*Contribution to Conference Proceedings of POSITIONs 2008, Dresden 7.-9.10.2008*

# Does GNSS outperform GPS in Geodetic Applications?

Asim Bilajbegović, Prof. Dr.-Ing. [1],
Rüdiger Lehmann, Prof. Dr.-Ing. [2]
[1,2]*University of Applied Sciences Dresden*
[1] *bilajbegovic@htw-dresden.de* [2]*r.lehmann@htw-dresden.de*

**Summary**

In the decision-making process, what kind of GPS equipment to purchase, one faces the dilemma, to take either GNSS (=GPS+GLONASS) or GPS receivers only. In the case of the full completeness of the GLONASS satellite system, this dilemma would certainly not exist. The solution to this dilemma is given for a constellation of 14 operational GLONASS satellites. Due to the short operational period of these satellites (for example GLONASS-M only 5 years), and not launching new ones, in this moment (July 2008), there are only 16 satellites operational. In our research work we used about 252 RTK measurements obtained with both GPS only and GNSS receivers. We will show how the answer to the dilemma depends on the obstruction of horizon at the station. Besides that, the initialisation time of both systems has been investigated on the basis of about 480 measurements, using rover's antenna with metal cover, during intervals of 0, 5, 2 and 5 seconds. Finally, the accuracy has been investigated and compared to the accuracy and redundancy of GPS and GNSS RTK measurements given by the manufacturer.

## 1 Introduction

The Tables 1 and 2 show the simplest interpretation and overview of the nowadays and futures developing satellite positioning systems.

Table 1: The overview of the GPS satellites and theirs signals, by Reaser (2006)

| Satellite block | Signal | | | | | | | | Year of launching or planned launching |
|---|---|---|---|---|---|---|---|---|---|
| | L1 C/A | L1 P(Y) | L1 M | L1C | L2 P(Y) | L2C | L2 M | L5 | |
| IIR | ✓ | ✓ | ✓ | | | | | | 1978 - 2005 |
| IIR-M | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | Sept 2005<br>1th satellite |
| IIF | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | March 2008 |
| IIIA | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | Jun 2013 |

Table 2: Overview of GLONASS satellites and signals used, by Dvorkin et al (2006)

| Satellite | Signal / frequency | | | Average of satellite's life span | Year of launching the first satellite | Total number of satellites | |
|---|---|---|---|---|---|---|---|
| | L1 | L2 | L3 | | | 1993 | 12 |
| GLONASS | ✓ | ✓ | | 2 years | 1983 | 1995 | 26 |
| GLONASS-M | ✓ | ✓ | | 5 years | Middle of 2003 | 2001 | 7 |
| GLONASS-K | ✓ | ✓ | ✓ | 7 years | Planned for the middle of 2008 | 2006 | 14 |
| | | | | | | March 2007 | 10 |
| | | | | | | Planned 2007 | 18 |
| | | | | | | Planned 2009 | Full constellation 24 |

Both Tables clearly show the planned modernisations and transitions from two to three carriers for both systems. Three frequencies will improve accuracy, reliability and initialization time of the rover.

For getting the information of the accuracy, the precision and the economy of the modern GPS and GNSS (GPS+GLONASS) receivers, it was necessary to take a right method of measuring, the testing network, the mono and hybrid satellite receivers. Since 1994, the RTK method of measuring has been developing. After the SAPOS network of the permanent stations has been established in Germany, in about 95% of the cases RTK method is used in practice. In geodetic applications, the highly precise real time positioning service (HEPS) is favoured. Therefore, for this investigation, the RTK method has been used throughout. The testing network of the University of Applied Sciences Dresden has been used. This network is situated in the flood planes of the river Elbe in the centre of Dresden, Fig.1. The horizontal uncertainty of the points in the test network is $\sigma_L = 10\,mm$, and for the heights $\sigma_h = 5\,mm$

