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POINT POSITIONING PERFORMANCE OF TRIMBLE-RTX IN DIFFERENT SATELLITE COMBINATIONS

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ABSTRACT: Today, new global positioning algorithms, techniques and technologies are emerging thanks to services such as International Global Navigation Satellite Systems (GNSS) Service (IGS) that offer orbit and clock correction data of satellite systems to all GNSS users. These solutions are developed in order to eliminate the disadvantages of current positioning techniques such as requiring more than one GNSS receiver and not exceeding a certain distance between the reference station and the rover. One of these innovative technology products is Trimble CenterPoint RTX Post-Processing (Trimble-RTX) technology. In this study, the point positioning performance of the Trimble-RTX service was investigated. The 31-day RINEX data obtained from 2 IGS stations are used in 4 different satellite combinations (GPS (G), GPS+GLONASS (G+R), GPS+GALILEO (G+E), GPS+GLONASS+GALILEO (G+R+E)) processed with Trimble-RTX. By comparing the obtained coordinates with the coordinates of the stations published by IGS, the accuracy and precision of the coordinates were evaluated for each satellite combination. As a result of the evaluation, it was seen that there were generally no significant differences between the results obtained from 4 different satellite combinations at the stations.

Keywords: *Accuracy, IGS, Online-PPP, Precision, Trimble-RTX*

Trimble-RTX’in Farklı Uydu Kombinasyonlarında Nokta Konumlama Performansı

ÖZ: Günümüzde uydu sistemlerinin yörünge ve saat düzeltme verilerini tüm GNSS kullanıcılarına sunan Uluslararası Uydularla Konum Belirlemede Sistemi (GNSS: Global Navigation Satellite Systems) Servisi (IGS: International GNSS Service) gibi servisler sayesinde yeni küresel konum belirleme algoritmaları, teknikleri ve teknolojileri ortaya çıkmaktadır. Bu çözümler, mevcut konumlandırma tekniklerinin birden fazla GNSS alıcısı gerektirmesi ve referans istasyonu ile gezici arasında belirli bir mesafeyi aşmaması gibi dezavantajlarını ortadan kaldırmak için geliştirilmiştir. Bu yenilikçi teknoloji ürünlerinden biri de Trimble CenterPoint RTX Ölçü Sonrası değerlendirme (Trimble-RTX) servisidir. Bu çalışmada Trimble-RTX hizmetinin nokta konumlandırma performansı incelenmiştir. Bu amaçla 2 IGS istasyonundan elde edilen 31 günlük RINEX verileri 4 farklı uydu kombinasyonunda (GPS (G), GPS+GLONASS (G+R), GPS+GALILEO (G+E), GPS+GLONASS+GALILEO (G+R+E)) Trimble-RTX ile çözümlenmiştir. Çözümleme sonucunda elde edilen koordinatlar, istasyonların IGS tarafından yayınlanan koordinatları ile karşılaştırılarak, her bir uydu kombinasyonu için koordinatların doğruluğu ve hassasiyeti incelenmiştir. İnceleme sonucunda istasyonlarda 4 farklı uydu kombinasyonundan elde edilen sonuçlar arasında genel olarak anlamlı bir farklılık olmadığı görülmüştür.

Anahtar Kelimeler: *Doğruluk, Hassasiyet, IGS, Online-PPP, Trimble-RTX.*

1. INTRODUCTION

With the development of technology, the process of change and development has begun in every field of science (Solak, 2020). Important developments in the science world have led to the development of different solutions with various algorithms and significant changes in different professions as well as satellite-based positioning (Geliskan, 2019). Satellite technologies are indispensable equipment of a world that serves global organizations and users and even has no borders like the internet. As a product of these technologies, the idea of global positioning was introduced to coordinate American military units and has been available to researchers and civilians since the 1990s. In the following process, Global Navigation Satellite Systems (GNSS) started to take place in daily life as a result of the acceleration of space studies with the development of computational technique and electronic science.

