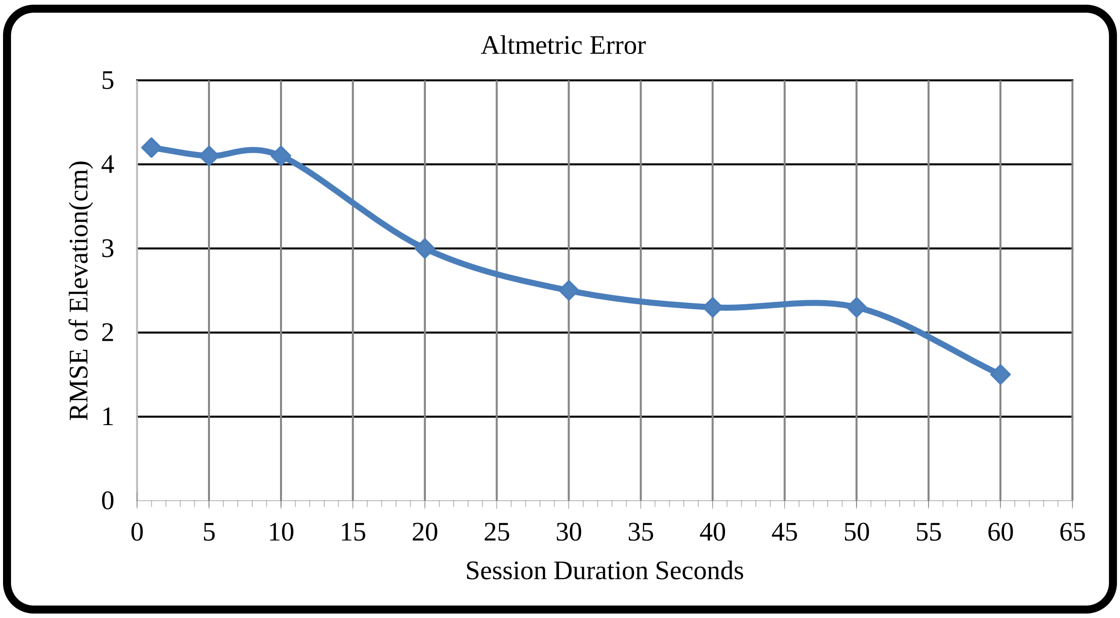

Fig. 4: The error in elevation with different session duration.

3 Test the Significance of Differences Session Duration Between the Results from Various Points.

Table 2: A nova single factor test results for the session durations.

The three tested model	The test statistic F	Result
1second	7.773	significant difference
5 second	5.55	significant difference
10 second	6.84	significant difference
20 second	10.36	significant difference
30 second	6.42	significant difference
40 second	3.39	no significant difference
50 second	1.14	no significant difference
60 second	0.7	no significant difference

Table 2. indicates that the F value is less than the critical F value (F<Fcrit), demonstrating a non significant effect of session durations. Conversely, when the F value exceeds the critical F value (F > Fcrit), demonstrating a significant effect of session durations. It is worth noting that significant differences in results are observed at 1, 5, 10, 20, and 30 seconds; however, no significant differences are noted at 40, 50, and 60 seconds. Thus, when the session duration of observation increases, the error in observations is close, Conversely,when the session duration of observation decreases, the error between observations is large.

5 . SUMMARY AND CONCLUSIONS

In this study conducted at Al-Azhar University, the evaluation of post-processed kinematic (PPK) accuracy in engineering works using GPS technology has been explored. The research focused on diverse session durations (SD) and compared Fast Static (FS) with PPK coordinates across varying SDs. Two Trimble R4 GPS receivers were utilized, and the findings revealed significant improvements in PPK accuracy, particularly with a 60-second duration, achieving a Root Mean Square Error (RMSE) of 1.7cm in two dimensions (2D).The study highlighted that longer SDs, such as 60 seconds, notably enhanced PPK accuracy, proving valuable for precision-demanding GPS works in X, Y, and Z dimensions. On the contrary, a 1-second SD resulted in a higher RMSE of 8cm in 2D. The horizontal accuracy ranged from 1 to 8 cm, while height accuracy ranged from 2 to 5 cm when comparing FS with PPK in different SDs. Statistical tests were applied to validate the results, confirming the significance of the observed differences. The research methodology involved establishing control points using the fast-static technique, and the study area at Al-Azhar University was carefully chosen to ensure optimal satellite signal reception and minimal interference.The evaluation of PPK results demonstrated that accuracy improved with longer session durations. Visual representations of errors in coordinates showed that accuracy notably increased during the second 60 seconds of the session duration. The study also conducted a significance test using ANOVA to compare session durations at different locations, revealing significant differences at shorter durations (1, 5, 10, 20, and 30 seconds) but non-significant differences at longer durations (40, 50, and 60 seconds). This research provides valuable insights into optimizing GPS technology for engineering applications. The findings underscore the importance of selecting appropriate session durations for PPK to achieve optimal accuracy in location determination, especially in precision-demanding scenarios. These insights contribute to the ongoing advancement and refinement of GPS technology in engineering projects.

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