3rd Intercontinental Geoinformation Days (IGD) – 17-18 November 2021 – Mersin, Turkey

Intercontinental Geoinformation Days

igd.mersin.edu.tr

Accuracy assessment of positioning based on single and MULTI-GNSS

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Keywords
Single GNSS
Multi-GNSS
Precise Point Positioning (PPP)
PPPH
International GNSS Service (IGS)

ABSTRACT

Global Navigation Satellite System (GNSS) globally gives users 24-hour service of 3D positioning, velocity, and time with the aid of radio signals transmitted from satellites orbiting in space. More satellites present during observation bring improvement in satellite geometry and redundancy which gives better quality of GNSS positioning result. This study aims at testing the positional accuracy of the use of multi-GNSS as compared to using a single satellite. Five International GNSS Service (IGS) stations (MRO1, PTVL, TONG, XMIS, and YAR3) were used for the study and the data obtained from these stations were post-processed using the PPPH software. In the single satellite category, GPS and GLONASS produced similar results with RMSE values of approximately >0.1m in both horizontal and vertical components. On the other hand, the combination of GPS+GLONASS gave the best result in the multi-GNSS category with RMSE values identical to those obtained from the GPS and GLONASS single satellites.

1. Introduction

Global Navigation Satellite System (GNSS) is the general term for all those navigation systems that provide users globally with a 3-dimensional positioning, velocity, and time solution 24-hour service with the use of transmitted radio signals from orbiting satellites in space (Garcia et al., 2019). Global Positioning System (GPS) for the United States, GALILEO for Europe, for Russians is the GLONASS, BeiDou for the People's Republic of China, and the QZSS for Japan.

The advent of the GNSS has made surveying and mapping applications easier, accurate, and more precise. This is the reason why geodesists are interested in utilizing forefront GNSS strategies. Recently, GNSS can be said to be one of the developments and useful advances to the field of surveying and geodesy. Since its inception, it has evolved to give overall all-weather navigation as well as precise and accurate positioning sureness capabilities to its users (Abdulmumin et al., 2020; Isioye et al., 2018).

The advantage of using multi-GNSS is in the availability of a larger number of satellites, which will benefit the user in; reducing signal acquisition time, improving positioning and accuracy in time, reducing problems caused by obstructions such as buildings and foliage, and Improving the spatial distribution of visible satellites, leading in improvement in dilution of precision (DOP) (Jeffrey, 2010; Langley et al., 2017).

Precise Point Positioning (PPP) is a GNSS positioning application known for its high precision and accuracy level; using a single receiver and undifferenced observations by application of the precise satellite orbit and clock products from the International GNSS Services (IGS), it provides a user with centimeter to millimeter level positioning globally. GPS was the only system that the PPP was mainly performed on some time ago. Today, the GLONASS, Beidou, and the GALILEO, multi-GNSS positioning that can highly improve the positioning, continuity, availability, and accuracy become the order of the day in GNSS-based applications (Wang et al., 2018).

Many kinds of research were conducted to test for the positional accuracy of the use of multi-GNSS (see Andreas et al., 2019; Bu et al., 2021; Fang et al., 2019; Garcia et al., 2019; Li et al., 2015; Tao et al., 2021; Wang et al., 2018).

The current study aims to assess the positional accuracy of multi-GNSS for geodetic and mapping applications.

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Cite this study

Abdulmumin L, Yusuf R, Haruna I & Musa A A(2021). Accuracy assessment of positioning based on single and Multı-GNSS. 3rd Intercontinental Geoinformation Days (IGD), 54-57, Mersin, Turkey

2. Method

The dataset used for this study was obtained from five International GNSS Service (IGS) Stations (see Table 1) through its website (ftp://cddis.gsfc.nasa.gov/gnss/data/daily/). The choice of these stations was based on multi-GNSS capabilities and those with consistent data. Seven days RINEX data files of the year 2019 were downloaded from day 359 to 365 which was equivalent to day 20853 to 20862 GPS calendar. Figure 1 shows pictorially the locations of these IGS GNSS sites.

The obtained data were then post-processed using the PPPH software to determine the obtainable positional accuracy using these multi-constellation permanent GNSS sites.

