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Analysis of the contribution of the multi-GNSS to long-distance RTK

Ceren Konukseven*[1], **Omer Faruk Atiz**[1], **Salih Alcay**[1], **Sermet Ogutcu**[1]

[1]*Necmettin Erbakan University, Faculty of Engineering and Architecture, Department of Surveying Engineering, Konya, Turkey*

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ABSTRACT

Global Navigation Satellite System (GNSS) can provide users a fast, cost-effective, and reliable positioning service. With Real-Time Kinematic (RTK) method, it has become a practical tool for real-time positioning in many engineering applications. However, the accuracy of RTK method depends on the base distance between the reference station and the rover due to the orbital error and atmospheric errors. In classical RTK, while a reliable accuracy can obtain for short baseline length, the accuracy decreases for long baseline lengths. The effect of baseline length can be mitigated by using the Network RTK technique. Nevertheless, the accuracy highly depends on the nearest reference station. With the new emerging satellite systems such as GALILEO and BEIDOU, it has been possible to perform multi-GNSS RTK surveying. In this study, the contribution of multi-GNSS to long-distance RTK is examined. For this purpose, a field test is conducted on an approximately 80 km baseline using different satellite combinations. The results are examined regarding the accuracy.

1. INTRODUCTION

In the last decade, the Global Navigation Satellite System (GNSS) is widely used for positioning in real-time or post-process. With the developments related to GNSS, the Real-Time Kinematic (RTK) and Network-RTK methods emerged (Inal et al. 2014). The real-Time Kinematic method is a relative positioning method that allows users to estimate rover's coordinates based on a reference station. Today, these methods have an essential role in the surveying community. The accuracy of the method depends on ionospheric-tropospheric errors, signal obstructions, multipath, the geometric configuration of satellites and other errors (Baybura et al. 2019). As the atmospheric conditions are changed between the reference and rover's location, the accuracy depends on the baseline length. In general, baseline length is limited to 15-20 km when correction information is provided by radio connection. The network-RTK method can mitigate the baseline limit of traditional RTK since the correction is calculated from the network and sent via the Internet. However, in Network-RTK the accuracy highly depends on the nearest reference station.

In recent years, new satellite systems are developed such as GALILEO and BEIDOU. With the new emerging GNSSs, it has been possible to perform multi-GNSS RTK. Several studies have been conducted for multi-GNSS RTK. Odolinski et al. in 2015 presented a new approach to single-frequency multi-GNSS RTK. Accordingly, multi-GNSS was improved the integer phase ambiguity resolution (Odolinski et al. 2015). The combination of GPS+GALILEO for RTK was showed better accuracy at the high cut off angles than only-GPS (Castro-Arvizu et al. 2020). He and Chen in 2020 proposed a network RTK algorithm that can process observations of five GNSS systems (BDS-2/BDS-3, GPS, GLONASS, GALILEO and QZSS) (He and Chen 2020). According to this, including multi-GNSS observations to the Network-RTK model gives better results compared with the classical Network RTK. Wang et al. in 2020 compared the traditional single baseline RTK and their newly developed multi-baseline RTK methods. They concluded that GPS/BDS combination gives better results compared with the only-GPS for the kinematic experiment (Wang et al. 2020). Xi et al. in 2020 investigated bridge monitoring with multi-GNSS RTK (Xi et al. 2020). They demonstrated that even for high cut-

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* **Corresponding Author**

*(ceren.konukseven@ogr.erbakan.edu.tr) ORCID ID 0000-0001-6598-9479
(oatiz@erbakan.edu.tr) ORCID ID 0000 – 0001 – 6180 – 7121
(salcay@erbakan.edu.tr) ORCID ID 0000 – 0001 – 5669 – 7247
(sermetogutcu@erbakan.edu.tr) ORCID ID 0000-0002-2680-1856

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off angles, 2 mm and 7 mm precisions can be obtained for horizontal and vertical components, respectively.

