Estimation of the contribution of GLONASS Constellation when used for Network RTK positioning with Geodetic GNSS Receivers

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Abstract

The development of the GLONASS satellite constellation has allowed for the presence of an efficient system which provides an important contribution to any surveying situation, particularly when there is the presence of obstructions to the satellite visibility. This paper reports on the results of positioning tests carried out with new generation Geodetic GNSS receivers supplied by different manufacturers in order to evaluate the contribution of the GLONASS constellation to NRTK (*Network Real Time Kinematic*) surveying in conditions of critical GNSS satellite geometry. The accurate and specific results have confirmed the dual-constellation receivers quality, even when differences in extreme conditions have been noticed.

Introduction to GLONASS constellation

Modern military radio navigation systems such as GPS and GLONASS come from space programmes developed by the USA *(United States of America)* and USSR respectively (*Union of Soviet Socialist Republics*) after the Second World War. Since the 1980s, USSR has been working on the creation of a military satellite radio navigation system, called GLONASS (ГЛОНАСС; ГЛОбальная НАвигационная Спутниковая Система; *Global'naja Navigacionnaja Sputnikovaja Sistema*) simultaneously with the American NAVSTAR-GPS system. The system, developed to provide a global-covering satellite constellation, was completed in 1995 utilising 26 operative satellites. However, because of the social and political crisis in USSR at the time, the system was unable to support itself economically and appeared to be doomed to a slow decline.

The original project consisted of 24 satellites orbiting in three planes with ascending axis separated by 120°. The GLONASS satellites operated near-circular orbits with a radius of approximately 19,100 km and an inclination angle of 64.8° to the equatorial plane with an orbital period of about 11 hours and 15 minutes.

The efficiency of the GLONASS constellation is currently ensured by the control segment within the Russian territory, which consists of an SCC System Control Centre near Moscow and several CTS Command Tracking Stations) located in Saint Petersburg, Schelkovo, Yenisseisk and Komsomolsk-Na-Amure.

Image 1. GLONASS satellites

GLONASS uses the FDMA (*Frequency Division Multiple Access*) method based on the transmission of the same code with different frequencies typical of each satellite. In actual fact, the two satellites which are on the same orbital plane, but poles apart, send signals at the same frequency. This approach is the main difference with GPS constellation, in which all satellites send signals at the same frequency (L1 and L2). This of course implies a higher complexity for the production of the receivers, as far as hardware and software are concerned, to allow the tracking and use of both constellations.

Since 2001 a new federal Russian programme called *Global Navigation System* has been undertaken by the Government with the financial and economic partnership of India, which is particularly focused on the civil use of GLONASS system. In order to understand how GLONASS has made its comeback, it is enough to observe that in 2007 the Russian President Vladimir Putin signed a decree that permits free access and use to the system navigation signals for both civilians and also for foreign users.

Currently, the system has 27 satellites, 23 of which are operative (http://www.glonass-ianc.rsa.ru/); the Russian federal Government aims to reach full efficiency by the end of this year.

In the scientific and professional field the interest in this satellite system is primarily due to the fact that the combined use of both GPS and GLONASS systems can provide an improved satellite geometry and therefore redundant information to estimate the position in poor visibility conditions, in which situations GPS by itself would not find any solution.

Image 2 represents the availability of GPS+GLONASS satellites in Palermo, with a 10° elevation mask. The sum of the two constellations (green colour) reaches a maximum of 18 satellites with 11 GPS satellites (purple colour) and 7 GLONASS satellites (red colour).

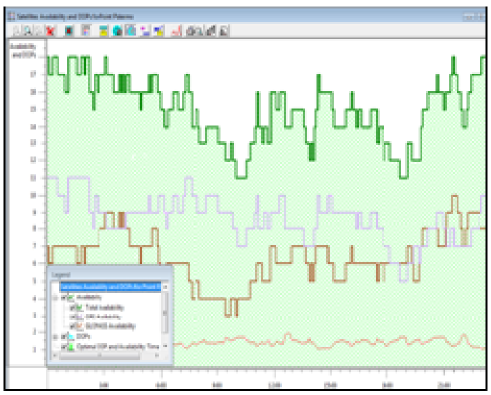


Image 2. The availability of GPS+GLONASS satellites during tests

Planning and implementation of surveys

The purpose of the tests was to check the use of GPS+GLONASS double constellations for the real-time calculation of measured position (according to Network RTK procedures) with the geodetic receivers from the three important manufacturers. The tests were carried out on 14th and 15th December 2010 in a location on the roof of DICA (Department of Civil, Environmental and Aerospace Engineering) of the Faculty of Engineering, University of Palermo. Three survey points with metal head placed at a distance of 3 metres from each other; this choice was made in order to work simultaneously with three receivers and have the same satellite configuration and similar internet access conditions for the reception of Network RTK corrections (please see image 3 below).