Figure 1. The Geographic Locations of the used IGS Stations

To compare the results obtained from the PPPH software with the known coordinates of the stations used, the difference in X, Y, Z, and XY components was computed and used in analyzing the results subsequently. Also, Root Mean Square Error was computed using Equations (1), (2), (3), and (4).

$$\mathrm{RMSE_x} = \sqrt{\sum_{i=1}^{n} \frac{\Delta x_i^2}{n}} \qquad 1$$

$$\mathrm{RMSE_y} = \sqrt{\sum_{i=1}^{n} \frac{\Delta y_i^2}{n}} \qquad 2$$

$$\mathrm{RMSE_z} = \sqrt{\sum_{i=1}^{n} \frac{\Delta z_i^2}{n}} \qquad 3$$

Where Δx_i and Δy_i are the differences between the obtained result from the PPPH software and the reference (true) coordinates of the used IGS stations.

Calculation of the Root Mean Square coordinate error RMSExy, which is a characteristic of point sets accuracy and is one of the most common accuracy measures in geodesy. RMSExy is calculated as follows;

$$RMSE_{xy} = \sqrt{0.5(RMSE_X)^2 + \left(RMSE_y\right)^2} \qquad 4$$

3. Results

The coordinates of the five used IGS stations are presented in Table 1. Similarly, all 3D coordinates obtained from the PPPH software were converted to the same coordinate system for easy comparison.

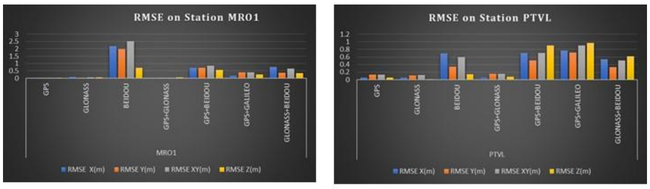
Table 1. Showing the used IGS stations, the cities and countries they belong to, their coordinates, and systems

STATIONS	COUNTRY	X (m)	Y (m)	Z (m)	SYSTEMS
MRO1	Australia	-2556629.766	5097138.226	-2848385.220	QZSS+GPS+GLO+GAL+BDS
PTVL	Vanuatu	-5950573.211	1230677.184	-1932017.019	QZSS+GPS+GLO+GAL+BDS
TONG	Tonga	-5930303.5403	-500148.768	-2286366.298	QZSS+GPS+GLO+GAL+BDS
XMIS	Australia	-1696344.7609	6039590.001	-1149275.083	QZSS+GPS+GLO+GAL+BDS
YAR3	Australia	-2389043.7708	5043313.583	-3078524.391	QZSS+GPS+GLO+GAL+BDS

The RMSE for each station has been computed using equations (1)-(4). These results are presented in tables 2, 3, 4, 5, and 6 for stations MRO1, PTVL, TONG, XMIS, and YAR3 respectively.

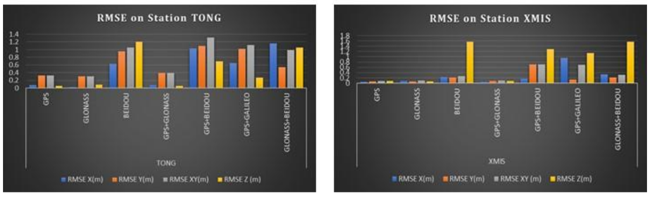
Considering the results from the single satellites, GPS and GLONASS produced identical results in both horizontal and vertical components with RMSE values less than 0.1 m in all the used stations (see Figure 2).

On the other hand, the combination of GPS and GLONASS (GPS+GLONASS) satellites proves to be better in the multi-GNSS category with RMSE values similar to that of GPS and GLONASS (>0.1 m) in the single satellite. The combinations of GPS and BEIDOU (GPS+BEIDOU), and GLONASS and BEIDOU (GLONASS+BEIDOU) produced poor results (see also Figure 2).



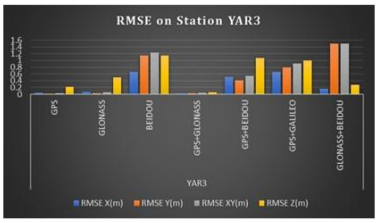
a) Station MRO1

b) Station PTVL



c) Station TONG

d) Station XMIS



e) Station YAR3

Figure 2. RMSE in coordinates of all the five used stations

4. Discussion

Although not all multi-GNSS combinations give the required accuracy, multi-GNSS capability can solve many GNSS project problems. Based on the current study, GPS and GLONASS have the best results when compared to the other single constellation (i.e., BEIDOU). On the other hand, the synergy between GPS and GLONASS (GPS+GLONASS) comes on top when considering the accuracy of the multi-GNSS systems.

