Advantages of Hybrid Global Navigation Satellite Systems

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Abstract: *In a decision-making situation, what kind of GPS equipment to purchase, one always has a dilemma, to buy hybrid (GPS+GLONASS) or only GPS receivers? In the case of completeness of the GLONASS satellite system, this dilemma probably would not have existed. The answer to this dilemma is given in the present paper, but for the constellation of the GLONASS satellites in summer 2006 (14 satellites operational). Due to the short operational period of these satellites (for example GLONASS-M), 5 years, and not launching new ones, at this moment (February 25, 2007), only 10 satellites are operational. For the sake of research and giving answers to these questions, about 252 RTK measurements have been done using (GPS) and GNSS receivers, on points with different obstructions of horizon. Besides that, initialisation time has been investigated for both systems from about 480 measurements, using rover's antenna with metal cover, during a time interval of 0.5, 2 and 5 seconds. Moreover, accuracy, firmware declared accuracy and redundancy of GPS and GNSS RTK measurements have been investigating.*

Key words: *GPS, GLONAAS, GNSS hybrid receivers*

1 Introduction

Tables 1 and 2 show the simplest interpretation and overview of today's and future's developing satellite positioning systems.

One can see from Tables 1 and 2 the planned modernisation and transitions from two to three carriers of both systems. Three frequencies will improve accuracy, reliability and initialization time of the rover.

In order to get the information of the accuracy, the precision and the economy of the modern GPS and GNSS (GPS+GLONASS) receivers, it was necessary to chose the right measuring method, the testing network, the mono and hybrid satellite receivers. The RTK method of measuring has been developed since 1994. After SAPOS network of the permanent stations was established (in Germany), the RTK method is used in practice in about 95% cases (in other words, since networking the permanent stations which means the highly precise real-time positioning service – HEPS). Therefore, for this research, RTK method has been chosen. Testing network of the University of Applied Sciences Dresden was used. This network ranged along the shore of the river

Prednosti hibridnih globalnih navigacijskih satelitskih sustava

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Sažetak: *Prilikom kupovine GPS opreme pojavljuje se dvojba: nabaviti li hibridne (GPS+GLONASS) ili samo GPS prijamnike? U slučaju potpune izgradnje satelitskog sustava GLONASS, ta se dvojba vjerojatno ne bi ni pojavljala. U ovom radu dan je odgovor na to pitanje, za konstelaciju GLONASS satelita u ljeto 2006. (14 operativnih satelita). Zbog kratkog operativnog trajanja tih satelita (npr. GLONASS-M) od 5 godina i nelansiranja novih, trenutačno (25. 2. 2007.) operativno je samo 10 satelita. U svrhu istraživanja i odgovora na postavljena pitanja obavljeno je oko 252 RTK mjerenja sa GPS i GNSS prijamnicima, na točkama s različitim stupnjevima zakloljenosti horizonta. Osim toga, ispitivano je i vrijeme inicijaliziranja obaju sustava iz oko 480 mjerenja pri prekrivanju antena rovera metalnim poklopcem, a u trajanju od 0,5, 2 i 5 sekundi. Nadalje, ispitivana je točnost, tvornička deklarirana točnost i pouzdanost GPS i GNSS RTK mjerenja.*

Ključne riječi: *GPS, GLONASS, GNSS hibridni prijamnici*

1. Uvod

Kratki pregled dosadašnjeg i budućeg razvoja satelitskih pozicijskih sustava najjednostavnije je prikazati u obliku tablica (tablica 1 i 2).

Iz tablica 1 i 2 vidi se planirana modernizacija i prelazak s dvije na tri noseće frekvencije obaju sustava. Tri frekvencije povećat će točnost i pouzdanost te skratiti vrijeme inicijaliziranja rovera.

Radi dobivanja informacija o točnosti, preciznosti i ekonomičnosti modernih GPS i GNSS (GPS+GLONASS) prijamnika, trebalo je izabrati metodu mjerenja, testnu mrežu, mono satelitske i hibridne satelitske prijamnike. Od 1994. god. RTK metoda mjerenja u stalnom je razvoju. Uspostavom SAPOS mreže permanentnih stanica (u Njemačkoj) u geodetskoj praksi u oko 95% slučajeva koristi se RTK odnosno, nakon umrežavanja permanentnih stanica, visokoprecizni pozicijski servis u realnom vremenu (HEPS). Zbog toga je za istraživanja izabrana RTK metoda mjerenja. Primijenjena je testna mreža Hochschule für Technik und Wirtschaft u Dresdenu, koja se proteže uzduž obala rijeke Labe u središtu

Table 1. Overview of GPS satellites and their signals, by Reaser (2006)

Tablica 1. Pregled vrsta GPS-satelita i korištenih signala, prema (Reaser 2006)

Satellite block Satelit tzv. blok	**Signal** **Signal**								Year of lunching or planned lunching of satellite Godina lansiranog ili planiranog lans. satelita
	L1 C/A	L1 P(Y)	L1 M	L1C	L2 P(Y)	L2C	L2 M	L5	
IIR	✓	✓	✓						1978-2005 1978.-2005.
IIR-M	✓	✓	✓	✓	✓	✓			September 2005 1st satellite u rujnu 2005. 1. satelit
IIF	✓	✓	✓	✓	✓	✓	✓		March 2008 u ožujku 2008.
IIIA	✓	✓	✓	✓	✓	✓	✓	✓	June 2013 u lipnju 2013.