Image 3 – Test area and equipment used

First of all, static GNSS surveying sessions were carried out on the positions selected for the test, in order to obtain the reference coordinates to be used and thus compared with the Network RTK survey test results. The processing was carried out using the commercial software solution *Topcon Tools* (issued to DICA) by setting the coordinates obtained with ETRF2000 reference system (Epoch 0.2008); the PALE Permanent Reference Station used for processing against is owned by RND (*National Dynamic Network*) and managed by IGMI (*Italian Geographic Military Institute)*.

The differential correction has been generated by the GNSMART software from Geo++ of Hannover, also issued to DICA. Geo++ was one of the first companies in the world to produce GNSS Permanent Stations management software with different network corrections. It is an independent company in contrast to the manufacturers whose tools were tested. Moreover, its GNSMART software is compatible with all the receivers used (note: it has dozens of installations throughout the world and in Italy it has been installed in six regional Permanent Stations networks). The correction format used during the tests was the standard RTCM 3.0, transmitted through the NTRIP protocol with the *Nearest* status from the GNSS PALE Permanent Station of Palermo, operative since 2007.

a) We have chosen not to transmit other kinds of correction because the PALE Permanent Station is located near the test area;

b) - to avoid proprietary network formats of each manufacturer (MAC, VRS or FKP).

Diagram 4 shows a Geo++ GNSMART menu with the satellites used during a session.

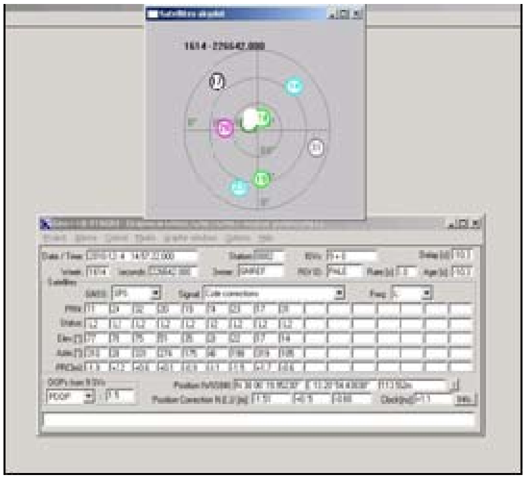


Diagram 4. Screenshot of Geo++ with the satellites used

In table 1 the receivers used during the tests and their main technical data are represented. They show the state of the art of the major companies.

Company	Model	Firmware	Channels
LEICA	**VIVA GS15**	1.2	120
TOPCON	**GR-3**	3.3p4	72
TRIMBLE	**R8 GNSS**	3.24	220

Company	Controller	Software	Version
LEICA	CS15	Smart Worx	1.2
TOPCON	FC250	TopSURV	7.2.3
TRIMBLE	TSC2	Survey Controller	12.10

Table 1: Receivers & Controllers used in the tests

The tests were carried out by intentionally changing the geometric configuration of the satellites belonging to GPS and GLONASS constellations. Two types of tests were carried out:

1. The first test was to check whether the receivers use GLONASS satellites for the calculation of the phase ambiguity. For this purpose the number of satellites transmitted during the differential corrections was been changed; at every variation in the receivers, the calculation of ambiguity has been reset and then positions for 300 epoch times have been registered. Four test sessions were performed, also by changing the distance between the receivers in order to give greater strength and reliability to results. This kind of test reproduces the situation at the beginning of surveying procedures.

2. The aim of the second test is to examine the behaviour of the receivers in the most difficult surveying environments, where, because of obstructions, the number of satellites would typically vary continually. This test started with transmitting the correction by using all the available satellites and then, about every 150 seconds, GPS satellites have been disabled one by one, while the receiver kept recording the positions without interruptions.