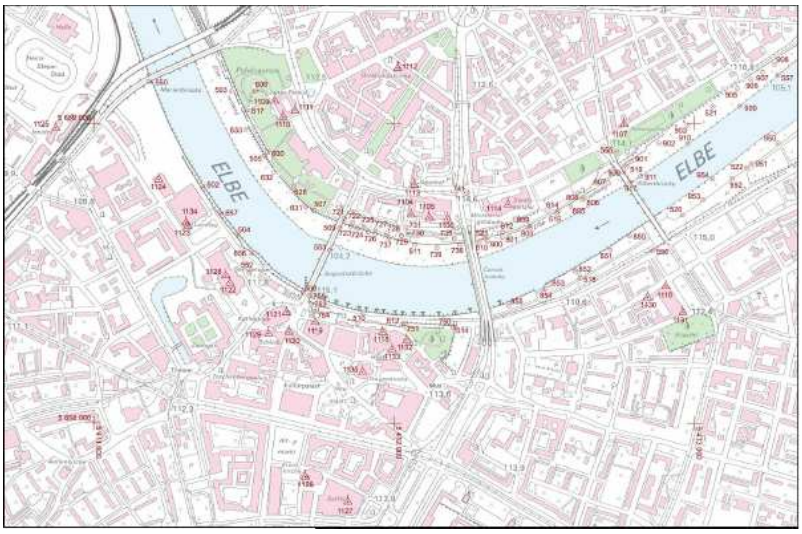


Fig. 1: Test network of the University of Applied Sciences Dresden

Trimble R8 GPS and R8 GNSS receivers were used. During field test measurements, the need for the new construction solution occurred, which would enable transport of two receivers by one person, Fig. 2, 3 and 6. Primarily due to the influence of the ionosphere, troposphere and identical constellation of satellites, measuring had to be carried out consecutively in time. Therefore, one carrier pole was used for both antennas, for both receivers and for the two portable field computers ACU(Advanced Control Unit), Fig. 2, 3 and 6.

Fig. 2: Transport over short distances

Fig. 3: Transport over longer distances

In the German federal state of Saxony, permanent stations are not equipped with GNSS receivers. Therefore, our own permanent station was used. During this investigation the corrections were transmitted by our own radio transmitter and using GPRS via NTRIP protocol and RTCM 3.0 format.

## 2 Short description of the equipment

The modern Trimble R8 GPS and R8 GNSS receivers were used in this investigation. Trimble R8 GPS is a dual-frequency, 24 channels GPS receiver, with integrated GPS antenna and 450 MHz radio-transmitter, Fig. 4. This system enables recording satellite signals at low elevations. It enables completely wireless Bluetooth®-communications between the receiver and the control unit (ACU). Besides phase observations on L1 und L2 carriers, code on C/A on the L1 carrier, P-code on L1 and L2 carriers, using this technology L2C signal can also be recorded. (The first satellite with L2C signal was launch on September 25, 2005).

Fig. 4: Trimble R8 GPS-receiver

Fig. 5: Trimble R8 GNSS-receiver

Maximal distance of the transmitting RTK-correction from base station, in accordance with firmware declaration, is 3-5 km by a transmitter power of 0.5 W. This investigation showed problems at much shorter distances of 1.6 km. All Trimble receivers can be used as rover as well as base station. The initialisation time of the rover is 10 seconds + 0.5 seconds/km for distances up to 30 km.

The Trimble® R8 GNSS-receiver is a multi-channel and multi-frequencies GNSS-system. The number of channel is 72, which enable recording L1 C/A-code, P-code on L1 and L2 carriers, L2C code, phase measurements on L1, L2 and L5 carriers, and recording GLONASS signals as well, Fig. 5. A new RTK-engine (Trimble Maxwell TM Custom Survey GNSS-chip) enables very fast initialization of the rover. According to firmware declarations, an initialisation takes less than 10 seconds. In the chapter 5, these times were investigated more closely.

### 3 Test networks and the analysis of the measurements

The test network of University of Applied Sciences Dresden was used for this investigation. Horizontal position and height accuracy of the network is better than 10 and 5 mm, respectively. The network consists of 38 points with no or low obstructions of the horizon, 48 points with medium obstructions up to 35% and 40 points show high obstructions of the horizon above 35%. The measurements have been done in two sessions using each rover, Table 3, 4, 5 and 6. For the elimination of outliers, it was necessary to define tolerances for the differences between observed coordinates and known coordinates of the test network.

The rover's antenna height was only 1.794 m, for the reason of the fast changes of GPS and GNSS receivers during measuring at each point, Fig. 6. Sensitivity of the circular level on the carrying pole is 8' for 2 mm of bulb shift, what introduces a centring error of 4.2 mm in the horizontal plane and only a negligible error in the antenna height.
On the base of the mentioned errors in the uncertainty of the coordinates of the test network, the horizontal (10mm+1mm/km) and the vertical (20mm+1mm/km) uncertainty, specified by manufacturer, maximal distance between rover and base station of the 3.6 km, and propagation of the errors, the expected standard deviations along side x and y axis and heights results as follows:

$$\sigma_{x,y} = \sqrt{7^2 + 4.2^2 + 9.62^2} = 12.6\ mm \quad \text{and} \quad \sigma_h = \sqrt{5^2 + 0^2 + 23.6^2} = 24.1\ mm, \qquad (1)$$

For a probability of 99% and $\chi^2 - distribution$ adequate tolerance deviations are:

$$\Delta_{x,y} = \sqrt{6.63} \cdot 12.6 = 32.4\ mm; \quad \Delta_h = \sqrt{6.63} \cdot 24.1 = 62.1\ mm \quad \Delta_L = \sqrt{2 \cdot 32.4^2} = 45.8\ mm.$$

These tolerance values were used for filtering outliers.