Generally, it can be said that the GPS, GLONASS, and GPS+GLONASS systems have similar results based on the present study. This implies that these systems can be integrated when there is a need or in the absence of GPS or GLONASS signal. The use of all other constellations apart from that can be discouraged based on the results obtained.

5. Conclusion

The use of multi-GNSS constellations can go a long way in solving the problems of GNSS mapping problems; in reducing the cases of signal loss, improving accuracy, and the likes. But this is not always achieved as proved in the just-completed study. If one must use it, GPS+GLONASS is the best.

Table 2. RMSE of Coordinates over the Station MRO1

STATION	SYSTEM	RMSE X (m)	RMSE Y (m)	RMSE XY (m)	RMSE Z (m)
MRO1	GPS	0.01122209	0.019920642	0.021442939	0.019221268
	GLONASS	0.07193277	0.026292212	0.057257682	0.068788550
	BEIDOU	2.16433165	1.992064209	2.512067984	0.706914569
	GPS+GLONASS	0.01072881	0.030276334	0.031212338	0.065561738
	GPS+BEIDOU	0.70344904	0.703063347	0.861230715	0.559836358
	GPS+GALILEO	0.15614839	0.380931349	0.396610454	0.243052520
	GLONASS+BEIDOU	0.75261300	0.378810029	0.653230588	0.330026654

Table 3. RMSE of Coordinates over the Station PTVL

STATION	SYSTEMS	RMSE X (m)	RMSE Y (m)	RMSE XY (m)	RMSE Z (m)
PTVL	GPS	0.055789283	0.130304436	0.136145026	0.057082015
	GLONASS	0.051122379	0.111169206	0.116898850	0.013628663
	BEIDOU	0.692271956	0.340628681	0.596362414	0.142641936
	GPS+GLONASS	0.053567458	0.152522690	0.157155678	0.075845406
	GPS+BEIDOU	0.699314189	0.506091667	0.707565505	0.905610153
	GPS+GALILEO	0.770024867	0.718223702	0.901284879	0.966270324
	GLONASS+BEIDOU	0.543639478	0.329314972	0.506182074	0.618524800

Table 4. RMSE of Coordinates over the Station TONG

STATION	SYSTEMS	RMSE X (m)	RMSE Y (m)	RMSE XY (m)	RMSE Z (m)
TONG	GPS	0.077604333	0.324084028	0.328696933	0.054437393
	GLONASS	0.023352265	0.311908094	0.312344878	0.086983963
	BEIDOU	0.629147622	0.953409063	1.052094201	1.203708856
	GPS+GLONASS	0.077413208	0.394794706	0.398571527	0.054437393
	GPS+BEIDOU	1.032198487	1.09483042	1.315815529	0.701663042
	GPS+GALILEO	0.650360825	1.024119742	1.122633443	0.277398973
	GLONASS+BEIDOU	1.159477708	0.54328713	0.983542161	1.048145364

Table 5. RMSE of Coordinates over the Station XMIS

STATION	SYSTEMS	RMSE X (m)	RMSE Y (m)	RMSE XY (m)	RMSE Z (m)
XMIS	GPS	0.043040494	0.071178059	0.077411615	0.082712
	GLONASS	0.084461850	0.070957578	0.092746320	0.064840
	BEIDOU	0.239802219	0.212843815	0.272130560	1.567636
	GPS+GLONASS	0.043040494	0.091178059	0.096123257	0.082712
	GPS+BEIDOU	0.169091541	0.706395001	0.716442511	1.284794
	GPS+GALILEO	0.962279309	0.140709576	0.694830857	1.143372
	GLONASS+BEIDOU	0.325883206	0.211420254	0.312727446	1.567636

Table 6. RMSE of Coordinates over the Station YAR3

STATION	SYSTEMS	RMSE X (m)	RMSE Y (m)	RMSE XY (m)	RMSE Z (m)
YAR3	GPS	0.050063747	0.01223673	0.037455666	0.218742
	GLONASS	0.068645985	0.027060598	0.055573479	0.501584
	BEIDOU	0.657043034	1.143607581	1.234378821	1.137980
	GPS+GLONASS	0.032646931	0.031324730	0.038912078	0.066095
	GPS+BEIDOU	0.515621678	0.412027338	0.550181229	1.067270
	GPS+GALILEO	0.657043034	0.790054190	0.916536086	0.996559
	GLONASS+BEIDOU	0.162068287	1.497160971	1.501540555	0.276233

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