In addition to multi-GNSS RTK, some studies have been conducted for long distance RTK. Baybura et al. in 2019 compared Network-RTK and long distance RTK methods using GPS/GLONASS satellite combination (Baybura et al. 2019). They concluded that the two methods showed similar results. Zhang et al. in 2020 investigated the contribution of QZSS to GPS+GLONASS+GALILEO RTK using a new triple frequency observation model (Zhang et al. 2020). The results showed that for longer baselines, QZSS improved the accuracy and ambiguity fixing rate. Bramanto et al. 2019 examined long distance RTK for cadastral surveying with a new algorithm (Bramanto et al. 2019). They demonstrated that long distance RTK -up to 90 km- can be used for cadastral measurements.

Despite many studies have been conducted for multi-GNSS or long distance RTK, it is worth to examine comprehensively the contribution of multi-GNSS to long distance RTK. In this study, the positioning performance of GPS, GPS+GLONASS and GPS+GLONASS+GALILEO+BEIDOU satellite combinations for long distance RTK is investigated. For this purpose, a field test is conducted. The results are analyzed in terms of accuracy.

This paper is organized as follows. In Section 2 the functional model of RTK is briefly described. Section 3 explains the field test. In section 4 the results and discussions are given. In Section 5 the work is concluded.

2. FUNCTIONAL MODEL OF RTK

RTK mathematical model is based on the double difference (DD) of carrier phase observations (Figure 1). DD technique eliminates the satellite/receiver clock offsets, most of the ionospheric error and many other error sources.

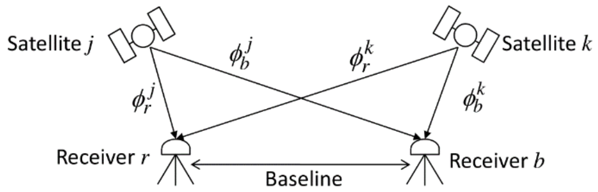

Figure 1. Double differences (Takasu 2013)

Although there are some small differences in the algorithms according to the device and software used, the fundamental steps are similar. Accordingly, first single differences (SD) then DD are composed. After obtaining the float solution, ambiguity resolution is performed. When the integer ambiguity is solved, fixed solution is obtained. Also, the ambiguity resolution part includes searching and validating steps (Aydin et al. 2004). For a satellite-receiver pair, the carrier phase observation can be written as follows:

$$\emptyset = \rho - I + Tr + c(b_{Rx} - b_{Sat}) + N\lambda + \varepsilon_{\emptyset} \qquad (1)$$

where ρ indicates the geometric range between the receiver and satellite; I is the ionospheric delay; Tr is the tropospheric delay; b_{Rx} and b_{Sat} are receiver and satellite clock offsets, respectively; λ is the wavelength of carrier phase; N is the integer ambiguity term and $\varepsilon_{\emptyset}$ is the measurement noise. The geometric range can be extracted using ECEF coordinates of receiver and satellite as given in Equation 2.

$$\rho = \sqrt{(X_{Sat} - X_{Rx})^2 + (Y_{Sat} - Y_{Rx})^2 + (Z_{Sat} - Z_{Rx})^2} \quad (2)$$

For two satellite-receiver pair as shown in Figure 1, the DD equation can be written as follows:

$$\emptyset_b^{jk} - \emptyset_r^{jk} = \rho_b^{jk} - \rho_r^{jk} - I_b^{jk} + I_r^{jk} + Tr_b^{jk} - Tr_r^{jk} + \lambda\left(N_{b,r}^{jk}\right) + \varepsilon_b^{jk} - \varepsilon_r^{jk} \qquad (3)$$

where superscript j and k denote the satellites and subscript r and b indicates the rover and base stations, respectively. The clock offsets are directly removed by DD. The tropospheric and ionospheric errors are can be neglected relatively. When $N_{b,r}^{jk}$ term is solved as an integer value in some way, RTK positioning is obtained in cm level and so-called “fixed” solution. If the ambiguity term could not solve as an integer, the solution is called “float”. Usually, the accuracy of the float solution is at a few meters level. For RTK, the integer ambiguity is solved by on-the-fly (OTF) ambiguity resolution techniques (Wang 1999).

3. FIELD TEST

For examining the contribution of multi-GNSS combinations to the long distance RTK, a field test is performed on an approximately 80 km baseline, in Konya closed basin area. The location of the field test is given in Figure 2.