Table 3: List of the results for the points, without or with low obstructions of the horizon; in the two sessions, 76 attempts of measuring using each receiver

| Receiver R8 | Number of the measurements with standard deviation within tolerance | | Number of the unsuccessful measurements | | Number of the measurements with standard deviations out of the tolerance | | Sum of the advantage of R8 GNSS |
|---|---|---|---|---|---|---|---|
| GNSS | 72 | 94.74% | 2 | 2.63% | 2 | 2.63% | |
| GPS | 67 | 88.16% | 1 | 1.32% | 8 | 10.53% | |
| Advantage of GNSS R8 in the percents with sign + | +6.58% | | -1.31% | | +7.90% | | +13.17% |

Table 4: List of the results for the points, with medium obstructions of the horizon; in two sessions, 96 attempts of the measuring using each receiver

| Receiver R8 | Number of the measurements with standard deviation within tolerance | | Number of the unsuccessful measurements | | Number of the measurements with standard deviations out of the tolerance | | Sum of the advantage of R8 GNSS |
|---|---|---|---|---|---|---|---|
| GNSS | 85 | 88.54% | 0 | 0.00% | 11 | 11.46% | |
| GPS | 78 | 81.25% | 0 | 0.00% | 18 | 18.75% | |
| Advantage of GNSS R8 in the percents with sign + | +7.29% | | 0.00% | | +7.29% | | +14.58% |

Table 5: List of the results for the points, with high obstructions of the horizon; in two sessions, 80 attempts for the measuring using each receiver

| Receiver R8 | Number of the measurements with standard deviation within tolerance | | Number of the unsuccessful measurements | | Number of the measurements with standard deviations out of the tolerance | | Sum of the advantage of R8 GNSS |
|---|---|---|---|---|---|---|---|
| GNSS | 20 | 25.00% | 35 | 43.75% | 25 | 31.25% | |
| GPS | 15 | 18.75% | 43 | 53.76% | 22 | 27.50% | |
| Advantage of GNSS R8 in the percents with sign + | +6.25% | | +10.10% | | -3.75% | | +12.51% |

Table 6: Recapitulation of the all measurements carried out (points with low, medium and high obstructions of the horizon); in two sessions 252 attempts the measuring using each receiver

| Receiver R8 | Number of the measurements with standard deviation within the tolerance | | Number of the unsuccessful measurements | | Number of the measurements with standard deviations out of the tolerance | | Sum of the advantage of R8 GNSS |
|---|---|---|---|---|---|---|---|
| GNSS | 177 | 70.34% | 37 | 14.68% | 38 | 15.08% | |
| GPS | 160 | 63.49% | 44 | 17.46% | 48 | 19.05% | |
| Advantage of GNSS R8 in the percents with sign + | +6.75% | | +2.78% | | +3.97% | | +13.50% |

Table 3, 4, 5 and 6 are reporting by themselves, and no comments required. The advantage is obvious in the redundancy of the hybrid R8 GNSS-receivers, for the all kind of the obstructions of the horizon. It makes up 13.5%, shown in the last column of the Table 6.

After eliminating the measurements with outliers, standard deviations of the single measurements calculated, depending on rate of the obstruction of the horizon, alongside of the coordinate axis x, y, h, as well as, in the horizontal plane and in the heights, Table 7.

Table 7: Standard deviations of a single measurement, depending on the rating of the obstruction of the horizon.

| | Standard deviations for R8 GNSS | | | | Standard deviations for R8 GPS | | | |
|---|---|---|---|---|---|---|---|---|
| Obstructions of the horizon | y [mm] | x [mm] | heights [mm] | horizontal plane [mm] | y [mm] | x [mm] | heights [mm] | horizontal plane [mm] |
| low | 11.98 | 10.78 | 33.09 | 16.11 | 12.16 | 13.01 | 32.83 | 17.81 |
| medium | 11.66 | 10.95 | 30.16 | 16.00 | 11.37 | 13.44 | 29.46 | 17.61 |
| high | 12.61 | 10.62 | 35.04 | 16.49 | 12.89 | 12.74 | 35.57 | 18.19 |

From Table 7, one can see the advantage in the horizontal position accuracy of the coordinates stated by the R8 GNSS-rover for all cases of the horizon obstructions. The same statements can be made for the accuracy of determining the heights. It is important to note that all measurements were testing for normal distributions.

