The accuracy of DGPS surveys on the basis of test measurements with a Leica GS20 receiver

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Presnosť DGPS meraní na základe testovacích meraní s prijímačom Leica GS20

In our article we deal with studying the accuracy of DGPS surveys. The test measurements focussed on this purpose with a LEICA GS20 GPS receiver were very useful for us for various reasons. Firstly, we got acquainted with the operation of a hand-held GIS GPS receiver which is considered to be a relatively new one on the market and the usage of the appropriate post-processing software, secondly when analyzing the results we studied the improving accuracy of our test measurements performed with a single receiver using various corrections. Accordingly, ground corrections originated from PENC control station were considered on the one hand, on the other hand EGNOS corrections were applied when we formed an opinion of the problem raised in the title of this study.

Key words: *DGPS, accuracy, Leica GS20, test measurements*

Introduction

In the past years – as the first author of this study - I have been dealing with the accuracy questions of various surveying procedures of GPS positioning at many home and international conferences on mine surveying. In those studies the examinations based on test measurements covered the accuracy of absolute GPS positioning on the on hand, on the other hand they included the accuracy of relative static GPS positioning based on phase measurement. Speaking of the 'golden opportunity' of compiling this study with my present co-author, let me mention our utilization of the following favourite occasion.

In the spring of 2004 Leica GEOPRO Ltd held an instrumental exhibition at the University of Miskolc where the latest products of the company 'Leica' were presented. When organizing this professional event the colleagues of this instrument-dealer firm visited me and asked me to help them in arranging their business at the university. In consequence of this, besides the usual tasks to be done, more students and I were listening to the presentations of the instrument exhibition. At the time Leica GS20 grabbed my attention. This GIS GPS receiver, namely, introduced very useful solutions for many application fields. For example, I can mention agriculture, where the registration of agricultural land according to the EU requirements is done with the help of a built-in area-computing program. I found the receiver itself very interesting – besides the afore-mentioned functions – because of the reception ability of EGNOS signals. The reason of that was that the stable EGNOS service was promised by 2005 at that time. We already know today that service has been available since the middle of 2006, more exactly from the end of this June. It is known that the EGNOS system has started the so-called its Initial Operation Phase (IOP) since the June 2005. Since then the system has been operated by the European Satellite Service Provider (ESSP). The IOP is 18 month long so that the system should be put into operation, stabilized and qualified gradually during this period of time. In June 2006 the operation of EGNOS System Test Bed (ESTB) was officially completed. At present EGNOS signals are transmitted for the following three application purposes: (1) for IO (Initial Operation) by the EGNOS satellite IOR-W (PRN126) since June 2006; (2) to perform industrial tests EGNOS by the satellite ARTEMIS (PRN124) since June 2006 and (3) for IO by the EGNOS E satellite AOR - (PRN120) since June 2007 as well [6].

Anyway, at that time our need to test DGPS surveys using EGNOS signals stimulated me and my coauthor to obtain the promotion of the director of GEOPRO Ltd for timely use of the company's GPS receiver and the appropriate GIS DataPRO post-processing software. For this, in general, we had only one week for each measuring epoch. With reference to the post-processing software another point of interest was that it was suitable for using DGPS signals of RTCM format for determining each surveyed point position after down-loading them through the Internet nearly in real time. The accuracy of points measured in this way – considering the accuracy of absolute GPS positioning – is much higher than we also supposed it in advance on the data of special literature [1].

The introduction is followed by an overview of the applied differential positioning procedures based on code measurements. Then the possibilities of RTCM-format data transfer are described shortly laying

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emphasis on those two which were used in our present study. After this part, the body of study is discussed, that is to say, the GS20 GPS receiver and the test measurements are outlined briefly, and furthermore we give the results and conclusions.

Surveying procedures of differential positioning based on code measurements

It is known that if a GPS receiver is located at one end point of a base line with known coordinates this instrument is called a reference receiver in practice. Considering this, at the other end of the base line another GPS receiver can be found, the coordinates of which we would like to determine with the measured code ranges to the satellites observed with our two receivers. If the base line is not too long, that is to say it does not exceed some km, we can suppose that each receiver observes the code distances under similar circumstances. In this case the effect of certain systematic errors such as orbit and clock errors and atmospheric ones can practically be considered nearly the same, and then they have an effect on the result of positioning to a minimum extent.

