Accuracy and reliability in NRTK GNSS

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BIOGRAPHY

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ABSTRACT

The work shows the results of testing conducted from 2008 to 2009 within the Network-based RTK GNSS of University of Palermo. The network is composed of eight Continuously Operating Reference Stations (CORS) located in western Sicily and managed by a Control Centre located at the *Dipartimento di Rappresentazione* (DIRAP) of University of Palermo. The main goal of the work is to verify the reliability of the CORS network (successful tests, failed initialization time, satellite configurations) and the accuracy of measurements positioning using VRS, FKP and Nearest Station techniques. The reliability was considered the probability that the operator can correctly determine its position within the CORS network, depending on the method of calculation used in surveys conducted in different areas and in different days. Accuracy was determined by comparing the coordinates of several points calculated in post-processing and NRTK surveys.

INTRODUCTION

The development of Network-based Real Time Kinematic (NRTK) Global Navigational Satellite System (GNSS) in the last years is probably due to the fact that these infrastructure has been proven to be an efficient technology for high accuracy positioning.
Today networks of permanent stations for the ongoing real-time is very timely in studies related to satellite positioning. These represent an innovation in the traditional mode of topographic survey, because solve one critical limitation of conventional RTK approach that is the distance between the reference and rover receivers. In RTK survey the distance must be less than about 20 km in order to be able to resolve the integer ambiguities reliably 'on-

the-fly' and obtain centimetre level position (Zhang et al., 2006).

Working inside NRTK GNSS users are released from the distance taking compared to the single station and can conduct surveys with greater productivity, reliability and safety.

In recent years numerous scientific studies have been conducted to determine the accuracy, the reliability and the repeatability of tests conducted in NRTK GNSS at universities, research institutions, public and private institutions.

One of the first studies was carried out in Canada, by Department of Geomatics Engineering, University of Calgary. The Multiple Reference Stations Approach (MultiRef) was used to understanding the effects of network geometry on the achievable user accuracy. The tests show that the best performance is achieved when the reference stations are balanced on all sides of the rover receiver and that reference stations external to these core stations do not contribute to performance improvement (Lachapelle et al., 2003).

In USA, the scientific research conducted by Grejner-Brzezinska et al. (2005) presents the result on the effects of the network geometry, station separation and the data reduction technique on the final quality and reliability of the rover positioning solution. A 24-h data set collected by the Ohio CORS network was processed under different network geometry and reference station separation. The horizontal and vertical positioning accuracy were achieved in these tests is at the sub-decimeter level.

In Australia, since 2005 many researches have been directed to investigate appropriate enhancement of sparse networks (inter-receiver distance between 50 to 200 kms) to maintain the same accuracy that has already been achieved within dense networks (inter-receiver distance of 40-70 km). The Victorian GPSnet™ network was used as a case study to evaluate the potential of currently available NRTK technologies. Tests indicate that NRTK solutions computed using sparsely configured nodes can provide very encouraging results in terms of the precision, accuracy and repeatability of the coordinates at the user's receiver and the time to resolve the carrier phase ambiguities (Gordini et. al., 2006).

In United Kingdom (UK) several static and kinematic tests were carried out in order to evaluate the accuracy, precision and availability of commercial NRTK service *SmartNet*. Centimetric accuracy was generally attained during both static and kinematic tests. Additionally, the influence of the number of satellites in view, dilution of precision (DOP) and age of corrections (AoC) over the accuracy and stability of the NRTK GPS solution was also investigated (Aponte et al., 2009).

Land Information New Zealand (LINZ) carried out a interesting study of accuracy and repeatability in several benchmarks, using a NRTK system. The tests shown that there is not a significant difference between the accuracy and the precision estimates. As expected, the vertical component is less accurate than the horizontal component. The accuracy of the horizontal component is typically between ±1-2cm and the vertical component between ±2-3cm (Nelson and Denys, 2008).

All these international studies were conducted according to different methodologies and mathematical models for calculation of the network correction. The size, the number of stations and the geometric configurations change significantly and, furthermore, some tests have been conducted with long time static survey.