Fig. 6: Pole with both rovers, both ACUs and the transporting bike.

## 4 Investigations of the accuracy declared by manufacturer

The task was to investigate the accuracy declared by the manufacturer, for the horizontal-positional and height precision (accuracy) as the function of distance between the rover and base station, (10mm+1ppm and 20mm+1ppm). As the longest distance between rover and base station was 3.6 km it follows, that achieved positional-horizontal precision should be 13.6 mm and standard deviation for the heights should be 23.6mm. Standard deviations from Table 7 calculated from the residuals of the known coordinate of the known points and the point's coordinates determinded by RTK measurements. It means, these standard deviations are biased by errors of the coordinates of known points. They totalize, for the horizontal plane 10 mm, alongside axis x and y up to 7 mm, and for heights (levelling) 5 mm. Using Table 7 achieved precision of measurements can be evaluated by following formulas:

$$s_L^p = \sqrt{(s_L^n)^2 - 10^2} \quad i \quad s_h^p = \sqrt{(s_h^n)^2 - 5^2}\,, \tag{2}$$

where

$s_L^n$ - Standard deviation in horizontal plane, Table 7

$s_L^p$ - Positional horizontal precision, Table 8

$s_h^n$ - Standard deviation of the height, Table 7, and

$s_h^p$ - Precision of measuring height, Table 9.

Table 8: Test of the horizontal positional precision in accordance to manufacturer declaration

| | Positional horizontal precision in accordance manufacturer declaration 13,6 mm | | | | | |
|---|---|---|---|---|---|---|
| | R8 GNSS | | | R8 GPS | | |
| obstruction of the horizon | $s_L^p$ u [mm] | Testing value | Significant limits of the testing value | $s_L^p$ u [mm] | Testing value | Significant limits of the testing value |
| low | 12.64 | 60.97 | 91.17 | 14.74 | 77.53 | 85.51 |
| medium | 12.50 | 70.96 | 105.89 | 14.50 | 87.53 | 97.96 |
| high | 13.11 | 17.66 | 36.68 | 15.19 | 17.46 | 29.12 |

Table 9: Test of the precision of the height in accordance to manufacturer declaration

| | Precision of the height in accordance to manufacturer declaration 23,6 mm | | | | | |
|---|---|---|---|---|---|---|
| | R8 GNSS | | | R8 GPS | | |
| obstruction of the horizon | $s_h^p$ u [mm] | Testing value $\bar{\chi}^2$ | Significant limits of the testing value | $s_h^p$ u [mm] | Testing value $\bar{\chi}^2$ | Significant limits of the testing value |
| low | 32.71 | 136.39 | 91.17 | 32.44 | 124.70 | 85.51 |
| medium | 29.75 | 133.48 | 105.89 | 29.03 | 116.51 | 97.96 |
| high | 34.68 | 41.03 | 36.68 | 35.21 | 31.16 | 29.12 |

The test of the standard deviation was implemented as follows: The Null hypothesis is

$$H_0 : \quad s = \sigma_0 ,$$

$$\text{Testing value} \quad \bar{\chi}^2 = \frac{k \cdot s^2}{\sigma_0^2} ,$$

Where:

k=n-1: redundant number of the measurements,

s: empirical standard deviation, and

$\sigma$: standard deviation by the manufacturer specification.

The significant limit of testing value $\chi^2$ can be taken from the table for $\chi^2 - distribution$, for the probability of 99% and variable number of degrees of freedom *k*, Tables 8 and 9.

If the $\overline{\chi}^2 < \chi^2$ then the null hypotheses is acceptable.

From Table 8 one can see, that both receivers fulfilling declared horizontal positional precision. On the contrary, the declarer precision of the determining the heights was not reached by any receiver, Tab. 9. This can be partially explained by different influence of the multipath-effects for the different antenna type used during the determination of the coordinates of the test network, Bilajbegović et al (2007), Wanninger et al (2006). Position precision, obtained by GNSS receiver is, in average, for 2 mm better (or 14%), but, the precision of the determination of the heights is worse by 0.3-0.7 mm (or 0.9-2.2%).