The literature [2] separates two surveying procedures. One of them is the *method of coordinate-corrections*; the other is *procedure of pseudorange corrections*. Let's name the known point of the base line **1** and the unknown point 2. The *method of coordinate-corrections* is based on that point 1 has known coordinates on the one hand; on the other hand its coordinates can be computed from the absolute point positioning. If we form the difference of these two, and add it to the coordinates of the unknown point, the effect of systematic errors is nearly eliminated, and the position of point 2 will be more accurate. This method did not spread in practice since it requires the observation of the same satellites with both receivers on the one hand, on the other hand random errors of positioning at point 1 can appear in the coordinates of point 2.

The *procedure of pseudorange corrections* provides better results than the afore-mentioned method. Here the point is that reference station 1 is selected in a way that all the satellites above the horizon can be observed with it. Then all the ranges are computed using the orbital information (precise ephemerides) and measured as well. After doing that, differences of code ranges are computed and sent to the code ranges to be corrected at point 2. These corrections contain the significant part of systematic errors. Then the coordinates of the unknown point 2 can be computed with the corrected code ranges. This procedure – comparing to the former one – leads to the same result technically. In contrast to the *method of coordinate-corrections* among the advantages, however, we have to mention as follows: (1) various receivers and software can also be used at points 1 and 2; selection of the observed satellites at point 2 could be to user taste if all the visible satellites are observed at point 1.

About the possibilities of RTCM data transfer

According to the literature [2] the following possibilities of data transfer can be solved among the reference station and the points to be determined with the use of DGPS technique: (1) ultra-short wave radios, in RDS system; (2) medium- and long wave radios, in AMDS system; (3) by means of radio beacons; (4) with the help of mobile telephone networks; (5) with geostationary satellites and (6) through the Internet (with GPRS service).

Now – considering the volume of this study - I do not intend to deal with all the listed possibilities. The last two, however, are discussed briefly since they were used in our test measurements.

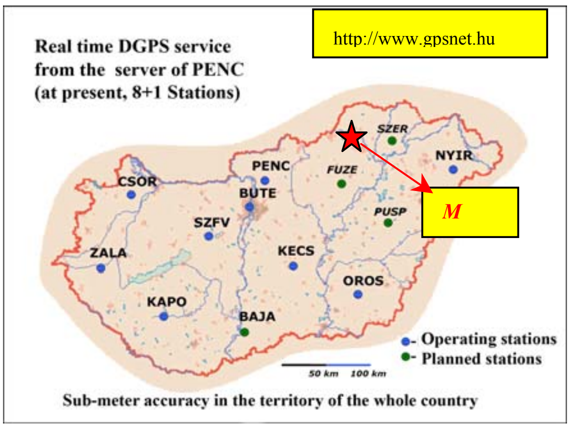


Fig. 1. The distribution of active GPS network.

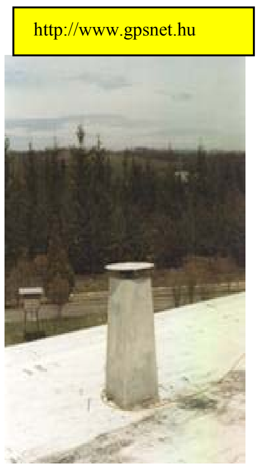


Fig. 2. Antenna location of PENC station.

The operators of EUREF Permanent GPS Network decided positively on a free and real time GNSS Infrastructure based on the Internet in June 2002. This system provides the transmission of RTCM format corrections of four kinds through the Internet. To use this free service you need only Internet connection which, of course, has to be paid for. In terrain circumstances the Internet connection with mobile telephones can be realized economically by means of GPRS service. It is known that KGO /PENC/ in Hungary is a GNSS provider as well. In addition, a so-called GBAS system containing 12 control stations is under construction in Hungary. The distribution of this active GPS network and antenna location of PENC station can be illustrated in Figures 1 and 2.