The registration of observations has been achieved with both fixed-phase and float-phase and standalone ambiguity. At the end of acquisition, only the fixed values indicated by the instruments have been taken into account, by following the directions of the manufacturers who indicate the fixed solution as a reliable one.

For the estimation of results we have considered the differences between the recorded positions and the position of reference calculated as previously said.

The planimetric differences are calculated according to the following formula:

$$dH=\sqrt{dE^2+dN^2}$$

where dE= Eknown – Emeasured and dN= Nknown – NMeasured, while the height differences are calculated according to the formula dU = UpKnown – UpMeasured.

Finally, we have not considered the coordinates with a difference of more than 10 cm as regards to the known coordinate, even if the position calculated was in fixed mode.

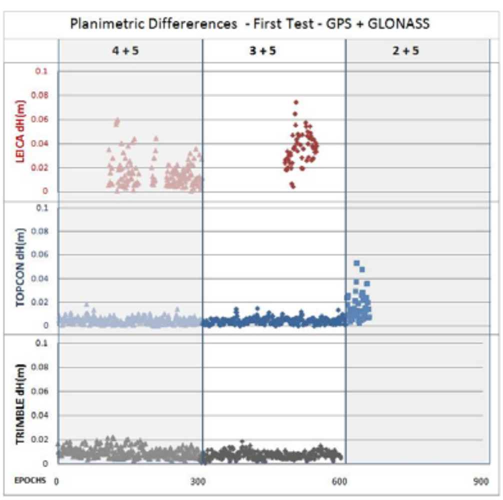
Only GPS Satellites surveying (tests with re-initialization)

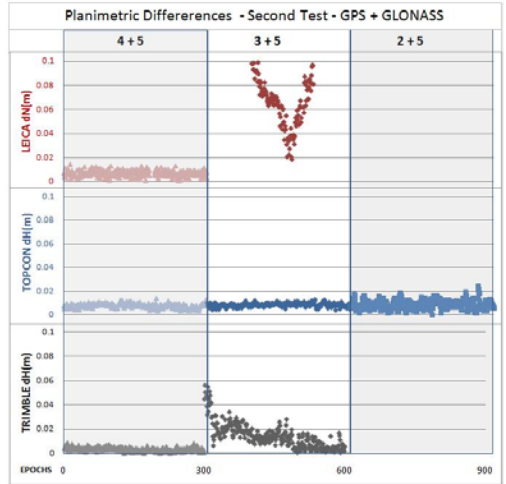
In the test where the correction has been transmitted from GPS satellites only, the geometry has been changed, starting with a situation where all GPS satellites were available and then using 6, 5 and 4 satellites respectively. The aforementioned variation was carried out using the Geo++ GNSMART software. The test was done three times on 14th December 2010 and once on 15th December 2010 and, at each configuration variation, the calculation of ambiguities was reset and the solutions for 300 epoch times recorded. From the examination of the results for the three receivers, excellent results were observed in terms of planimetric differences for all four tests conducted simultaneously. Data coming from the receivers correlate very well and show a moderate trend within an interval of 1-2-cm, without any remarkable variation due to the reduction of the number of satellites (from 9+0 to 5+0). On the contrary, in the extreme condition (4+0), no receiver was able to calculate the phase ambiguities. The height differences also correlate with the planimetric results, namely there are no important variations when the satellite configuration changes.

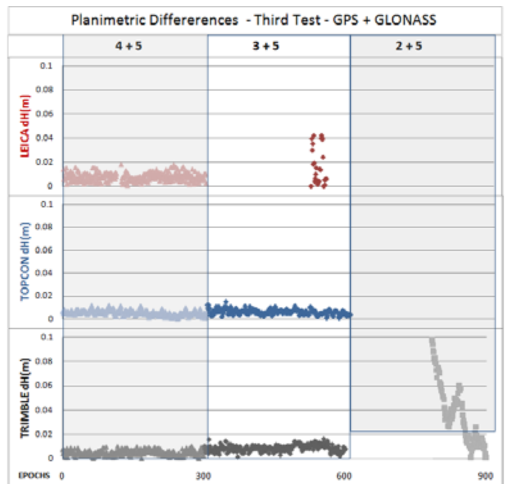
GPS+GLONASS surveying (test with re-initialization)

As far as the GPS+GLONASS configuration tests were concerned, we changed from a 4+5 to a 3+5 geometry, and finally to a 2+5 one. The afore mentioned variation also carried out using the Geo++ GNSMART software, with the same operating mode as the previous test performed with GPS satellites only.