## 5 Investigation of the initialisation time of the receivers

With a view to the investigation of the receiver's initialisation time a reference station was placed at a distance of about 100 m from rover. The rover's antennas were separated by about 2 m and were covered by metal cover, for the period of 0.5, 2 and 5 seconds, Fig. 7. The measuring were implemented successively, one after another one, for both receivers. 80 measurements were taken, using both systems, and for each period of covering of the antenna, or in total, 480 measurements. The initialisation measurements were carried out at two days. For the sake of the elimination of the eventual outliers, the coordinates of the rovers were determined from 1000 measurements during the first day, but, from the 4000 measurements during second day. The recorded measurements enabled to readout the lost initialisation time-intervals and re-initialisation time-intervals of the receivers. Analysing the resulting measurements, it was possible to identify two intervals of the initialisation, as follows: after lost of the initialisation due to the high standard deviations and interval time of the initialisation after lost of initialisation in consequence of covering antenna.

Selected investigating results are displayed in the Table 10.

Fig.7: Investigation of the initialisation times of the receivers

Table10: Overview of the intervals of the initialisations of the rover receiver

| | R8 GNSS [seconds] | Declared time-interval of the initialisations | R8 GPS [seconds] | Declared time-interval of the initialisation |
|---|---|---|---|---|
| Time-interval after the initialisation lost because of high standard deviations | 13.9 | < 10 s | 24.0 | 10 s |
| Time-interval after the initialisation lost because (antenna covering) | 8.0 | < 10 s | 25.2 | 10 s |
| Generally, average time-interval of the initialisation | 8.2 | < 10 s | 25.2 | 10 s |
| Time –interval after covering antenna for the about 0,5 seconds | 5.2 | < 10 s | 21.7 | 10 s |
| Time–interval after covering antenna for the about 2 seconds | 6.9 | < 10 s | 24.5 | 10 s |
| Time–interval after covering antenna for the about 5 seconds | 12.5 | < 10 s | 27.6 | 10 s |

Manufacturer's declaration for the time-intervals of the initialisation for the R8 GNSS is <10 seconds, but for the R8 GPS receivers 10 s +0,5 s/km (up to 30 km distances from the reference station). Obviously, in accordance to the Table 10, the time-interval of the initialisation is a function of lasting of covering of the antenna, and it is shorter for shorter time of covering antenna. Beside of that, average time of the initialisation of the R8 GNSS-receiver is shorter, an in the average, is tree times shorter relative to R8 GPS-receiver, and is even shorter than declared manufacturer time. Time-interval of the initialisation for R8 GPS-receiver is longer for about 2,5 times than manufacturer declared time.

## 6 Conclusions

The investigation described in this paper shows that for the constellation of 14 GLONASS satellites:

- Hybrid R8 GNSS-receiver are more reliable relating to R8 GPS, for the measurements on the points with the horizon obstructions: low, medium and high ones, expressed in percents, it is better by 13% ,

- The horizontal positional standard deviation is better by about 14% than for R8 GPS-receiver,
- The accuracy for the heights is the same as for R8 GPS,
- The initialisation time-interval is 2.5 times shorter than for R8 GPS,
- The initialisation time-interval is a little shorter than in the manufacturer's specification,
- The both systems R8 (GNSS and GPS) yield horizontal precision specified but not for the heights,
- Receiver R8 GPS has almost 2.5 times longer initialisation time relating to manufacturer's specification,
- Using the hybrid system R8 GNSS one can determine about 70% points in the cities area, whereas, by the receiver R8 GPS about 63% points.

It's worth noting that all statements above are valid for a constellation of 29 GPS and 14 GLONASS satellites and for the area of the test network of University of Applied Sciences in Dresden. It varies depending on the number of available satellites and measurement location.

## 7 References

Bilajbegović, A., Vierus, M. (2007): Untersuchung der Multipath-Effekte verschiedener GPS-Antennentypen und ihrer Einflüsse auf die Genauigkeit der Koordinatenbestimmung. Allgemeine Vermessungsnachrichten 1/2007, pp. 9-18.

Dvorkin, V., Karutin, S. (2006): GLONASS: Current status and perspectives. Allsat open conference, Hannover, 22.06.2006

Reaser, C. R. (2006): Navstar Global Positioning System. Allsat open Conference, Hannover, 22.06.2006

Wanninger, L., Rost, Ch., Hartlieb, G., Köhr, M. (2006): Zur Problematik des Antennenwechsels auf GNSS-Referenzstationen. Zeitschrift für Vermessungswesen 4/2006, pp. 171-175.