International GNSS Service (IGS), which started its operations officially on January 1, 1994, has produced many high quality GNSS products (precise satellite orbit and clock products, earth rotation parameters, the coordinates and velocities of the stations, the time information of fixed stations) produced at different delay times and accuracies since 1994. These products have been made available to the scientific world (Kahveci and Yildiz, 2017). While these products are widely used in scientific research and engineering projects and many GNSS applications for geodetic and geophysical purposes, they have also led to the emergence of these new algorithms and techniques in satellite-based positioning.

When performing satellite-based positioning, two methods are used, absolute and relative positioning. However, both methods have some difficulties in obtaining high-accuracy coordinate information. For this reason, organizations such as the IGS produce high-precision orbital information and provide free of charge to users, and many new algorithms on positioning have been developed (Inyurt and Ulukavak, 2020). The most widely used among these is the technique called Precise Point Positioning (PPP). The aim of the PPP technique is to achieve very high point positioning accuracy with a single receiver. Thanks to the developing technology and developed algorithms in recent years, this goal has been tried to be achieved step by step (Alcay et al., 2013). The PPP method is a special case of the zero-difference method, and unlike position determination methods such as Differential GPS and Real Time Kinematic (RTK), it does not require a fixed station and consequently simultaneous observation (Alcay et al., 2013). Although PPP was developed by R.J. Anderle (1976), it has become today's standard positioning technique due to the improvements in the quality and accuracy of IGS products and has been widely used all over the world (Ucarli et al., 2021). Some of the prominent advantages of this method are the need for data collected with only one receiver, its high accuracy, ease of application, low cost, and location determination in a global reference system (Alkan et al., 2017). On the other hand, in the PPP technique, the convergence time for the ambiguity float solution required for position accuracies in the level of cm is 20 minutes on average. This is also an important limiting factor in real-time applications of the PPP technique (Bulbul et al., 2021).

The emergence of new satellite systems such as Galileo and BeiDou, as well as the recent launch of GLONASS at full capacity, has provided additional satellite resources and new frequencies for PPP. In addition to GPS, the inclusion of other satellite systems in the PPP solution not only increases the number of visible satellites, but also significantly strengthens the geometry of the satellite. Therefore, solutions in which more than one system is used jointly (multi-GNSS) offer important opportunities to improve PPP performance in terms of location accuracy and convergence time (Bahadur and Nohutcu, 2019).

The first study that included the relationship of PPP with GPS and initiated its development was conducted by Zumberge et al. (1997). Afterwards, Yigit and Gurlek (2017) investigated the usability of PPP to detect the dynamic displacement response of a vertically vibrating structure, Ochałek et al. (2018) assessed the accuracy of Trimble RTX with a Spectra Precision SP60 model GNSS receiver. Ilci (2020) tested the positioning performance and convergence time of Trimble-RTX technology, which is a real-time PPP service, evaluated the accuracy performance of the online GNSS post-processing service. Alkan (2021) investigated the usability and achievable accuracy of the Trimble-RTX correction service in kinematic applications, and Sisman and Ilci (2021) revealed the effect of different levels of resolution of the parameters known to be effective in positioning with satellites on the horizontal and vertical position error. Yigit et al (2022) was investigated that Real-Time PPP with Trimble RTX correction service for real-time dynamic displacement monitoring based on high-rate GNSS observations.

In the studies carried out up to now, the accuracies of Trimble-RTX real-time positioning service have evaluated, but the accuracy assessment of Trimble-RTX post-processing service in different satellite combinations has received limited attention. The fact that the service is updated at certain intervals also makes it necessary to investigate the positioning performance at certain intervals. In this study, the point positioning performance of the web-based Trimble-RTX service, which provides real-time data over the global tracking station network with the help of innovative methods and advanced algorithms, for real-time high-precision location information with satellite orbit calculation, receiver/satellite clock and other system corrections has been investigated. The RINEX data for 31 days (July 1-July 31, 2021) obtained from EBRE and MERS stations. Then, it was arranged as 4 different satellite combinations (GPS, GPS+GLONASS (G+R), GPS+GALILEO (G+E), GPS+GLONASS+GALILEO (G+R+E)). The coordinates were obtained by analyzing these data with the Trimble-RTX service. The obtained coordinates were compared with the coordinates of EBRE and MERS stations for the date of 15 July 2021 published by IGS, and the root mean square error (rmse) in the direction of the coordinate axes were calculated in order to evaluate the precision and accuracy of the measurements for each satellite combination, and the 3D rmse of the points were obtained using the calculated values. The 3D rmse obtained for different satellite combinations were compared with statistical methods.