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

Tablica 2. Pregled vrsta GLONASS-satelita i korištenih signala, prema (Dvorkin i dr. 2006)

Satellite Satelit	Signal / frequency Signal odn. frekvencija			Satellites average operational time Prosječno operativno vrijeme satelita	Year of launching the first satellites Godina lansiranja prvih satelita	Total number of satellites Ukupan broj satelita	
	L1	L2	L3			1993 1993.	12 12
GLONASS	✓	✓		2 years 2 god.	1983 1983.	1995 1995.	26 26
GLONASS-M	✓	✓		5 years 5 god.	Middle of 2003 sredina 2003.	2001 2001.	7 7
GLONASS-K	✓	✓	✓	7 years 7 god.	Planned for the middle of 2008 planirano sredinom 2008.	2006 2006.	14 14
						March 2007 ožujak 2007.	10 10
						Planned 2007 planirano 2007	18 18
						Planned 2009 planirano 2009.	Full constellation 24 24 – puna konstelacija

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.

Trimble R8 GPS and R8 GNSS receivers were used. During field test measuring, the need for the new construction solution occurred, which would enable transport of two receivers by one person, Fig. 2, 3 and 6. Primarily because of influence of the Ionosphere, Troposphere and the same constellations of satellite, measuring had to be carried out directly one after another. For the sake of that, one carrier (stick) of the antennas was used for both receivers and for the two portable field computers ACU-(Advanced Control Unit), Fig. 2, 3 and 6.

Since Sachsen does not have GNSS receivers on permanent stations, our own permanent station was used. The corrections were transmitted during this investigation by own radio transmitter and using GPRS, in other words NTRIP protocol and RTCM 3.0 format.

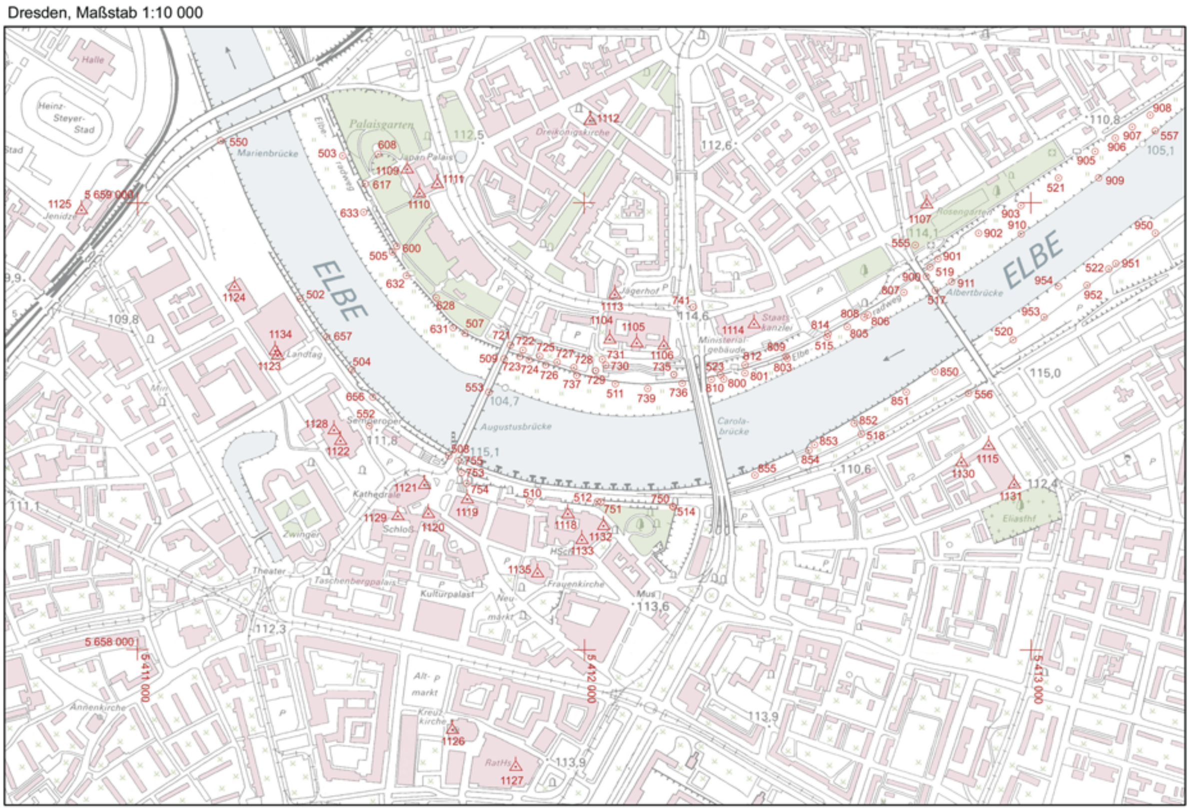


Fig. 1. Test network of the University of Applied Sciences Dresden
Sl. 1. Testna mreža Hochschule für Technik und Wirtschaft u Dresdenu

Dresdena (sl. 1). Horizontalna nesigurnost točaka testne mreže iznosi σ_L = 10 mm, a visinska σ_h = 10 mm.