In Figure 1 the UM Roof Antenna indicated with a star can also be seen. Moreover, it comes out from this figure that leaving out Nyírbátor PENC station was the nearest to UM (MISKOLC). Otherwise, our post-processing software could only use this Hungarian station for data process at that time. The DGPS corrections from the server operating in KGO /PENC/ are provided free even at present. By the time the complete network is ready the operators of this system will be providing a sub-meter accuracy in the country [3].

As far as the data transfer with geostationary satellites is concerned, among the SBAS systems there are free (e.g. EGNOS) and fee-paying (e.g. Omni-Star) ones. They are so-called regional/global satellite-based augmentation systems. In our study we used EGNOS signals when we did our test measurements. EGNOS is an augmentation to the American GPS system, the task of which is to provide the users in the European and near-European regions with various RTCM corrections. EGNOS consists of three geostationary satellites, these are AOR-E, ESA Artemis and IOR-W. The ground control system includes 34 RIMS (Ranging and Integrity Monitoring Station) and 4 MCC (Mission Control Centre) [5]. The last ones compute differential corrections and integrity data which are then uploaded to the geo-satellites so that they should send back these useful data for the regions covered by the system. The correction signals are broadcasted to the users who have suitable receivers to signal reception on GPS L1 frequency. Leica GS20 is a GPS receiver which is capable of receiving the EGNOS and American WAAS signals. In these WADGPS networks, in general, complex data processing of each monitoring station is realized. For the whole region covered by the network a uniform model of differential corrections is developed. The effects of orbit, clock and atmospheric errors are considered in the model. The master control station computes the corrections in the corner points of a square network with known allocation and dimensions in the service field with the use of this model. Then master control station uploads the correction system, in the form of a radio message, to the geostationary satellites and they transmit it to the service region. In case of GBAS systems the computed corrections are sent back to monitor stations which broadcast corner point corrections to users only in their range of influence. Corrections related to the location of a certain receiver are determined by means of weighted interpolation using the data of the nearest four corner points.

An accuracy of lower than 2 m has been expected by the operators since June 2006 because the EGNOS system has been considered to be stable since then in contrast to the accuracy of 5-15 m which is characteristic of absolute GPS positioning.

Introduction of Leica GS20 hand-held GPS receiver

The instrument used in our test measurements was a so-called manual GIS GPS receiver. It combines the simple handling of navigation receivers with the functionality and flexibility of geodetic ones. In Figure 3 we can see that the instrument architecture unites a built-in antenna, a receiver, a keyboard, a monitor, a storage facility and a battery.

http://www.leica.com/index.

Fig. 3. T*he instrument architecture unites a built-in antenna, a receiver, a keyboard, a monitor, a storage facility and a battery.*

Considering technical parameters of this instrument we can say that it is a single frequency receiver with 12 channels and it can be used for both code and phase measurements. The GS20 GPS receiver is capable of receiving EGNOS corrections thereby each user is able to perform DGPS measurements in 'nearly real time' as we did too. Survey data of the instrument can be processed with GIS DataPRO office software which enables downloading RTCM corrections through the Internet besides the customary processing functions. The post-processing program has a searching function through the Internet . If we run it the near reference stations to survey site can be listed. Among them, of course, it is practical to download correction data of the nearest control station. We also did it in this way, and this reference station was PENC /KGO / in our case at that time.

Possibilities when configuring a GS20 GPS receiver [4]:

- selection among three surveying modes (point survey, continuous survey and area survey),
- objects to be measured could be: points, lines and areas,
- configuring the way of satellite reception which could be maximum search, hyper search or maximum accuracy (The meaning of each satellite reception covers how many coming satellite signals are considered by the receiver.),
- /Here we also mention that MaxTrack technology integrated in the receiver guarantees permanent signal reception under difficult terrain circumstances (e. g. forested areas.)/
- setting up the elevation mask above which the satellites are observed with the instrument,
- loading ready code lists after selecting them, or preparing user-defined code lists,
- the use of PDOP filter to eliminate wrong data automatically from the survey set,
- setting up CQ observation as well.