It was observed that the differences resulting from the evaluation of the Topcon and Trimble receivers have maintained the same trend. It was, however, coherent with the dispersion values of the previous GPS configurations only in the 4+5 satellite configuration. In this scenario the Leica receiver has provided valid solutions for two out of three sessions.







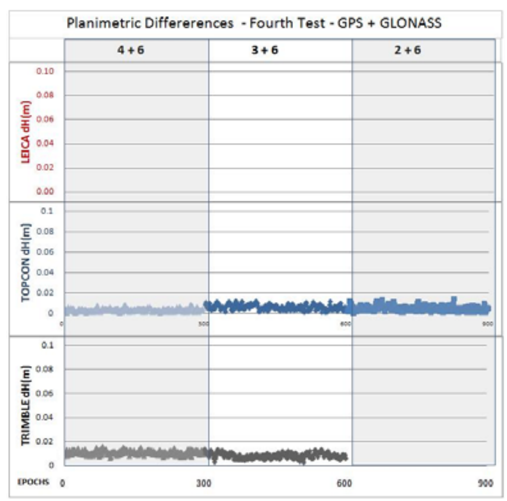
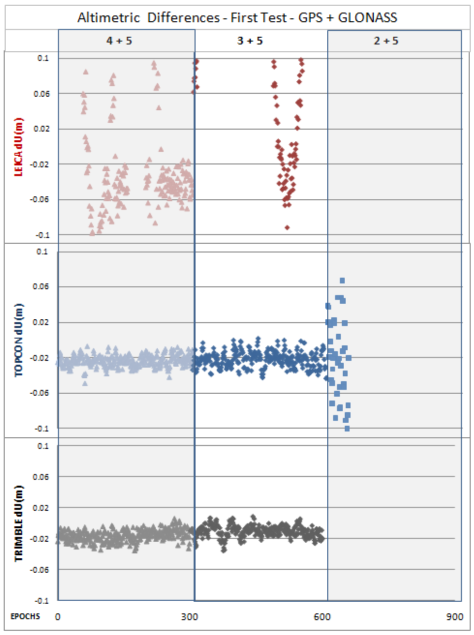


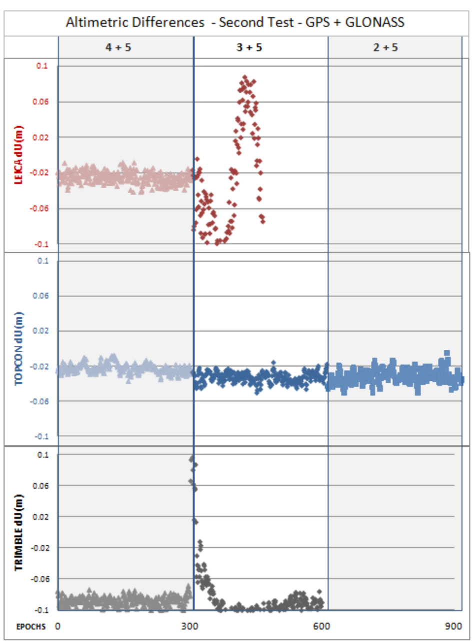
Diagram 5. Planimetric diagrams of the tests with GPS+GLONASS re-initialization

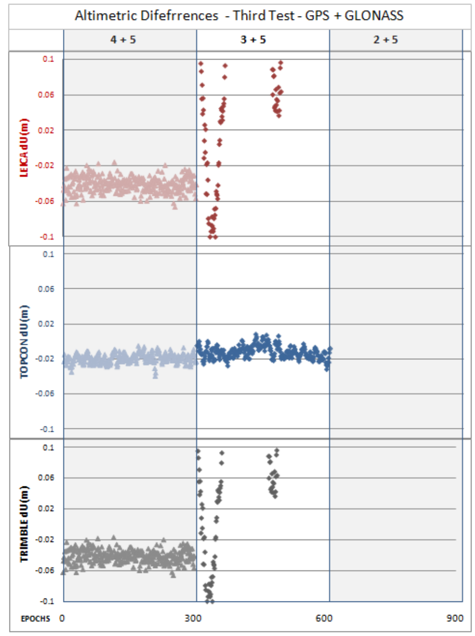
During the transition to 3+5 configuration, data coming from Trimble and Topcon receivers showed the same trend as that of the test with GPS only, whereas Leica receiver did not provided all the solutions.