In Italy many researches have been carried out to investigate the accuracy and the reliability of NRTK GNSS. Most of the researches were conducted using local CORS networks implemented and managed by regions. The results of positioning accuracy achieved in these tests is at the centimeter level. Further analysis have been carried out to evaluate time to fix ambiguities (TTFA), influence of the number of satellites, dilution of precision (PDOP, GDOP) (Biagi et al., 2006).

The University of Palermo, in order to carry out scientific tests on the use of CORS networks for real time positioning, have realized a network of reference stations called UNIPA NRTK GNSS (Dardanelli et al., 2008). The network was designed and built with eight CORS located in western Sicily with distance between 22 and 80 kilometres (Figure 1).

All reference stations are equipped with Topcon NET G-3 GPS and GLONASS enabled receivers. The network Control Centre (CC) was realized at the DIRAP of University of Palermo. The network is managed through the GNSMART software by Geo++ (Wubbena et alii, 2001) in order to produce the NRTK corrections (Figure 2). The RTCM 2.3 format message was used and Networked Transport of RTCM via Internet Protocol (NTRIP) was used to send the NRTK corrections.

Figure 1 – UNIPA CORS network

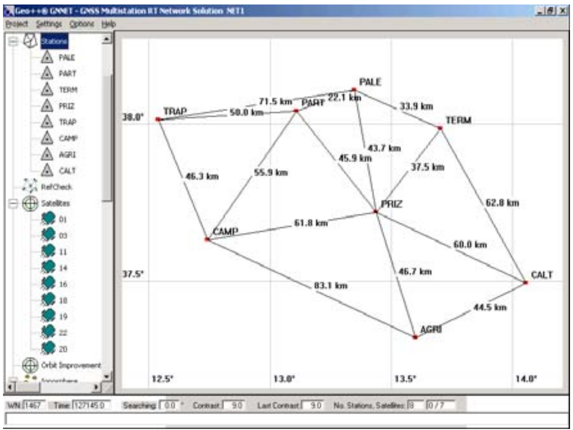

Figure 2 – GNSMART screenshot of UNIPA NRTK GNSS

The network provide access to

- the daily rinex data (30");
- hourly raw data (1");
- real-time GNSS data streams Code, Nearest Station, VRS and FKP.

The coordinates of the reference stations were established in IGS05 and ETRF89 (epoch 1989.0) system. Recently, two reference stations have been included and calculated in the Italian GPS dynamic permanent network called *Rete Dinamica Nazionale* (RDN). The aims of this network is monitoring the reference system possible variations. The RDN network was calculated in the reference system ETRF2000 at 2008.0 epoch. For this reason, the coordinates of the UNIPA network have been also recalculated in the system ETRF2000. All calculations were performed with the Bernese 5.0 software.

CASE STUDY

To assess the reliability and accuracy of the real time positioning several test areas have been chosen. Within the test areas many GPS reference marks have been identified. In this way it was possible to use GPS reference marks already materialize permanently, easily reachable and detectable without special arrangements. All GPS reference marks used had good-excellent sky visibility and therefore were suitable for GPS-GLONASS observations.
In test areas 75 GPS reference marks have been selected, including 15 of geodetic GPS italian network, called IGM95, and 60 of geodetic GPS local network. The design of the GPS reference marks is given in figure 3.

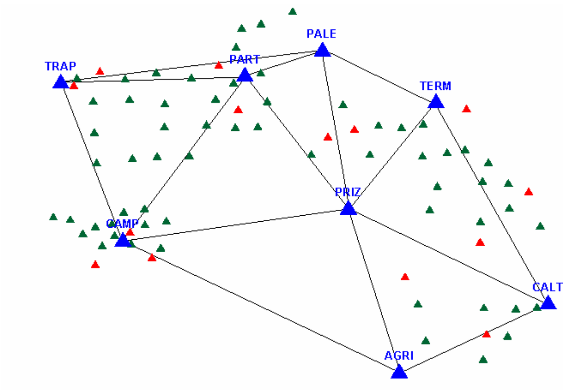

Figure 3 – Overview of GPS reference marks (red IGM95, green GPS local network)