In the GPS receiver there is a line- and area managing function with the help of which data management can be solved at the survey site. The accuracy of each survey point is controlled continuously and can be illustrated on the display if it is needed. Digital storage of the measured data is solved on a Compact Flash card. Data download in a PC is realized with the mentioned card or through a cable as well.

Test measurements with a Leica GS20 GPS receiver at the University of Miskolc (UM)

To our test measurements for studying the accuracy of DGPS procedure a four-point survey network was formed on the top of the main building of the University of Miskolc. This survey network consisted of a known GPS reference point (UM Roof Antenna) established previously and further three ventilation holes (S1, S2 and S3). At the points listed here we conducted measurements in 8 survey sets from which 4 were processed with RTCM corrections from PENC /KGO/ and 4 were evaluated with EGNOS corrections. To study the test measurements the distance (nearly **115.5 km**) between the UM Roof Antenna and PENC /KGO/ was computed on the basis of the available data.

About the survey sets, in general, we can mention as follows: (1) all the four points (UM supporting console and the 3 ventilation holes) were measured 4 times in a survey set; (2) 20 positions were stored for a point in a survey set with a data-capture density of 10 sec.; (3) the maximum search satellite reception mode, a 15-degree observation mask and four satellites were considered, furthermore favourable survey epochs were selected in terms of PDOP value. (The last one was planned with GPSurvey 2.35a software, but sometimes it occurred that we could not do the measurements when it would have been ideal considering PDOP values.)

The first 4 survey sets were measured between November 29th, 2004 and December 2nd, 2004. The real average PDOP values at the survey points were as follows: UM Roof Antenna (2.49, from 5 measurements), Point S1 (1.97, from 4 measurements), Point S2 (2.18, from 4 measurements) and Point S3 (2.17, from 4 measurements). Here we used RTCM corrections from PENC when we post-processed the test surveys.

The second 4 survey sets were observed between March 1st, 2005 and March 3rd, 2005. At that time our receiver was able to work with a so-called 'test' EGNOS signals. In this case the real average PDOP values at the survey points were as follows: UM Roof Antenna (5.84 /the last one: 13.3/, from 4 measurements), Point S1 (3.38 /the last one: 4.35/, from 4 measurements), Point S2 (4.26 /the last one: 7.98/, from 4 measurements) and Point S3 (3.26 /the last one: 4.61/, from 4 measurements).

Test measurements at the ELTE survey site

The second part of the test measurements needed to our accuracy study was performed at the ELTE site in Budapest. The advantage of this site - in contrast to Miskolc – was the shorter distance (about **38.7 km**) to PENC monitor station. In addition, we trusted in more stable reception of EGNOS correction signals in the region of Budapest. This, however, was not always justified.

Our survey network consisted of three points in the field of ELTE. Accordingly, the monitored points were the ELTE Roof Antenna allocated at the top of the university building and two other GPS survey points established for training purpose in the university garden. These points, which were used for our test measurements, were established by Hungarian the Army and colleagues at ELTE in 1999. At that time terrain surveys were conducted with Trimble 4000 SSi and Trimble 4600 LS type GPS receivers using differential phase measurements. Computations were performed in WGS 84 system and coordinates of the measured points were transformed into EOV local plane system with the use of WATSZ and other transformation programs. The point heights were also determined with GPS with reference to the Baltic Sea level.

At the ELTE site we did the measurements six times altogether. Our measuring epochs were as follows: August 4th, 2005; November 13th, 2005; November 20th, 2005; November 24th, 2005; November 25th, 2005 and in the end November 19th, 2005. At all the three points 8 survey sets were measured from which 4 were processed with RTCM corrections from PENC /KGO/ station and 4 were evaluated with EGNOS corrections.