Odabrani su testni prijamnici R8 GPS i R8 GNSS tvrtke Trimble. Kako bi bili ekonomični, pri izvođenju terenskih mjerenja trebalo je konstrukcijski riješiti mogućnost da mjerenja i transport dvaju prijamnika obavlja jedna osoba (sl. 2, 3 i 6). Ponajprije, zbog utjecaja ionosfere, troposfere i iste konstelacije satelita mjerenja su se morala obaviti neposredno jedno nakon drugoga. U tu svrhu korišten je jedan nosač (štap) antena za oba prijamnika i dva terenska računala ACU (Advanced Control Unit), sl. 2, 3 i 6.

Kako Saska nema GNSS prijamnike na referentnim stanicama, morali smo koristiti vlastitu permanentnu stanicu. Obavljena su ispitivanja odašiljanjem korekcija vlastitim radioodašiljačima i koristeći GPRS, odnosno protokol NTRIP i format RTCM 3.0.

2. Kratak opis opreme

Za istraživanja u ovom radu korišteni su moderni prijamnici Trimble R8 GPS i R8 GNSS. Trimble R8 GPS (sl. 4) je dvofrekvencijski GPS prijamnik s 24 kanala, s integriranom GPS antenom i radioodašiljačem od 450 MHz. Taj sustav omogućuje mjerenja satelitskih signala s malim elevacijskim kutevima. Pruža kompletnu beskabelnu bluetooth®-komunikaciju između prijamnika i kontrolne jedinice (ACU). Osim faznih mjerenja na nosećim valovima L1 i L2, kodnim mjerenjima C/A na frekvenciji L1, P-koda na frekvencijama L1 i L2 može se tom tehnologijom primati i novi L2C-signal. Prvi satelit s L2C-signalom lansiran je 25. 9. 2005.

Maksimalna udaljenost prijenosa RTK korekcija od bazične stanice, po podacima proizvođača, iznosi 3-5 km, a snaga odašiljača je 0,5 W. Naša ispitivanja pokazala su probleme na udaljenostima i do 1,6 km. Svi prijamnici Trimble mogu se koristiti kao rover i kao bazična stanica. Vrijeme inicijaliziranja rovera iznosi 10+0,5 sekundi/km za udaljenosti do 30 km.

Trimble® R8 GNSS prijamnik je višekanalni i višefrekvencijski GNSS. Ima 72 kanala, može registrirati L1 C/A-kod, P-kod na nosećim valovima L1 i L2, L2C-kod, fazna mjerenja na L1, L2 i novom nosećem valu L5, te registrirati GLONASS signale (sl. 5). Novi RTK-stroj (Trimble MaxwellTM Cutom Survey GNSS-chip) omogućava vrlo brzo inicijaliziranje rovera, koje je po podacima proizvođača manje od 10 sekundi. U poglavlju 5 posebice su ispitivana ta vremena.

2 Short Description of the Equipment

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

Maximum distance of transmitting RTK-correction from base station, in accordance with firmware declaration, is 3-5 km, and the transmitter strength is 0.5 W. This investigation shows problems on the distance of 1.6 km. All Trimble receivers could be used as the rover, as well as the base station. The initialisation time of the rover is 10+0.5 seconds/km for the distance of up to 30 km.

Trimble® R8 GNSS-receiver is a multi-channel and multi-frequency GNSS. There are 72 channels, which enable recording of L1 C/A-code, P-code on L1 and L2-carriers, L2C-code, phase measuring on L1, L2 and new one, L5 carrier, and recording GLONASS-signals, as well, Fig. 5. New RTK-engine (Trimble Maxwell ™ Custom Survey GNSS-chip) enables very fast initialization of the rover, what is in accordance to firmware declaration less than 10 seconds. In Chapter 5, these times were investigated particularly.

3 Test Network and the Analysis of Measuring Results

The test network of the 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 35%) and 40 points with big obstructions of the horizon (obstructions above 35%). The measurements have been done in two sessions using every rover, Tables 3, 4, 5 and 6. In order to eliminate outliers, it was necessary to define the tolerance for the observing coordinates in relations to the 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 on every point, Fig. 6. Sensitivity of the circular level on the carrying stick is 2-8', which introduces a centring error of 4.2 mm in the horizontal plane and an error in the antenna height of 0 mm.

On the basis of the errors mentioned in the uncertainty of the coordinates of the test network, the horizontal (10+1 mm/km) and the vertical (20+1 mm/km) uncertainty, specified by the manufacturer, the maximum distance between the rover and the base station of 3.6 km, and propagation of the errors, the expected standard deviations alongside *x* and *y* axes and height, resulting as follows:

$$\sigma_{x,y} = \sqrt{7^2 + 4.2^2 + 9.62^2} = 12.6 \text{ mm}$$
$$\sigma_h = \sqrt{5^2 + 0^2 + 23.6^2} = 24.1 \text{ mm.} \tag{1}$$

Fig. 2. Transport of the receivers between points on short distances

Sl. 2. Transport prijamnika za kratke udaljenosti točaka

Fig. 3. Transport of the receivers for longer distances

Sl. 3. Transport prijamnika za dulje razmake između mjerenih točaka

3. Testna mreža i analiza rezultata mjerenja

U ovom radu za istraživanja je korištena testna mreža Hochschule für Technik und Wirtschaft u Dresdenu, koja ima horizontalnu položajnu i visinsku točnost bolju od 10, odnosno 5 mm. Mreža se sastoji od 38 točaka bez zaklona ili s malim zaklonima horizonta, 48 točaka sa srednjim (zakloni do 35%) i 40 točaka s velikim zaklonima horizonta (zakloni iznad 35%). Mjerenja su obavljena dva puta sa svakim roverom (tablice 3, 4, 5 i 6). Da bi se eliminirale grube pogreške, bilo je potrebno odrediti granice dopuštenih odstupanja mjerenih koordinata u odnosu na zadane koordinate testne mreže.