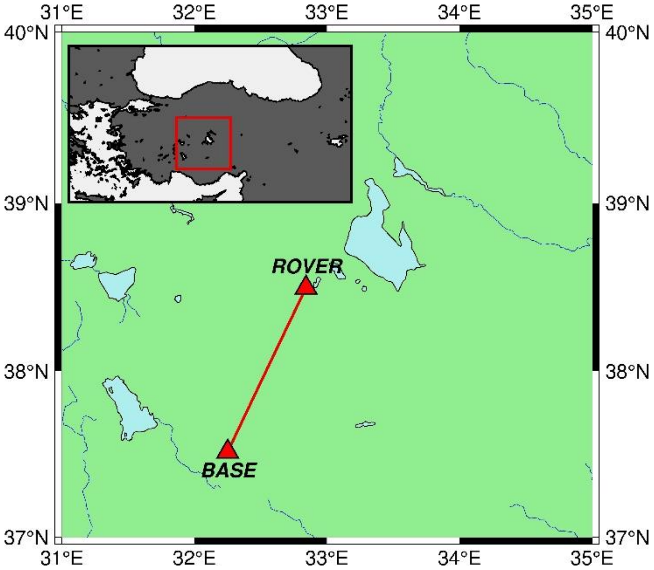

Figure 2. The location of the field test

The field test is conducted considering three different satellite options: GPS, GPS+GLONASS, GPS+GLONASS+GALILEO+BEIDOU. For the sake of clarity, hereafter these options are called G, GR and GREC. In order to make equivalent and simultaneous observation using three receivers, an apparatus was used which allows placing receivers on the same stand. Further, a power supply was provided to each receiver for the probability of battery out. As the rover, the CHCNav i50 GNSS receiver was used which takes advantage of GPS, GLONASS, GALILEO, and BEIDOU signals with embedded 624-channel GNSS technology. The status of rovers during the measurements is shown in Figure 3.

Figure 3. The rovers during the test

The permanent GNSS receiver established at the rooftop of the Engineering and Architecture Faculty of Necmettin Erbakan University, in Konya, was used as the reference station. This station is composed of a CHC N72 reference receiver connected by a TNC type connector to the CHC C220GR choke ring antenna. The reference receiver is a multi-frequency GNSS receiver and capable of monitoring all GPS (L1/L2/L5), GLONASS (L1/L2), BEIDOU (B1/B2) and GALILEO (E1/E5A/E5B) signals. The communication between the reference station and rovers is provided by the Internet (GSM), using NTRIP (Networked Transport of RTCM via Internet Protocol).

The satellite elevation cut-off angle is taken as 10° since the location of the field test has an open sky. With these configurations, 1-hour RTK surveying with 1-second epoch interval was performed. Besides, to determine the reference coordinates 5-hour static surveying was performed.

4. RESULTS AND DISCUSSION

For analyzing the results, first, reference coordinates were obtained by the post-process relative positioning method. The static data of the reference station and the data of rovers from 5-hour static surveying were used. The processes were applied using GAMIT which is a well-known and powerful GNSS data processing software (Herring et al. 2010). Only GPS data was used for estimating reference coordinate values. The coordinates of both reference and RTK generated in ITRF 2014 reference coordinate system. After obtaining reference coordinates of rovers, the cartesian coordinates were transformed to topocentric coordinate system, which can be expressed as north (n), east (e) and up (u) components. Also, topocentric coordinates can be used for accuracy representation.

For a proper analysis, an alignment was performed between the results of G, GR and GREC configurations considering time. However, only fixed results were taken into consideration. The topocentric coordinate components for each satellite configuration (G, GR and GREC) are provided in Figure 4-6, for north, east and up, respectively.