About the surveys at the ELTE site we can mention as follows: (1) all the three points were measured 4 times in a survey set; (2) 20 positions were stored for a point in a survey set with a data-capture density of 10 sec.; (3) the maximum search satellite reception mode, a 15-degree observation mask and four satellites were considered. Unfortunately, we were not able to plan the 'ideal' measuring epochs in terms of PDOP value preliminary at the site in the lack of the necessary software. Because of the unfavourable average PDOP values it occurred that we had to repeat some measurements. Besides this, on November 19th, 2005 there was not a continuous signal when we conducted the measurements which led to worse results than we had expected before.

Results of our test measurements and their assessment

Results of our test measurements were evaluated in the tables as follows. Coordinates referred to WGS 84 ellipsoid and resulted from the measurements were transformed into national EOV local plane system and heights above the geoid by means of BL - Trafo Pro software. When doing the measurements at the University of Miskolc a local parameter set computed for the site of our test surveys was applied instead of a national one. Conversion accuracy of each coordinate using this local parameter set could be some cm on the basis of former department tests. Coordinates of the surveys conducted at the ELTE site were transformed by means of a so-called national parameter set because it was at our disposal in the Budapest area and it also provided the necessary accuracy. In Table 1 differences of the average coordinates related to University Roof Antenna are given which were computed from the four-four survey sets and compared to the coordinates considered as reference in this case, and surveyed earlier by a differential phase measurement.

Tab. 1. Coordinate differences related to the UM Roof Antenna.

UNIVERSITY ROOF ANTENNA / supporting console /			
Reference coordinates	y [m]	x [m]	H_{GPS} [m]
	777984.165	305713.490	-
DGPS corrections / from PENC station /	777984.030	305715.151	159.338
Coordinate differences	Δy = 0.135	Δx = -1.661	-
Applying EGNOS corrections	777984.099	305714.478	156.898
Coordinate differences	Δy = 0.066	Δx = -0.988	-

Studying the data in the Table 1 it can be seen that coordinate differences are of similar character in both cases and those are more advantageous in case of EGNOS corrections. It can also be observed that values (**Δx**) are much larger in both cases, and coordinate difference (**Δx**) exceeds 1.5 m using DGPS corrections from PENC station, and it is smaller than 1 m when EGNOS corrections are applied.

In Table 2 coordinate differences related to the 'real' point coordinates found at the ELTE site are illustrated. Those – as we mentioned earlier – were determined by differential phase measurement.

Tab. 2. Maximum values of coordinate differences related to the ' real' coordinates.

Applying EGNOS corrections								
SURVEY SETS	1		2		3		4	
SURVEY POINTS	y [m]	x [m]	y [m]	x [m]	y [m]	x [m]	y [m]	x [m]
ELTE Roof Antenna	1.2	-0.6	0.5	-1.5	0.2	0.0	1.3	1.3
Point 2	1.5	0.0	-0.7	-2.3	-0.3	0.2	-3.5	-4.9
Point 5	0.4	1.3	0.6	-0.3	0.8	-1.7	-0.1	0.4

DGPS corrections / from PENC /								
SURVEY SETS	1		2		3		4	
SURVEY POINTS	y [m]	x [m]	y [m]	x [m]	y [m]	x [m]	y [m]	x [m]
ELTE Roof Antenna	-0.3	-1.4	0.1	0.2	0.3	-0.4	0.0	0.6
Point 2	0.9	-0.5	-0.7	0.4	-0.6	-1.0	-0.8	-0.5
Point 5	-0.1	0.9	-0.3	-0.7	0.5	1.0	-0.3	-0.3

From the data of this table you can also see that we got better results when we used corrections from PENC station than when EGNOS corrections were applied. In the former case differences – with an exception of only one value – do not exceed 1.0 m, in the latter one, ignoring some extreme data, they were smaller than 2.5 m. (Extreme values were due to periodical EGNOS signals and unfavourable PDOP values.)

In the following Tables 3 and 4 ranges of coordinate differences related to the average values were compared. Studying Table 3 it can be seen that if we ignore 3.3 m as a value of **x** for the Roof Antenna all the coordinate differences can be found within a nearly 2 m-wide range. We can also observe that data describing the widths of the ranges in question were slightly smaller when using DGPS corrections from PENC station than those when EGNOS corrections were applied, taking all into account. Considering the survey results at the ELTE site, we can, however, establish that a 5 m-value occurred in the case of Point 2. When corrections from PENC were used, however, ranges of coordinate differences were smaller than 2 m with an exception of one value.