TESTING PROCEDURE

From the 2008 to 2009 four surveys projects were carried out in order to evaluate the performance of the UNIPA NRTK GNSS. The coordinates of all GPS reference marks, available in the ETRF89 system (epoch 1989.0), were recalculated into IGS05 system through a static survey.
The static survey were performed using dual-frequency geodetic GNSS receivers Topcon Hiper-Pro and Topcon GR3, equipped with controller FC-100 and FC-200. The occupation time was about 60 minutes. The user receiver's configuration and setting was elevation mask

10 degrees, epoch/logging rate 15 second, maximum PDOP 6.
The post-processing solutions was carried out with Topcon Tools ver. 7.2, a commercial software managed by Topcon. Each GPS reference marks was measured with three baseline from the closer reference stations. The precision of all GPS reference marks coordinates in IGS05 is about few millimetres .
The survey was verified by recalculating the coordinates of the vertices in ETRF89 system and comparing the results with the official coordinates; the differences are in the same order of magnitude of the intrinsic accuracy of the geodetic network (Table 1).

	IGM95			GPS local network		
	E (m)	N (m)	H (m)	E (m)	N (m)	H (m)
st. dev	0.022	0.026	0.045	0.038	0.022	0.062

Table 1 – Comparison between official coordinates and static survey coordinates of GPS reference marks

The coordinates of the GPS reference marks calculated in the IGS05 system have been assumed as true value for all the following evaluations, in particular for accuracy evaluation of the NRTK solutions.

NRTK SURVEY

The NRTK survey has been carried out using a protocol developed in scientific application in Italy (Biagi et al., 2006).
This protocol provides:

1. measurements conducted from Monday to Friday, in typical working hours (8.00-18.00), no prior knowledge about geometric configuration of the satellite constellations or active stations online;
2. NRTK survey with geodetic tripod;
3. two separate sessions of survey at different times of the day, to obtain configurations of satellite constellations to each other as independent as possible;
4. one session for each network service (Nearest Station, VRS, FKP);
5. interval of data logging 1 second;
6. cut-off equal to 10°;
7. registration period at the 5th time in solution phase ambiguity fixed;
8. failed tests for which it is obtained fixed solution within 300 seconds from the connection to the network software (receiver float or even stand alone).

The NRTK measurements were performed using dual-frequency geodetic GNSS receivers Topcon Hiper-Pro with controller FC-100.
Overall 73 GPS reference marks have been measured in NRTK survey. Not for all the points was possible to calculate VRS and FKP solutions. Nearest Station solution has been also used for GPS reference marks distant less than about 20 km from the nearest reference station. Only 42 GPS reference marks have been measured in Nearest Station.
The analysis of results obtained in NRTK survey is discussed separately with regard to reliability (successful tests, failed initialization time, satellite configurations) and to the accuracy of measurements positioning.

RELIABILITY ANALYSIS

Reliability describes the probability of performing a certain function without failure under given conditions for a specified period of time. The tests were also carried out to verify any technical problems with regard the NRTK techniques. In order to evaluate the reliability of the network solutions generated by UNIPA NRTK GNSS, the concept of reliability was considered the probability that the operator can correctly determine its position within the CORS network, depending on the method of calculation used (VRS, FKP, Nearest Station). In GNSS applications it is very difficult to separate the contribution of all possible factors of failure (bad GDOP, no GSM and GPRS connections).