In the 2+5 satellite combination, Topcon's receiver provided all the solutions for two sessions, whereas those deriving from Trimble receiver were present only in one out of four tests, with clear discontinuities (Diagram 5 above).

Similar results to those coming from the diagrams of the horizontal residues have been obtained for height differences (Diagram 6).







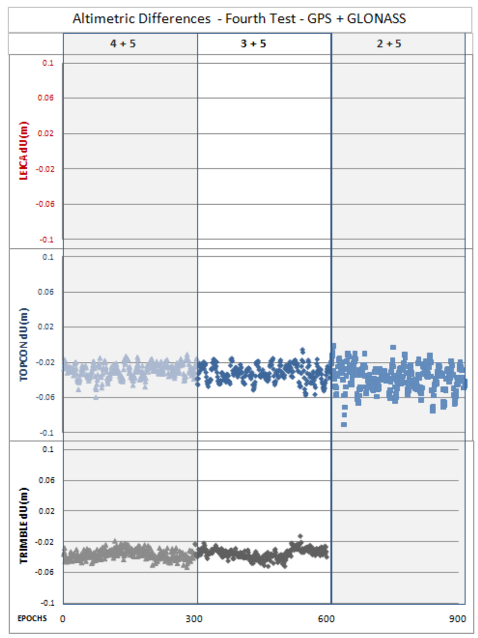


Diagram 6. Altimetric diagrams of the tests with GPS+GLONASS re-initialization

Table 2 below shows the summary of the results obtained during those tests where the receivers were reset at the variation of the number of the GPS satellites. Please see the key below the table for an explanation of the results...

14/12/2010		**GPS + GLONASS**						
Session 1		9+0	6+0	5+0	4+0	4+5	3+5	2+5
	Leica							
9.20 -	**Topcon**							
10.30	**Trimble**							
14/12/2010		**GPS + GLONASS**						
Session 2		8+0	6+0	5+0	4+0	4+5	3+5	2+5
	Leica							
10.57 -	**Topcon**							
11.52	**Trimble**							
14/12/2010		**GPS + GLONASS**						
Session 3		9+0	6+0	5+0	4+0	4+5	3+5	2+5
	Leica							
15.00 -	**Topcon**							
16.15	**Trimble**							
15/12/2010		**GPS + GLONASS**						
Session 4		9+0	6+0	5+0	4+0	4+5	3+5	2+5
	Leica							
8.00 -	**Topcon**							
8.50	**Trimble**							

Key to Results

- presence of fixed solutions
- fixed solutions which are present only in part
- lack of fixed solutions for the session

Table 2: summary of the results obtained in the tests with re-initializati

Test with continuous recording

During this test, which lasted approximately 20 minutes, the receivers were left to record continuously with one second interval, whilst the geometry of the GPS constellation was modified every 150 seconds within the GNSMART software. The results of the planimetric (East and North) and Height differences were calculated and determined in comparison with the position obtained with the static survey computed with Topcon Tools; the diagrams express the trend over time of the differences of the three receivers.

From examination of the data contained in the scatter plots of Diagrams 7 and 8 from the three receivers, it is preliminarily observed that, as long as 4 satellites are used for the Nearest solution (in other words, a survey with acceptable theoretical geometrical conditions), data resulting from the receivers agree with each other, with a straight trend and residues within a range of 1-2 cm.