In Tables 5 and 6 standard deviations describing our sets of measurements with corrections of two kinds were summarized considering the measured points as well. From the data of these tables it is also easy to establish even by sight here that standard deviations are slightly favourable in case of ground-based DGPS corrections than that of EGNOS corrections.

Studying the accuracy of plane coordinates for each survey point using corrections of two kinds we can establish as follows:

[1] the σ_{by} values were smaller than ±1.1 m when ground-based corrections were used therefore positioning accuracy in this case was better than ±2.2 m at 2σ significance level (95 %);

[2] the same accuracy feature did not exceed ±1.5 m considering all of them when satellite-based corrections were applied, (with an exception of Point 2 at the ELTE site where there was no stable EGNOS signal) and when it was used for describing the positioning accuracy we obtained ±3 m at 2σ significance level.

Tab. 3. Ranges of coordinate differences related to average values (measurements at the Univ. of Miskolc).

SURVEY POINTS	DGPS CORRECTIONS / from PENC /		EGNOS CORRECTIONS	
	y [m]	x [m]	y [m]	x [m]
Univ. Roof Antenna	1.0	2.1	0.6	3.3
Point S1	0.8	0.3	2.1	1.9
Point S2	0.4	1.3	1.0	1.4
Point S3	0.8	1.6	1.0	1.4

Tab. 4. Ranges of coordinate differences related to average values (measurements at the ELTE site).

SURVEY POINTS	DGPS CORRECTIONS / from PENC /		EGNOS CORRECTIONS	
	y [m]	x [m]	y [m]	x [m]
ELTE Roof Antenna	0.6	2.0	1.1	2.8
Point 2	1.7	1.5	5.0	5.0
Point 5	0.8	1.7	0.9	2.9

Tab. 5. Standard deviations' describing the survey sets (measurements at the Univ. of Miskolc).

SURVEY SETS	DGPS CORRECTIONS / from PENC /			EGNOS CORRECTIONS		
	σ_y [m]	σ_x [m]	σ_{xy} [m]	σ_y [m]	σ_x [m]	σ_{xy} [m]
Univ. Roof Antenna	0.390	0.798	0.888	0.334	1.424	1.467
Point S1	0.317	0.162	0.356	0.871	0.812	1.191
Point S2	0.187	0.584	0.613	0.481	0.650	0.809
Point S3	0.356	0.702	0.787	0.420	0.688	0.806

Tab. 6. Standard deviations' describing the survey sets (measurements at the ELTE site).

SURVEY sets	DGPS CORRECTIONS / from PENC /			EGNOS CORRECTIONS		
	σy [m]	σx [m]	σxy [m]	σy [m]	σx [m]	σxy [m]
ELTE Roof Antenna	0.249	0.875	0.909	0.537	1.168	1.285
Point 2	0.819	0.616	1.025	2.085	2.408	3.185
Point 5	0.369	0.858	0.934	0.407	1.241	1.306

After these, let's come to the comparison of the evaluated survey sets considering the corrections of two kinds point by point. Firstly, on the basis of Tables 7 and 8, let's see how similar the coordinate averages are to each other at the survey points of the two survey sites (UM and ELTE) which were computed with both ground-based (PENC) and satellite-based corrections (EGNOS).

Tab. 7. Coordinate averages and their differences (measurements at the Univ. of Miskolc).
1 DGPS corrections / from PENC / 2 EGNOS corrections