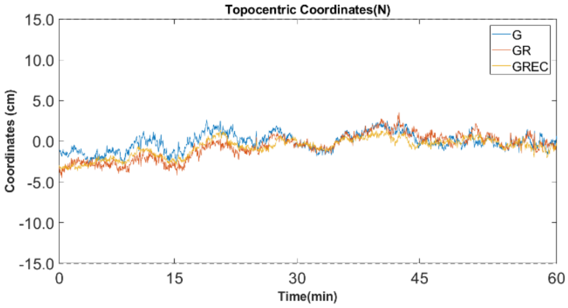

Figure 4. Coordinates for north component

In Figure 4 coordinates of G, GR and GREC satellite for north component are given. According to this, ± 4 cm accuracy is achieved for G, GR and GREC. In the first 30 minutes, G shows better accuracy of ± 2 cm compared with the GR and GREC combinations.

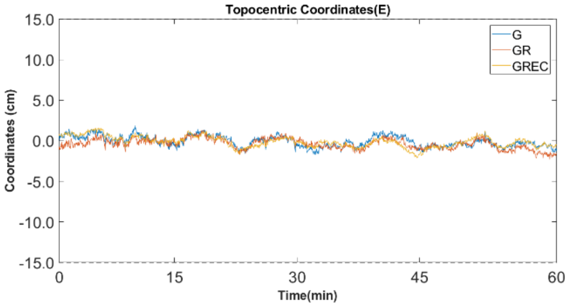

Figure 5. Coordinates for east component

In figure 5 coordinates for east component are given. It is seen that the accuracy of ± 2 cm is achieved for all options. Besides, it is not clear to recognize one of the G, GR, and GREC configurations have a superiority.

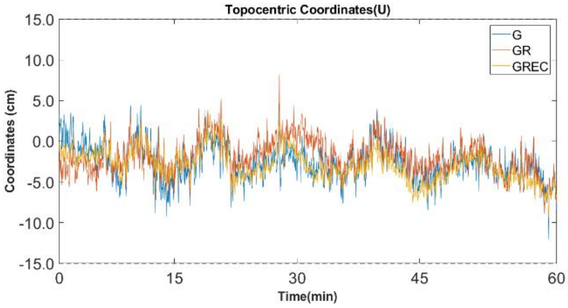

Figure 6. Coordinates for up component

In figure 6 coordinates for up component are given. Accordingly, the accuracy of ± 9 cm is achieved for all options. In the first 10 minutes, GREC shows better accuracy of ± 2 cm compared with the G and GR. However, after the first 10 minutes, all options showed almost similar results.

Furthermore, absolute maximum, absolute minimum, mean and root mean square error (RMSe) values were calculated. The statistical values for each satellite configuration are given in Table 1.

Table 1. The statistical values for G, GR and GREC

		n (cm)	e (cm)	u (cm)
G	Maximum (abs)	2.93	1.87	12.09
	Minimum (abs)	0.00	0.00	0.01
	Mean	-0.08	-0.07	-2.63
	RMSe	1.10	0.69	3.43
GR	Maximum (abs)	4.49	2.30	9.32
	Minimum (abs)	0.00	0.00	0.00
	Mean	-0.65	-0.37	-1.93
	RMSe	1.66	0.74	2.89
GREC	Maximum (abs)	3.65	2.10	9.47
	Minimum (abs)	0.00	0.00	0.01
	Mean	-0.73	-0.12	-2.96
	RMSe	1.63	0.78	3.51

As can be seen from Table 1, for absolute maximum GR and GREC combinations give better results in up component. When mean values are analyzed, it is seen that similar results are obtained. Furthermore, the RMSe values are less than 1.7 cm and 0.8 cm for north and east components, respectively. In the up component, RMSe values are bigger than horizontal components and similar for three configurations.

5. CONCLUSION

In this study, the contribution of multi-GNSS combinations to long distance RTK is investigated. For this purpose, a field test was conducted. In the field test, 1-hour RTK measurement was conducted with three satellite combinations, namely G, GR, and GREC. The results demonstrated that the accuracy of ± 5 cm and ± 10 cm were obtained in long distance RTK for horizontal and vertical components, respectively. In addition, the results are investigated using basic statistical parameters and RMS errors. According to this, G, GR and GREC configurations have similar results and there are no significant differences. In the open sky conditions, when the number of visible satellites is sufficient and have a good geometry, different GNSS configurations give almost equal results.

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