Visina antene rovera iznosila je samo 1,794 m, radi lakše i brže izmjene GPS i GNSS prijamnika tijekom mjerenja na svakoj točki (sl. 6). Osjetljivost kružne libele na štapu kreće se od 2 do 8', što odgovara maksimalnoj pogrešci centriranja od 4,2 mm u horizontalnoj ravnini i pogrešci u visini antene od 0 mm.

Na osnovi spomenutih pogrešaka u nesigurnosti koordinata testne mreže, specificirane horizontalne (10+1 mm/km) i vertikalne (20+1 mm/km) nesigurnosti od strane proizvođača, maksimalne udaljenosti rovera od bazične postaje od 3,6 km i zakona o prirastu pogrešaka, dobivena su očekivana standardna odstupanja uzduž osi *x* i *y* i visine:

$$\sigma_{x,y} = \sqrt{7^2 + 4.2^2 + 9.62^2} = 12.6 \text{ mm}$$

$$\sigma_h = \sqrt{5^2 + 0^2 + 23.6^2} = 24.1 \text{ mm}, \tag{1}$$

odnosno s vjerojatnošću od 99% i χ^2- razdiobom adekvatna dopuštena odstupanja:

$$\Delta_{x,y} = \sqrt{6.63} \cdot 12.6 = 32.4 \text{ mm}$$

$$\Delta_h = \sqrt{6.63} \cdot 24.1 = 62.1 \text{ mm}$$

$$\Delta_L = \sqrt{2 \cdot 32.4^2} = 45.8 \text{ mm}.$$

Navedene dopuštene vrijednosti korištene su za filtriranje grubih pogrešaka.

Tablice 3, 4, 5 i 6 dovoljno govore same o sebi te im ne treba dodatni komentar. Očigledna je prednost u pouzdanosti hibridnih prijamnika R8 GNSS za sve stupnjeve zaklona horizonta. Ona iznosi oko 13,5% (zadnji stupac tablice 6).

Nakon eliminacije mjerenja opterečenih grubim pogreškama, izračunana su standardna odstupanja jednostrukih mjerenja u ovisnosti o stupnju zaklonjenosti horizonta uzduž koordinatnih osi *x*, *y*, *h*, odnosno u horizontalnoj ravnini i visine (tablica 7).

Iz tablice 7 vidljiva je prednost u pogledu horizontalne položajne točnosti koordinata određenih R8 GNSS roverom za sve stupnjeve zaklonjenosti horizonta. Ista se konstatacija ne može izreći za točnost određivanja visina. Vrijedno je spomenuti da su sva mjerenja podvrgnuta testovima normalne raspodjele.

Fig. 4: Trimble R8 GPS-receiver
Sl. 4: Trimble R8 GPS prijamnik

Fig. 5: Trimble R8 GNSS-receiver
Sl. 5: Trimble R8 GNSS prijamnik

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

Receiver R8	Number of measurements with standard deviation within tolerance		Number of unsuccessful measurements		Number of measurements with standard deviations out of tolerance		Sum of the advantages of R8 GNSS in percentages
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 percentage with sign +	+6.58%		–1.31%		+7.90%		+13.17%

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

Receiver R8	Number of measurements with standard deviation within tolerance		Number of unsuccessful measurements		Number of measurements with standard deviations out of tolerance		Sum of the advantages of R8 GNSS in percentages
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 percentage with sign +	+7.29%		0.00%		+7.29%		+14.58%

Table 5. List of the results for points with big obstructions of the horizon; in two sessions, 80 attempts for measuring using every receiver

Receiver R8	Number of measurements with standard deviation within tolerance		Number of unsuccessful measurements		Number of measurements with standard deviations out of tolerance		Sum of the advantages of R8 GNSS in percentages
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 percentage with sign +	+6.25%		+10.10%		–3.75%		+12.51%

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

Receiver R8	Number of measurements with standard deviation within the tolerance		Number of unsuccessful measurements		Number of measurements with standard deviations out of tolerance		Sum of the advantages of R8 GNSS in percentages
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 percentage with sign +	+6.75%		+2.78%		+3.97%		+13.50%

Table 7. Standard deviations of single measurements, depending on the rating of the horizon obstructions.