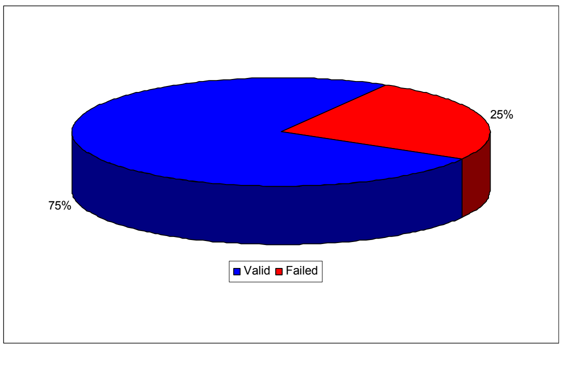

Figure 4 - Percentage of valid and failed tests

We have compared valid tests, in which it was obtained correction in Nearest Station or in VRS or in FKP, to failed tests, in which the receiver has not received the network correction. Overall 75% of the tests were valid while the 25% were failed (Figure 4).
The reliability was analyzed for every single mode of measurement. The failed tests were divided into tests with abortive results and negative tests. Abortive are test in which the receiver while properly connected to the CC not receive the network correction during the acquisition time established by the protocol (300 seconds); negative are tests in which it was not possible to operate the connection to the Internet provider.
The Nearest Station correction was achieved in 89% of GPS reference marks, the remaining 11% of the tests is abortive type (Figure 5).

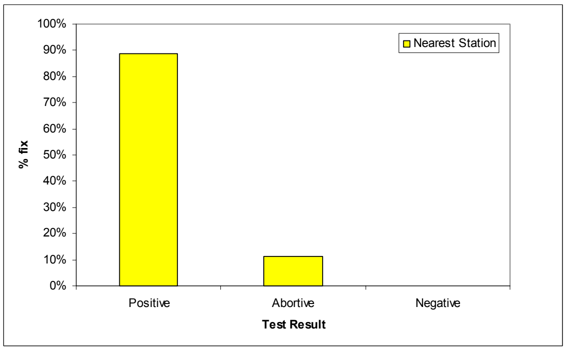

Figure 5 - Percentage of fixed solutions (Nearest Station)

For VRS survey the correction was obtained in 67% of tests, 22% are abortive type and the remaining 11% negative (Figure 6).
For FKP survey the correction was obtained in 53% of tests, 37% are abortive type and the remaining 10% negative (Figure 7).

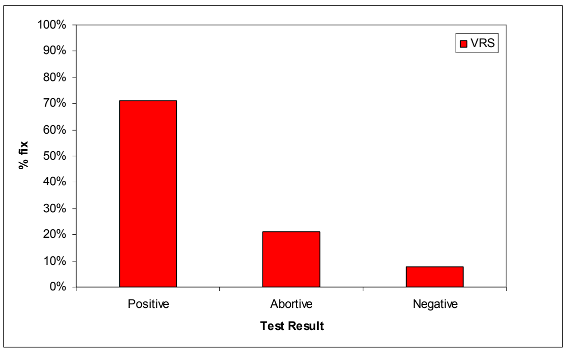

Figure 6- Percentage of fixed solutions (VRS)

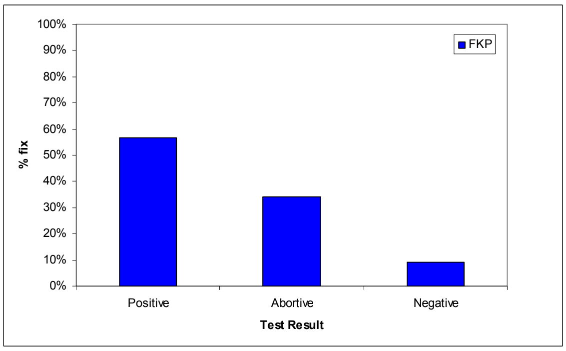

Figure 7- Percentage of fixed solutions (FKP)

The TTFA for NRTK survey was also measured to investigate the reliability of the three network correction. The VRS and Nearest Station have a high number of fixed in the first 60 second, more than 50%. Many FKP solution solve in the last range class (270-300 second) (Figure 8).

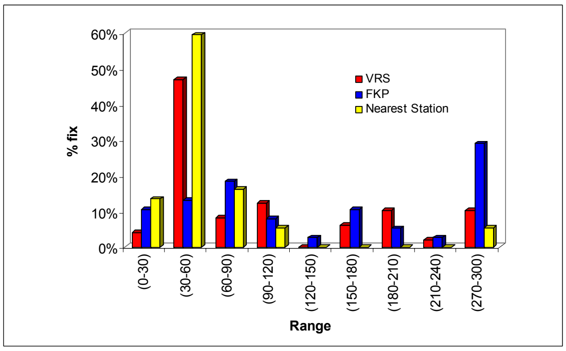

Figure 8 - Relationship between percentage of fixed solutions and TTFA

Further analysis can be done studying relationship by fixed solutions and number of satellites, PDOP, GDOP.