2. MATERIAL AND METHOD

2.1. PPP and Trimble CenterPoint RTX Post-Processing Service

As a result of the rapidly continuing modernization studies in GNSS systems, the precise satellite orbit and clock corrections produced by organizations such as the IGS, Jet Propulsion Laboratory (JPL), Center for Orbit Determination in Europe (CODE) are put into service. Thus, it enables high-precision position determination. The availability of higher-accuracy satellite and clock information and the development of algorithms that allow point positions to be calculated with a single GNSS receiver have led to the emergence of the method called Precise Point Positioning (PPP) (Ebner, 2008; Pan et al., 2014). The PPP is an absolute positioning method and it has been widely used in many researches in terms of both increasing positioning accuracies and ease of use, depending on the improvements in the quality and accuracy of IGS products (Yigit et al., 2016).

The success of the PPP technique largely depends on the orbital information of GNSS satellites. Therefore, the evaluation is based on precise orbit (ultra-rapid, rapid, final) and satellite clock information instead of broadcast orbit information. In recent years, the accuracy of precise satellite orbit and clock information offered by organizations such as IGS, CODE, JPL has increased the interest in the PPP method (Alcay et al., 2013). Today, PPP is a method used in the agricultural industry, hydrography, deformation monitoring, sensor positioning for the construction of submarine maps, aerial mapping. Different studies have been carried out on the accuracy and precision of both static and kinematic position determination of the PPP method (Pirti and Yazici, 2022).

Users have different software alternatives to determine position with PPP method. Thanks to different software packages and web-based GNSS software, positioning can be performed with PPP. While CSRS-PPP, AUSPOS, APPS, Magic-GNSS, SCOUT, Trimble CenterPoint RTX are web-based online GNSS software; Bernese, GIPSY-OASIS and GrafNav can be given as examples of academic and package programs that can provide PPP services (Alcay et al., 2013; Choy et al., 2013; Dawidowicz and Krzan, 2014; Ogutcu, 2020).

The Trimble RTX service used in this study can be accessed at https://trimblertx.com/. Thanks to the service, GNSS observation data can be uploaded to the system and coordinate information can be received as a report. Position calculations are performed in the ITRF2008 datum for data collected before March 23, 2017, and in the ITRF2014 datum for data collected after March 23, 2017. It also offers the user a different coordinate system and tectonic plate selection. Observation files in RINEX 2.x, RINEX 3.x, Trimble T01, T02 and DAT formats can be uploaded to the service. Observation files should be a minimum of 60 minutes and a maximum of 24 hours. Data files should only be static. It should also include dual frequency code and carrier phase observations (L1 and L2). After the observation files are uploaded to the system, the results are sent to the e-mail address in less than 2 minutes (Pirti and Yazici, 2022).

2.2. Study Area and Method

In this study, two Multi GNSS Experiment (MGEX) IGS stations, which are approximately on the same latitude, MERS (Erdemli, Türkiye) and EBRE (Roquetes, Spain), were selected to investigate the point positioning performance of the Trimble-RTX service (Figure 1). RINEX data with 24-hour and 30-second recording intervals between 01.07.2021 and 31.07.2021 of the stations used within the scope of the study were obtained.

a b

Figure 1. MERS (a) and EBRE (b) stations used in the application (https://igs.org/network/)

31-day RINEX data were evaluated using Trimble-RTX, one of the web-based services developed for the PPP technique. In the evaluation, daily point coordinates were obtained by analyzing the RINEX data, which included G, G+R, G+E and G+R+E satellite combinations, and the obtained daily coordinates were compared with the values published by IGS. Errors, separately for G, G+R, G+E and G+R+E, to evaluate the accuracy of coordinates obtained with Trimble-RTX;

$$\varepsilon_{X_t} = X_t - X_r, \quad \varepsilon_{Y_t} = Y_t - Y_r, \quad \varepsilon_{Z_t} = Z_t - Z_r \tag{1}$$