In critical conditions, with 3 GPS satellites and 6 GLONASS, the differences resulting from the measurements of the Topcon and Trimble receivers maintain the same trend, which is coherent with the dispersion values of the previous configurations. On the other hand, the differences coming from the analysis of the Leica receiver show a clear discontinuity, passing sharply to a difference of 7-8 cm. By reducing the number of GPS satellites, we observe that the differences resulting from the Topcon and Trimble receivers are centimetric, namely they are of the same order of magnitude as the tests with GPS satellites only and with a greater availability of solutions deriving from Topcon receiver (in configurations 3+6, 2+6 and 0+6), whereas the residuals resulting from the measurements of the Leica receiver are present only up to the 3+6 geometry.

Similar results to those of the diagrams of the planimetric differences are obtained for the height and – especially to the use of 4 GPS satellites – the differences from the three receivers are coherent with each other with a straight trend and are in an interval of ± 2-5 cm. In conditions of poor visibility, data resulting from Topcon and Trimble receivers show the same straight trend, whereas Leica receiver has not provided valid solutions for 3+6, 2+6 and 0+6 configurations. Finally, in the extreme situation with no GPS satellite and 6 GLONASS satellites, only the Topcon receiver has been able to provide compatible results with the values of previous configurations.

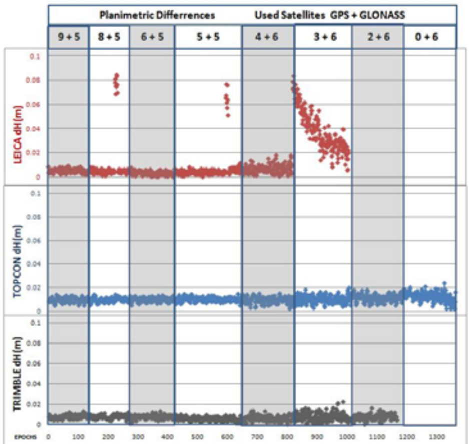


Diagram 7. Diagrams of the planimetric differences

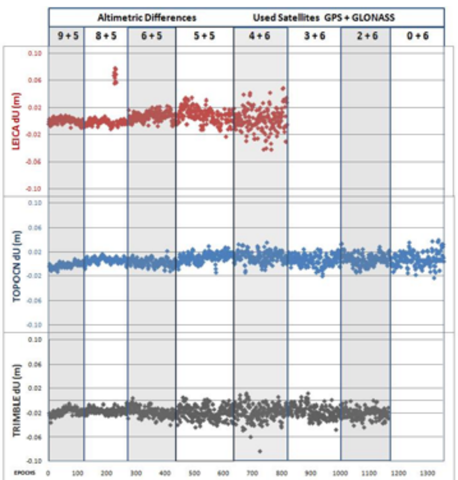


Diagram 8. Diagram of the altimetric differences

CONCLUSIONS

As already stated, the interest of research centres and universities in the GLONASS system is due to the fact that the combined use of both satellite systems can provide better satellite geometry in critical conditions such as those represented by natural and urban environments or by areas subject to electromagnetic interferences.

The new political interest of the Russian federal government for the GLONASS system will allow the use of the system in its full operational capability (26 satellites) as was the case for the GPS by the end of the year; however, the joint use of the American and Russian satellite configuration is now possible thanks to GNSS satellite receivers available on the market.

The first results from the tests conducted in this work, intentionally varying the geometric configurations of the satellites belonging to the GPS and GLONASS constellations, have revealed a good performance in terms of precision and accuracy by all receivers used in optimal satellite visibility conditions, namely with the availability of numerous GPS and GLONASS satellites.

By recreating the operating conditions of a GPS survey (obstacles, signal loss, surveying in urban areas, electromagnetic interferences) - with a limited number of GPS and GLONASS satellites (tests with continuous recording) - Topcon and Trimble receivers have showed low values of planimetric and vertical residuals and high rates of fixed solutions. On the contrary it was observed that the results from the Leica receiver did not provide coherent solutions with those of previous configurations, with less than 4 GPS satellites, even in presence of 6 GLONASS satellites.

Finally, in extreme Network RTK surveying conditions with GLONASS satellites only, the only receiver that has provided *fixed* solutions with centimetric residuals was Topcon’s.

However, please note that this study does not purport to make value judgments on the operation of the receivers used, the author also intends to continue experimenting on the contribution of the GLONASS constellation in Network RTK surveys with further tests, verifying the results obtained through other types of correction (VRS, MAC, FKP) generated by different commercial management software of permanent stations.

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