	R8 GNSS				R8 GPS			
Obstructions of the horizon	Standard deviations alongside *y* [mm]	Standard deviations alongside *x* [mm]	Standard deviations for heights [mm]	Standard deviations in the horizontal plane [mm]	Standard deviations alongside *y* [mm]	Standard deviations alongside *x* [mm]	Standard deviations for heights [mm]	Standard deviations in the 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
big	12.61	10.62	35.04	16.49	12.89	12.74	35.57	18.19

Tablica 3. Pregled rezultata za točke bez zaklona ili s malim zaklonom horizonta; u dvije sesije 76 pokušaja mjerenja sa svakim prijamnikom

Prijamnik R8	Broj mjerenja sa standardnim odstupanjima u granicama tolerancije		Broj neuspjelih mjerenja		Broj mjerenja sa standardnim odstupanjima većim od granica tolerancije		Zbroj svih prednosti R8 GNSS-a u postotcima
GNSS	72	94,74%	2	2,63%	2	2,63%	
GPS	67	88,16%	1	1,32%	8	10,53%	
Prednosti GNSS R8 u postotcima s predznakom +	+6,58%		–1,31%		+7,90%		+13,17%

Tablica 4. Pregled rezultata za točke sa srednjim zaklonom horizonta; u dvije sesije 96 pokušaja mjerenja sa svakim prijamnikom

Prijamnik R8	Broj mjerenja sa standardnim odstupanjima u granicama tolerancije		Broj neuspjelih mjerenja		Broj mjerenja sa standardnim odstupanjima većim od granica tolerancije		Zbroj svih prednosti R8 GNSS-a u postotcima
GNSS	85	88,54%	0	0,00%	11	11,46%	
GPS	78	81,25%	0	0,00%	18	18,75%	
Prednosti GNSS R8 u postotcima s predznakom +	+7,29%		0,00%		+7,29%		+14,58%

Tablica 5. Pregled rezultata za točke s velikim zaklonom horizonta; u dvije sesije 80 pokušaja mjerenja sa svakim prijamnikom

Prijamnik R8	Broj mjerenja sa standardnim odstupanjima u granicama tolerancije		Broj neuspjelih mjerenja		Broj mjerenja sa standardnim odstupanjima većim od granica tolerancije		Zbroj svih prednosti R8 GNSS-a u postotcima
GNSS	20	25,00%	35	43,75%	25	31,25%	
GPS	15	18,75%	43	53,76%	22	27,50%	
Prednosti GNSS R8 u postotcima s predznakom +	+6,25%		+10,10%		–3,75%		+12,51%

Tablica 6. Rekapitulacija svih obavljenih mjerenja (točke s malim, srednjim i velikim zaklonima horizonta); u dvije sesije 252 pokušaja mjerenja sa svakim prijamnikom

Prijamnik R8	Broj mjerenja sa standardnim odstupanjima u granicama tolerancije		Broj neuspjelih mjerenja		Broj mjerenja sa standardnim odstupanjima većim od granica tolerancije		Zbroj svih prednosti R8 GNSS-a u postotcima
GNSS	177	70,34%	37	14,68%	38	15,08%	
GPS	160	63,49%	44	17,46%	48	19,05%	
Prednosti GNSS R8 u postotcima s predznakom +	+6,75%		+2,78%		+3,97%		+13,50%

Tablica 7. Standardna odstupanja jednostrukih mjerenja u ovisnosti o stupnju zaklonjenosti horizonta

	R8 GNSS				R8 GPS			
Zaklonjenost horizonta	Stand. odst. uzduž osi *y* [mm]	Stand. odst. uzduž osi *x* [mm]	Stand. odst. visine [mm]	Stand. odst. u hor. položaju [mm]	Stand. odst. uzduž osi *y* [mm]	Stand. odst. uzduž osi *x* [mm]	Stand. odst. visine [mm]	Stand. odst. u hor. položaju [mm]
mala	11,98	10,78	33,09	16,11	12,16	13,01	32,83	17,81
srednja	11,66	10,95	30,16	16,00	11,37	13,44	29,46	17,61
velika	12,61	10,62	35,04	16,49	12,89	12,74	35,57	18,19

For probability of 99% and χ^2 – distribution adequate tolerance deviations:

$$\Delta_{x,y} = \sqrt{6.63} \cdot 12.6 = 32.4\,\text{mm}$$

$$\Delta_h = \sqrt{6.63} \cdot 24.1 = 62.1\,\text{mm}$$

$$\Delta_L = \sqrt{2 \cdot 32.4^2} = 45.8\,\text{mm}.$$

Listed tolerance values were used for the filtering outliers.

Table 3, 4, 5 and 6 speak for themselves, and not many comments are necessary. The advantage is obvious in the redundancy of hybrid R8 GNSS-receivers, for all kinds of obstructions of the horizon. It makes up 13.5%, shown in the last column of Table 6.

After eliminating measurements with outliers, standard deviations of the single measurements were calculated, depending on rating of the horizon obstructions, alongside of the coordinate axes *x*, *y*, *h*, i.e. in the horizontal plane and in the heights, Table 7.

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

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

Fig. 6. Stick with both rover, both ACUs and the transporting bike

Sl. 6. Štap s oba rovera, oba ACU-a i transportnim biciklom

between the rover and the base station, (10 mm+1 ppm and 20 mm+1 ppm). Since the longest distance between rover and base station was 3.6 km, it follows that achieved positional-horizontal precision out to be 13.6 mm and standard deviation for heights 23.6 mm. Standard deviations from Table 7 calculated from the residuals of known coordinates of known points and the point's coordinates set down by RTK measurements. It means these standard deviations are biased by errors of the coordinates of known points. They amount for the horizontal plane 10 mm, alongside axes *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 formulae:

$$s_L^p = \sqrt{(s_L^n)^2 - 10^2} \quad \text{and} \quad s_h^p = \sqrt{(s_h^n)^2 - 5^2}\,, \qquad (2)$$

where:

s_L^n – Standard uncertainty in horizontal plane, Table 7

s_L^p – Positional horizontal precision, Table 8

s_h^n – Standard uncertainty of height, Table 7, and

s_h^p – Precision of measuring height, Table 9.