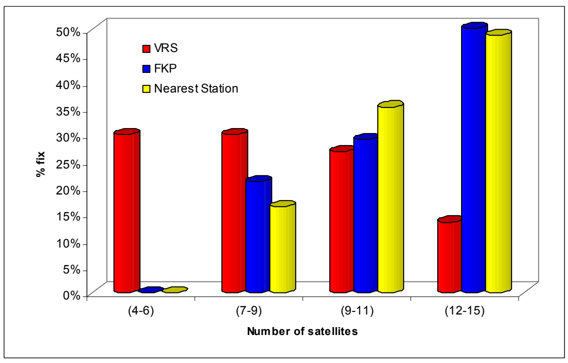

Figure 9 - Relationship between percentage of fixed solutions and number of satellites

The VRS have a high number of fixed solutions (60%) with a number of satellites within a range between 7-9. FKP and Nearest Station haven't fixed solution with less than 7 satellites; instead, they have higher percentage of fixed solution within a range of satellite between 12-15 (79% for FKP and 84% for Nearest Station) (Figure 9).

The comparison between fixed solution with PDOP show that in all cases more than 60% of the fixed solutions have been obtained with values in the range 1-2, about 30÷40% with values between 2 and 3, while a relatively small percentage (10%) with values between 3 and 4 only for VRS (Figure 10).

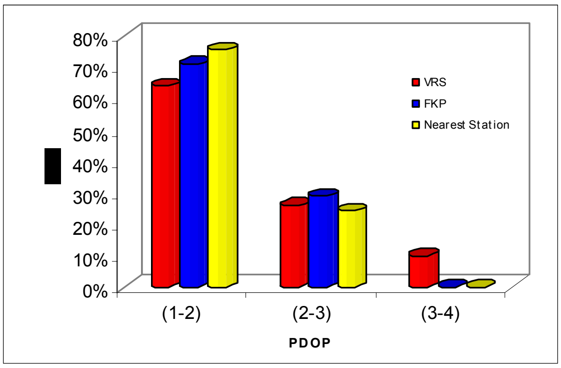

Figure 10 - Relationship between percentage of fixed solutions and PDOP

The comparison between fixed solution with GDOP show that in all cases about the 90% of the fixed solutions have been obtained with values in the range 1-3. All fixed solutions have been obtained with values of less than 6 (Figure 11).

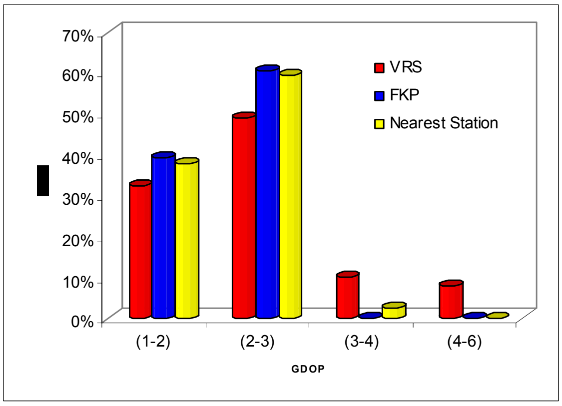

Figure 11 - Relationship between percentage of fixed solutions and GDOP

ACCURACY ANALYSIS

Accuracy can be defined as how far the coordinates calculated during testing are from the true values (Feng and Wang 2007). As mentioned previously the coordinates of the GPS reference marks calculated during the static survey were considered as true values for all accuracy check. This procedure was adopted because when assessing the accuracy of test data by using field data, the control data must be measured with an accuracy of at least an order of magnitude higher than that of the test data (Gordini et al., 2006). The choice of using the coordinates of the GPS reference marks calculated by a static survey allow also the checks in the same reference system embodied by the network of CORS (IGS05).