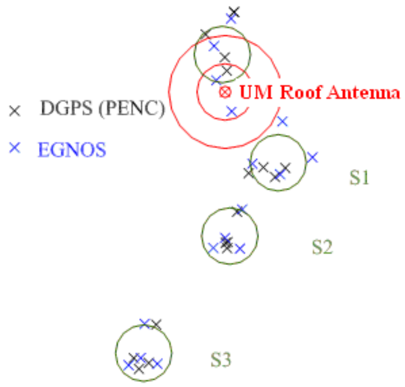
UNIVERSITY ROOF ANTENNA [m]			
	y	x	H_{GPS}
1	777984.030	305715.151	159.338
2	777984.099	305714.478	156.898
	Δy = -0.069	Δx = 0.673	ΔH_{GPS} = 2.440
POINT S1			
	y	x	H_{GPS}
1	777985.915	305710.682	156.921
2	777986.178	305711.291	155.752
	Δy = -0.263	Δx = -0.609	ΔH_{GPS} = 1.169
POINT S2			
	y	x	H_{GPS}
1	777984.315	305708.388	156.553
2	777984.342	305708.399	155.828
	Δy = -0.027	Δx = -0.011	ΔH_{GPS} = 0.725
POINT S3			
	y	x	H_{GPS}
1	777981.301	305704.238	156.474
2	777981.244	305704.271	156.194
	Δy = 0.057	Δx = -0.033	ΔH_{GPS} = 0.280

Tab. 8. Coordinate averages and their differences (measurements at the ELTE site).
1 DGPS corrections / from PENC / 2 EGNOS corrections

ELTE ROOF antenna [m]			
	y	x	H_{GPS}
1	651097.258	236763.903	147.230
2	651096.484	236763.842	144.311
	Δy = 0.774	Δx = 0.060	ΔH_{GPS} = 2.919
POINT 2			
	y	x	H_{GPS}
1	651119.723	236876.798	104.742
2	651120.170	236878.164	104.148
	Δy = -0.447	Δx = -1.366	ΔH_{GPS} = 0.594
POINT 5			
	y	x	H_{GPS}
1	651029.526	236615.433	105.404
2	651029.029	236615.730	103.506
	Δy =0.497	Δx = -0.297	ΔH_{GPS} = 1.898

From the data of the tables you can see that the similarity of horizontal coordinate averages is very good for the measurements at the UM, especially for the coordinates (**y**), moreover the differences for the coordinates (**x**) are only a bit larger than 0.5 m. As far as vertical coordinate averages are concerned, we can observe differences larger than 1-2 m. The largest value, about 2.5 m appeared at the UM Roof Antenna. We obtained a bit worse results when doing the measurements at the ELTE site. The coordinate difference (**Δx**) for the point 2 exceeded 1 m. In vertical sense we received the largest difference for the ELTE Roof Antenna, but it was smaller than 3 m.

After studying the results in the above tables, using Figures 4 and 7 the allocations of each evaluated survey point position can be observed around the real and most probable position. In Fig. 4 the measurements in Miskolc can be seen. The most probable positions were calculated from the averages of 4 survey sets with corrections from PENC and 4 with EGNOS corrections. In these positions we drew circles of 1 m radius, and we illustrated the allocations of each survey point position considering the appropriate circles. The more accurate coordinates of the University Roof Antenna which were determined with a former department measurement can also be seen in Figure 4 made with an AutoCAD program. We drew circles with radii of 1 m and 2 m around this point as well.



Tab. 4. Measurements at the University of Miskolc.

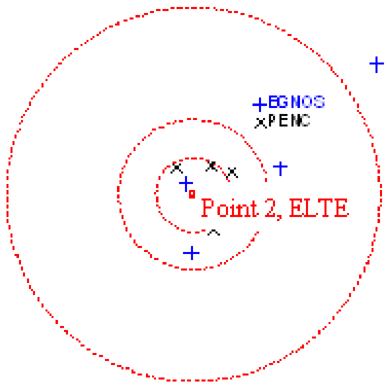


Fig. 5. Test measurements at Point 2 of ELTE site.

In Figures 5-7 the measurements at the ELTE site can be seen. Around the real coordinates of each observed points more circles were drawn with radii of 1 m and 2 m (in case of Point 2 with radii of 1 m, 2 m and 5 m), and the measured point positions were illustrated considering these circles.