In order to make correct conclusions, the test of the standard deviation was used (Reißmann 1976, page 339).

Null hypothesis is:

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

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

Where:

$k = n - 1$	redundant number of measurements,
s	evaluated standard deviation, and
σ	standard deviation by manufacturer specification.

The significant limit of testing value $\overline{\chi}^2$ can be taken from the table for χ^2 – distribution, for the probability of 99% and variable number degree of freedom *k*, Tables 8 and 9. If the $\overline{\chi}^2 < \chi^2$, the null hypothesis is acceptable.

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

4. Ispitivanje deklarirane točnosti proizvođača

Trebalo je ispitati deklariranu horizontalnu položajnu i visinsku preciznost (točnost) proizvođača kao funkciju udaljenosti rovera od bazične stanice, (10 mm+1 ppm i 20 mm+1 ppm). Kako je najduža udaljenost rovera od bazične stanice iznosila 3,6 km, slijedi da je ostvarena položajna horizontalna preciznost trebala iznositi 13,6 mm i standardno ostupanje u visini 23,6 mm. Standardne pogreške iz tablice 7 računane su iz odstupanja poznatih koordinata i koordinata točaka određenih RTK mjerenjima. Znači da su ta standardna odstupanja opterećena pogreškama koordinata danih točaka. One su iznosile u horizontalnoj ravnini 10 mm, uzduž osi *x* i *y* po 7 mm i u visini (nivelman) 5 mm. S pomoću tablice 7 može se izračunati ostvarena preciznost mjerenja po formulama:

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

gdje su:

s_L^n – standardna nesigurnost u horizontalnoj ravnini (tablica 7)

s_L^p – položajna horizontalna preciznost (tablica 8)

s_h^n – standardna nesigurnost visine (tablica 7)

s_h^p – preciznost mjerenja visina (tablica 9).

U svrhu donošenja ispravne odluke korišten je test standardnog odstupanja (Reißmann 1976, str. 339).

Nulta hipoteza glasi:

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

Test veličina $\overline{\chi}^2 = \frac{k \cdot s^2}{\sigma_0^2}$,

gdje su:

$k = n - 1$	broj prekobrojnih mjerenja,
s	procijenjeno standardno odstupanje i
σ	standardno odstupanje po specifikaciji proizvođača.

Signifikantna granica testne veličine $\overline{\chi}^2$ uzima se iz tablica χ^2 – razdiobe za sigurnost od 99% i varijabilni broj stupnjeva slobode *k* (tablice 8 i 9). Ako je $\overline{\chi}^2 < \chi^2$, prihvaća se nulta hipoteza.

Iz tablice 8 vidi se da oba prijamnika zadovoljavaju deklariranu horizontalnu položajnu preciznost.

Naprotiv, deklarirana preciznost određivanja visina nije postignuta ni s jednim prijamnikom (tablica 9). To se može donekle objasniti zbog različitog utjecaja multipath-efekata na različite tipove antena, koje su se koristile pri mjerenjima i određivanju koordinata testne mreže (Bilajbegović, Vierus, 2007, Wanninger i dr., 2006). Položajna preciznost određena GNSS prijamnikom u prosjeku je za 2 mm bolja (ili 14%), a preciznost određivanja visina lošija za 0,3–0,7 mm (ili 0,9–2,2%).

5. Istraživanje vremena inicijaliziranja prijamnika

U svrhu ispitivanja vremena inicijaliziranja prijamnika postavljena je referentna stanica na udaljenosti od oko 100 m od rovera. Antene rovera bile su međusobno udaljene oko 2 m i prekrivane su metalnim poklopcem u trajanju 0,5, 2 i 5 sekundi (sl. 7). Mjerenja su izvođena sukcesivno, jedno nakon drugoga za oba rovera. Ukupno je obavljeno sa svakim sustavom i za svako vrijeme prekrivanja antene 80 mjerenja, ili ukupno 480 mjerenja. Mjerenja inicijaliziranja obavljena su u dva dana. Kako bi se eliminirale eventualne grube pogreške mjerenja, prvoga dana određene su koordinate rovera iz 1000, a drugoga iz 4000 mjerenja. Iz registriranih podataka mjerenja moglo se očitati vrijeme izgubljenog inicijaliziranja i vrijeme reinicijaliziranja prijamnika. Prilikom analize rezultata mjerenja mogla su se identificirati dva vremena inicijaliziranja, i to: nakon gubitka inicijaliziranja zbog velikog standardnog odstupanja i nakon gubitka inicijaliziranja zbog prekrivanja antene. Rezultati ispitivanja skupljeni su u tablici 10.

Tvornička deklaracija vremena inicijaliziranja za prijamnik R8 GNSS iznosi <10 sekundi, a za R8 GPS 10 s + 0,5 s/km, (do 30 km udaljenosti od referentne stanice). Očigledno, prema tablici 10, vrijeme inicijaliziranja je funkcija trajanja prekrivanja antene i kraće je za kraća vremena prekrivanja antene. Osim toga, srednje vrijeme inicijaliziranja prijamnika R8 GNSS u prosjeku je kraće tri puta u odnosu na prijamnik R8 GPS i kraće je od tvornički deklariranog vremena. Vrijeme inicijaliziranja prijamnika R8 GPS dulje je za oko 2,5 puta od tvornički deklariranog vremena.