Accuracy analysis was conducted by considering separately each coordinate component East, North, and Height, calculated in static survey compared to those in NRTK. The comparison was performed separately for VRS, FKP and Nearest Station.

The accuracy of every NRTK GNSS solution was determined as the standard deviation of the difference between static and NRTK coordinates for all measured points.

As can be seen in table 2 VRS accuracy is ±4.7 cm, ±2.7 cm and ±13.0 respectively for East, North and Height; FKP accuracy is ±4.6 cm, ±2.6 cm and ±13.1 cm respectively for East, North and Height; Nearest Station accuracy is ±3.2 cm, ±2.3 cm and ±14.3 cm., respectively for East, North and Height.

There is not a significant difference between the accuracy of East and North component for different correction (VRS, FKP, Nearest Station).

	VRS			FKP			Nearest Station		
	E (m)	N (m)	H (m)	E (m)	N (m)	H (m)	E (m)	N (m)	H (m)
min	-0.190	-0.110	-0.331	-0.118	-0.036	-0.358	-0.053	-0.041	-0.319
max	0.148	0.093	0.259	0.121	0.060	0.210	0.149	0.090	0.293
mean	0.006	0.002	-0.012	0.013	0.006	-0.011	0.012	0.005	-0.025
st. dev	0.047	0.027	0.130	0.046	0.026	0.131	0.032	0.023	0.143

Table 2 - Statistical terms for the East, North and Height

As expected, accuracy of East and North component was with values between few centimetre (2-5 cm), in the same order of magnitude of national and international studies. The Height have very low value of accuracy for this type of applications. The

Height is the most difficult component in the GNSS positioning. It is difficult to determine exactly the causes of this low accuracy but more investigations are required for this.
Additionally, it was conducted another analysis on the accuracy with regard only to the GPS reference marks where we have obtained all the three corrections (VRS, FKP, Nearest Station) in the same session of survey. Comparing the coordinates from static survey we have been obtained the following results: VRS ±1.7 cm, ±1.6 cm and ±15.7 respectively for East, North and Height; FKP ±2.7 cm, ±2.1 cm and ±15.90 cm respectively for East, North and Height; Nearest Station ±3.1 cm, ±2.1 cm and ±15.8 cm., respectively for East, North and Height (Table 3).

	VRS			FKP			Nearest Station		
	E (m)	N (m)	H (m)	E (m)	N (m)	H (m)	E (m)	N (m)	H (m)
min	-0.026	-0.015	-0.331	-0.034	-0.029	-0.358	-0.053	-0.041	-0.319
max	0.024	0.038	0.259	0.052	0.044	0.210	0.051	0.032	0.293
mean	0.008	0.005	-0.016	0.011	-0.003	-0.019	0.013	0.001	0.005
st. dev	0.017	0.016	0.157	0.027	0.021	0.159	0.031	0.021	0.158

Table 3 - Statistical terms for the East, North and Height in GPS reference marks where we have obtained all the three corrections

CONCLUSION

The research has shown good reliability of the network CORS; overall 75% of tests were valid while 25% of the tests are considered failed. In particular, Nearest Station solution (89%) is more reliability than VRS (67%) and FKP (53%).
TTFA for NRTK survey have a higher number of fixed solutions within the first 60 second, but only for FKP fixed solutions could be resolved also some minutes.
The VRS solution has been obtained in 60% of the tests with a low number of satellites; FKP and Nearest Station correction, instead, need a high number of satellites.
Furthermore, by comparing the percentage of fixed solutions with the PDOP, more than 60% of the solutions have been obtained with values in the range 1-2, 30%-40% with values between 2 and 3.
Most of the fixed solutions have been obtained with values of GDOP in a range between 1–3.
As expected, accuracy of the East and North coordinates is about some centimeter; this values is in the same order of magnitude of national and international studies. Only for the Height coordinate we have been obtained less accurate results. However, further analysis have to be carried out to investigate this problem and to test other methods of network solutions (Master Auxiliary Concepts - MAC).

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