In equation (1), the subscript t represents the day of the year and the subscript r represents the reference coordinates obtained from the IGS. The root mean square errors (rmse) in the direction of the coordinate axes for each satellite combination,

$$m_X = \pm\sqrt{\frac{[\varepsilon_{X_t}\varepsilon_{X_t}]}{n}}, \quad m_Y = \pm\sqrt{\frac{[\varepsilon_{Y_t}\varepsilon_{Y_t}]}{n}}, \quad m_Z = \pm\sqrt{\frac{[\varepsilon_{Z_t}\varepsilon_{Z_t}]}{n}} \tag{2}$$

where n is the number of errors calculated with equation (1) for each coordinate axes. By using the rmse in the direction of the coordinate components, the 3D rmse;

$$m_P = \pm\sqrt{m_X{}^2 + m_Y{}^2 + m_Z{}^2} \tag{3}$$

The Fisher distribution is used to test whether the variances of two normally distributed measurement *groups* are statistically congruent. For this reason, the F-test was used to statistically compare the 3D rmse obtained in different satellite combinations at the stations with each other (Ghilani and Wolf, 2006). In comparison, test value;

$$F_{test} = \frac{m_i^2}{m_j^2} \tag{4}$$

In calculating the test value, the larger variance was written into the numerator. In the equation, m_i and m_j show the variances of the i and j measurement groups. F_{test} value was compared with $F_{tablo} = F_{f_i,f_j,1-\alpha}$ value with f_i, f_j are degrees of freedoms and α is probability of error. In comparisons, it was taken as $F_{tablo} = F_{31,31,0.95} = 1.822$.

Average coordinates for each satellite configuration for each station, n days, for the purpose of examining the precision of the measurements;

$$\bar{X} = \frac{[X_t]}{n}, \qquad \bar{Y} = \frac{[Y_t]}{n}, \qquad \bar{Z} = \frac{[Z_t]}{n} \tag{5}$$

Errors that appear separately for G, G+R, G+E and G+R+E;

$$V_{X_t} = X_t - \bar{X}, \quad V_{Y_t} = Y_t - \bar{Y}, \quad V_{Z_t} = Z_t - \bar{Z} \tag{6}$$

For each satellite combination, the rmse are;

$$m_X = \pm\sqrt{\frac{[V_{X_t}V_{X_t}]}{n-1}}, \quad m_Y = \pm\sqrt{\frac{[V_{Y_t}V_{Y_t}]}{n-1}}, \quad m_Z = \pm\sqrt{\frac{[V_{Z_t}V_{Z_t}]}{n-1}} \tag{7}$$

3D rmse were calculated using equation (3).

3. RESULTS AND DISCUSSION

The 31-day RINEX data of the selected stations were processed using the web-based Trimble-RTX post-processing service and the coordinates of each day were obtained. After the coordinates were obtained, the errors were calculated by comparing with the coordinates of the stations published by IGS on 15 July 2021. The rmse in the direction of the coordinate axes based on them were calculated using equations (1) and (2) and, the rmse were given in Table 1 for the MERS station and in Table 2 for the EBRE station.

Table 1. The rmse obtained at MERS station

Satellite System	m_X (cm)	m_Y (cm)	m_Z (cm)
G	±0.7	±0.5	±0.5
G+R	±0.7	±0.4	±0.5
G+E	±1.1	±0.5	±0.5
G+R+E	±1.0	±0.3	±0.4

In Table 1, the rmse obtained in the direction of the axes at the MERS station generally varies between 0.3 cm and 1.1 cm. The rmse obtained only with GPS observations are more consistent with each other in the direction of different axes than other combinations. When R, E, or both are added to the GPS observations, an increase in the rmse in the X direction is observed.