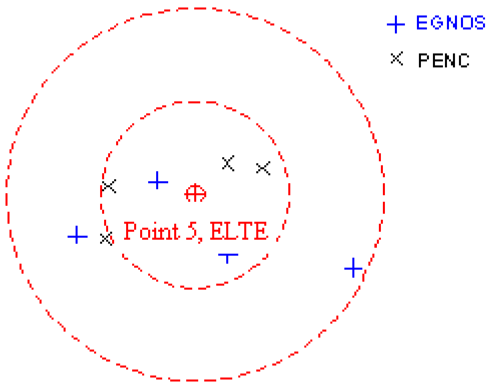


Fig. 6. Test measurements at Point 5 of ELTE site.

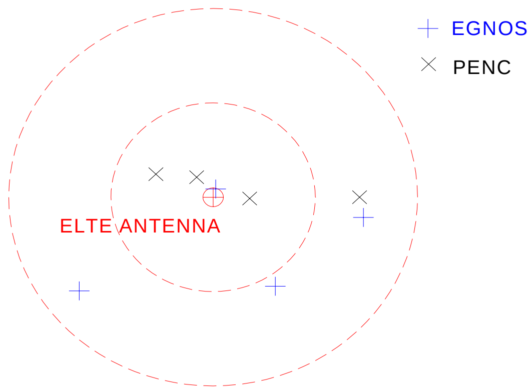


Fig. 7. Test measurements at ELTE Roof Antenna.

Finally, let us show some interesting results. At the University of Miskolc we were able to measure the lengths between the observed survey points with a steel tape as well. If we calculate the averages from the coordinates with corrections of two kinds and after determining the lengths we can compare them with the ones measured with the tape. Then we obtained the results found in Table 9.

Each length difference is smaller than 10 cm at the ventilation holes /S1, S2 and S3), its value, however, is about 84 cm between the roof antenna and Point S1. If we use here the accepted reference coordinates the difference is only 34 cm. This relatively larger difference is a result of the unstable positioning because of certain reasons. By the way, this unstable positioning can also be seen in Figure 4 very well.

Tab. 9. Comparing the computed and measured lengths between the observed points.

SIDE	LENGTH [m] / from calculation /	LENGTH [m] /from tape measurements/	LENGTH DIFFERENCE [m]
University Roof Antenna - S1	4.311 3.132	3.468	0.843 0.336
S1 – S2	3.110	3.104	0.006
S2 – S3	5.145	5.206	0.061

Summary

Summarizing the results we can say that they met our prior expectations. In connection with ground-based corrections the distances between each survey point and PENC station were of great significance. It was more than 100 km in case of test measurements at the UM, while it was less than 40 km considering the survey points at ELTE site. This is the reason why the positioning accuracy (**±2 m)** in Miskolc decreased for nearly **±1 m** in case of survey points at ELTE site – due to the nearer active GPS control station – when we used ground-based corrections through the Internet. With establishing further GPS control stations the accuracy could increase to a sub-meter level depending on the survey location related to the active control stations.

As far as EGNOS correction signals are concerned, we could receive only the test signals until June 2005, therefore in Miskolc we corrected our measurements with them. At the ELTE site we could use more stable corrections than the former ones, but in spite of this there was no significant increase in accuracy. The positioning accuracy of **±2 m** was characteristic of EGNOS which was, in general, found in the literature [1; 6]. It is proved that geometric factor (PDOP) requires much attention so that we could get better results. When we processed our measurements with EGNOS corrections we often went over the 'ideal' measuring epochs which thereby appeared in the results as well.

Since the themes of this conference cover mine surveying as well, as we have tested the accuracy of the above DGPS procedures, we think, it is also worth considering some possible applications in mining, too. Accordingly, considering accuracy features of our test measurements, we can say as follows:

[3] As far the tested Leica GS20 hand-held GPS receiver, we can state, in general, that this instrument can mainly be used for mining tasks with lower accuracy requirements.

[4] According to the former point the tested DGPS methods with the applied corrections of two kinds can be used in mining navigation systems with lower accuracy, in road navigation, furthermore, even in mine surveying when we determine the boat position to measure the underwater surface. In addition, it can also be used to develop mining GIS systems or set out bore holes for prior mining investigation as well.

References

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[6] http://esamultimedia.esa.int/docs/egnos/estb/egnos_pro.htm