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

Sl.7. Ispitivanja vremena inicijaliziranja prijamnika

Table 8. Test of the horizontal positional precision according to manufacturer declaration

Positional horizontal precision according to 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
big	13.11	17.66	36.68	15.19	17.46	29.12

Table 9. Test of the precision of height according 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 $\overline{\chi}^2$	Significant limits of the testing value	s_h^p u [mm]	Testing value $\overline{\chi}^2$	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
big	34.68	41.03	36.68	35.21	31.16	29.12

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 loss because of big standard deviations	13.9	< 10 s	24.0	10.1 s
Time-interval after the initialisation loss because of antenna covering	8.0	< 10 s	25.2	10.1 s
Generally, average time-interval of the initialisation	8.2	< 10 s	25.2	10.1 s
Time-interval after covering antenna for about 0,5 seconds	5.2	< 10 s	21.7	10.1 s
Time-interval after covering antenna for about 2 seconds	6.9	< 10 s	24.5	10.1 s
Time-interval after covering antenna for about 5 seconds	12.5	< 10 s	27.6	10.1 s

Tablica 8. Test horizontalne položajne preciznosti prema tvorničkoj deklaraciji

Položajna horizontalna preciznost prema tvorničkoj deklaraciji 13,6 mm						
	R8 GNSS			R8 GPS		
Zaklonjenost horizonta	s_L^p u [mm]	Testna veličina	Signifikantna granica testne veličine	s_L^p u [mm]	Testna veličina	Signifikantna granica testne veličine
mala	12,64	60,97	91,17	14,74	77,53	85,51
srednja	12,50	70,96	105,89	14,50	87,53	97,96
velika	13,11	17,66	36,68	15,19	17,46	29,12

Tablica 9. Test preciznosti visina prema tvorničkoj deklaraciji

Preciznost visina prema tvorničkoj deklaraciji 23,6 mm						
	R8 GNSS			R8 GPS		
Zaklonjenost horizonta	s_h^p u [mm]	Testna veličina $\overline{\chi}^2$	Signifikantna granica testne veličine	s_h^p u [mm]	Testna veličina $\overline{\chi}^2$	Signifikantna granica testne veličine
mala	32,71	136,39	91,17	32,44	124,70	85,51
srednja	29,75	133,48	105,89	29,03	116,51	97,96
velika	34,68	41,03	36,68	35,21	31,16	29,12

Tablica 10. Pregled vremena inicijaliziranja rover prijamnika

	R8 GNSS [sekunda]	Deklarirano vrijeme inicijaliziranja	R8 GPS [sekunda]	deklarirano vrijeme inicijaliziranja
Vrijeme inicijaliziranja nakon gubitka inicijaliziranja zbog velikog standardnog odstupanja	13,9	< 10 s	24,0	10,1 s
Vrijeme inicijaliziranja nakon gubitka inicijaliziranja zbog prekrivanja antene	8,0	< 10 s	25,2	10,1 s
Općenito, srednje vrijeme inicijaliziranja	8,2	< 10 s	25,2	10,1 s
Vrijeme inicijaliziranja nakon prekrivanja antene u trajanju od oko 0,5 sekundi	5,2	< 10 s	21,7	10,1 s
Vrijeme inicijaliziranja nakon prekrivanja antene u trajanju od oko 2 sekunde	6,9	< 10 s	24,5	10,1 s
Vrijeme inicijaliziranja nakon prekrivanja antene u trajanju od oko 5 sekundi	12,5	< 10 s	27,6	10,1 s

5 Investigation of the Initialisation Time of the Receivers

In order to investigate the receiver's initialisation time, a reference station was settled down on the distance of about 100 m from the rover. The distance between the rover's antennas was about 2 m and they 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 the both receivers. 80 measurements were carried out using both systems and for every period of covering the antenna, or in total, 480 measurements. The measuring of the initialisation was carried out in two days. For the sake of the elimination of 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 read out 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 initialisation, as follows: after loss of the initialisation due to the big standard deviations and interval time of the initialisation after loss of initialisation in consequence of covering the antenna.

The investigation results are gathered in Table 10.