Table 2. The rmse obtained at EBRE station

Satellite System	m_X (cm)	m_Y (cm)	m_Z (cm)
G	±3.3	±0.1	±1.1
G+R		No results were obtained.	
G+E	±1.0	±0.2	±0.5
G+R+E	±1.0	±0.8	±0.4

Table 2 shows that the rmse at the EBRE station generally vary between 0.1 cm and 1.0 cm, and the rmse in the X-axis direction obtained by GPS observations jumps to 3.3 cm. When E or R+E are added to the GPS observations, the axial rmse becomes more consistent with each other. After examining the rmse in the direction of the coordinate axes, the 3D rmse were obtained by Equation (3) and shown in Figure 2.

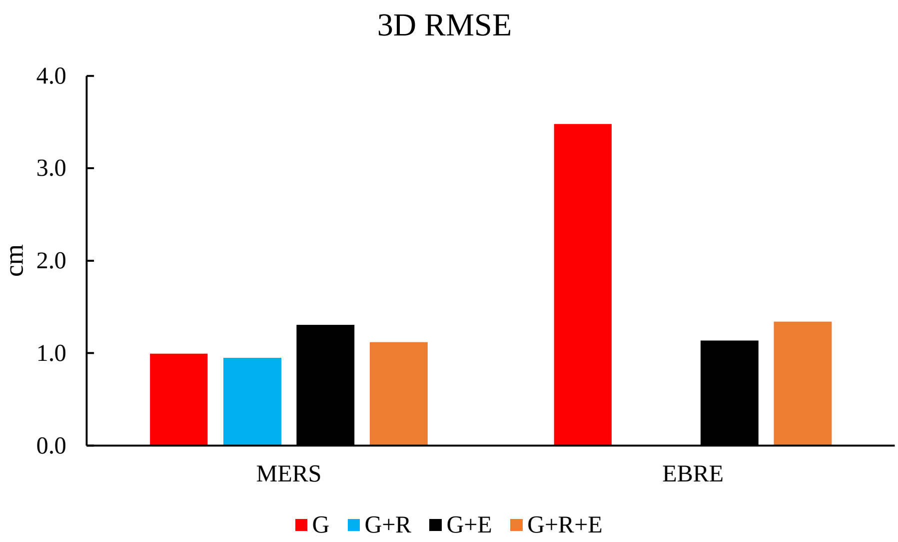

Figure 2. The 3D rmse of stations (cm)

In Figure 2, it is seen that the rmse are generally around 1 cm, very close results are obtained in four different satellite combinations at the MERS station, but these values are 3.5 cm in the G satellite combination at the EBRE station. It is thought that this situation is due to the decrease in the number of observations when only the G satellite combination is taken into account in that station, and as a result, the number of cycle slips increases. F-test was used to statistically compare the 3D rmse obtained in different satellite combinations at stations with each other and equation (4) was used to calculate the test value. F test results are shown in Tables 3 and 4.

Table 3. Comparison of different satellite combinations at MERS station

Satellite System	G	G+R	G+E	G+R+E
G	-	0.78	0.54	0.64
G+R		-	0.69	1.22
G+E			-	0.85
G+R+E				-

* significant test values

When the test values obtained in Table 3 are compared with the table value of 1.822, it is seen that these test values are not significant. This shows that the positioning results obtained in different satellite combinations at the MERS station are of the same accuracy.

Table 4. Comparison of different satellite combinations at EBRE station

Satellite System	G	G+R	G+E	G+R+E
G	-	-	3.18*	2.92*
G+R		-	-	-
G+E			-	1.09
G+R+E				-

* significant test values

Table 4 shows that the results obtained in the G satellite combination at EBRE station are not in agreement with the results obtained in other combinations. It was also seen in the statistical test results that a larger rmse was obtained in the G satellite combination at the EBRE station and therefore a lower accuracy than the other combinations. After the accuracy assessment of the coordinates was completed, the rmse were obtained using equations (5)-(7) and the 3D rmse were calculated in order to examine their precisions. The 3D rmse showing the precision of the coordinates are given in Figure 3.

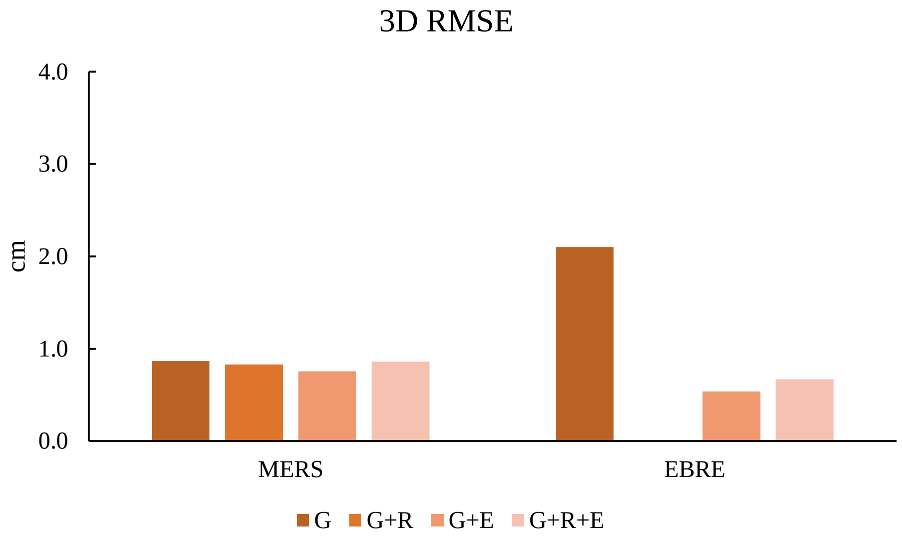

Figure 3. 3D rmse for the precision of the coordinates (cm)

When Figure 3 is examined, it is seen that 3D rmse smaller than ±1 cm are obtained in all combinations at the MERS station. This shows that the precision of the coordinates obtained at the MERS station is quite high. Similar to the accuracy assessment at the EBRE station, the rmse in the G satellite combination jumped around ±2 cm. Despite this, it is seen that the coordinate repeatability is quite good, since the 3D rmse are generally in the millimeter level, and therefore, the rmse that are almost 50% better than those obtained in the accuracy assessment are obtained.

4. CONCLUSIONS

In recent years, PPP technique has come to the fore among GNSS measurement techniques. In this technique, point locations can be determined with only a single GNSS receiver without the need for data collected at another station.

In this study, point positioning performance of Trimble CenterPoint RTX Post-Processing (Trimble RTX) service, which uses absolute solution technique (PPP), was investigated in different satellite combinations. The 31-day-24h-30 sec (1.07.2021- 31.07.2021) observation data of MERS and EBRE stations were obtained in RINEX format. The obtained RINEX data divided into four different satellite combinations, and these were sent to the Trimble RTX service for each day, then coordinates, which are belong to four different satellite combinations and each stations have been obtained. The differences between the coordinates obtained in the International Terrestrial Reference Frame (ITRF) 2014 observation epoch for 31 days from Trimble-RTX and the coordinates published by the IGS of the MERS and EBRE stations were examined. Due to the low rmse values in the results obtained, it was seen that the solutions of Trimble-RTX in different satellite combinations gave results close to the values published by IGS.

The F-test was used to statistically compare the rmse obtained in different satellite configurations at the stations with each other. As a result of the comparison, it was seen that there was no significant difference between the results obtained from the four different satellite combinations of the MERS station. In the EBRE station, it was observed that there were significant differences between the results obtained from the G satellite combination and other satellite combinations, and more accurate results could be obtained with the E or R+E observations added to the GPS satellites in the measurements. The fact that the results obtained only with GPS observations also have cm accuracy reveals that different positioning systems can be used in different combinations in practical applications.

When an evaluation is made in terms of the precision of the measurements, it is seen that the solutions of Trimble-RTX in different satellite combinations are reliable because the rmse values are lower than those obtained in the accuracy evaluation. Some disadvantages of the Trimble RTX service used in this study are that it cannot be interfered with in the evaluation processes other than options such as antenna height, and the time to obtain the results is prolonged depending on the internet speed. In line with the data obtained within the scope of the research, it is thought that Trimble RTX technology can be an alternative to the post-process positioning techniques that are frequently used today, and its use will become widespread due to its accuracy, reliability and reproducibility.

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