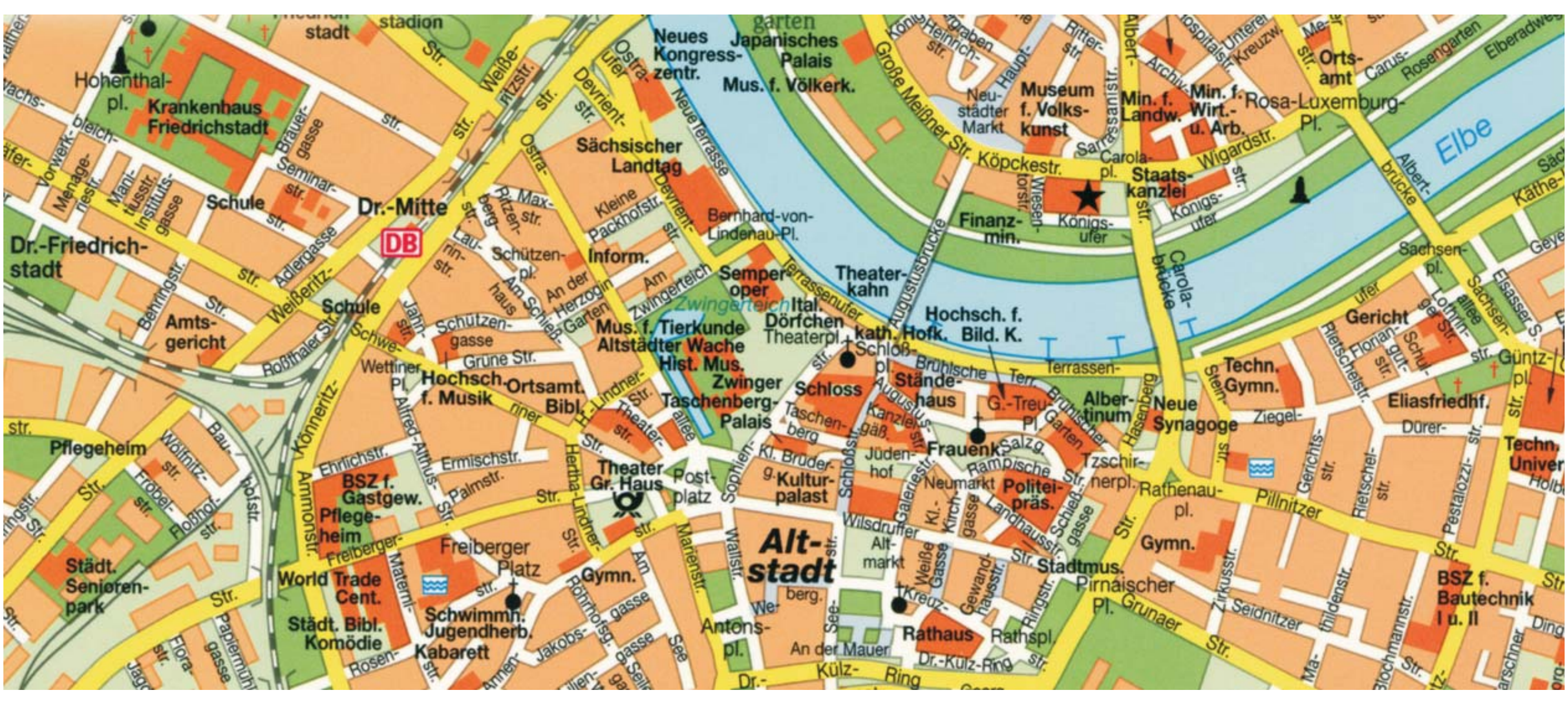
Manufacturer's declaration for the time-intervals of the initialisation for the R8 GNSS is <10 seconds, but for the R8 GPS receivers 10 s +0.5 s/km (up to 30 km distances from the reference station). Obviously, in accordance with Table 10, the time-interval of the initialisation is a function of time of covering the antenna, and it is shorter for shorter time of covering antenna. Besides that, average time of the initialisation of the R8 GNSS-receiver is shorter, and in the average, is three times shorter than R8 GPS-receiver, and is even shorter than declared manufacturer time. Time-interval of the initialisation for R8 GPS-receiver is about 2.5 times longer 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 than R8 GPS for measurements on points with horizon obstructions: low, medium and big ones, expressed in percentage, it is 13.5% better,
- Horizontal positional standard deviation is about 14% better than for R8 GPS-receiver,
- Accuracy for heights is equal to R8 GPS's,
- Initialisation time-interval is shorter 2.5 times than for R8 GPS,
- Initialisation time-interval is a little shorter than in the manufacturer's specification,
- Both systems R8 (GNSS and GPS) yield horizontal precision specified but not for heights,
- Receiver R8 GPS has almost 2.5 times longer initialisation time in relation to manufacturer's specification,
- Using hybrid system R8 GNSS one can determine about 70.3% points in a city area, whereas, using the R8 GPS receiver about 63.5% points.

It is worth noting that all statements mentioned above are for the constellation of 29 GPS and 14 GLONASS satellites and for the area of the test network of University of Applied Sciences in Dresden, and it varies depending on the number of available satellites and area of measuring.



6. Zaključak

Istraživanja u ovom radu pokazuju da je pri konstelaciji od 14 GLONASS satelita:

- hibridni prijamnik R8 GNSS pouzdaniji u odnosu na R8 GPS za mjerenja na točkama s malim, srednjim i velikim zaklonima horizonta, izraženo u postotcima za 13,5%
- da daje manja horizontalna položajna standardna odstupanja za oko 14% u odnosu na prijamnik R8 GPS
- da daje podjednaku točnost visina kao i R8 GPS
- da ima vrijeme inicijaliziranja kraće za 2,5 puta u odnosu na R8 GPS
- da je njegovo vrijeme inicijaliziranja neznatno kraće u odnosu na tvorničku specifikaciju
- da oba R8-sustava (GNSS i GPS) daju specificiranu horizontalnu preciznost, ali ne i visinsku
- da R8 GPS ima gotovo 2,5 puta dulje vrijeme inicijaliziranja u odnosu na tvorničku specifikaciju
- da se s hibridnim sustavom u izgrađenom gradskom području s R8 GNSS moglo odrediti oko 70,3%, a s prijamnikom R8 GPS 63,5% točaka.

Sve navedene konstatacije vrijedile su za konstelaciju od 29 GPS i 14 GLONASS satelita i za područje testne mreže Hochschule für Technik und Wirtschaft u Dresdenu. One variraju u ovisnosti o broju raspoloživih satelita i području mjerenja.

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