Study on the Quality of the GNSS Measurements in Static Mode if Applying Certain Values of the Parameters, Following the Current Regulatory Requirements

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Key words: Geodesy, GNSS, measurements, quality assessment

SUMMARY

The continuous GNSS modernization leads to improvement of the results from the measurements. From technical point of view this necessitates an update of the requirements for conducting of GNSS measurements.

This paper studies the overall quality of the results from the geodetic measurements, conducted and processed with certain, but various values of the cut-off angle and length of the session.

Several spatial chords with different lengths were measured and the results were analysed, using own geodetic software. The experiment is one continuation of a previous study of the author, now done in the light of current requirements for the GNSS measurements and technical possibilities.

Recommendations and proposals are also given.

АБСТРАКТ

Непрекъснатата модернизация на GNSS води до подобрение на резултатите от геодезическите измервания. Това от своя страна е предпоставка за необходима актуализация на изискванията за провеждане на GNSS измервания.

В статията е извършено изследване на общото качество на резултатите от геодезическите измервания, проведени и обработени с конкретни, но различни стойности на ъгъла над хоризонта и продължителността на сеанса. Няколко пространствени хорди с различни дължини бяха измерени и резултатите от обработката на измерванията бяха анализирани, използвайки собствен геодезически софтуер.

Експериментът е едно продължение на предишни изследвания на автора, сега извършен в светлината на днешните изисквания за GNSS измервания и съвременните технически възможности.

В заключение към материала на база на: проведените геодезически измервания, получените числени резултати и извършения анализ са дадени препоръки и предложения за бъдеща работа.

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1. INTRODUCTION

GNSS constellation is subject of continuous improvements from various aspects (e.g. enhanced internal atomic clocks, improved accuracy, etc.). This inevitably changes the overall performance of the system and leads forward to better navigation and possibility to obtain higher accuracy than before. More information about the GNSS modernization could be found at: [http://www.gps.gov/systems/gps/modernization], [http://www.af.mil/News/ArticleDisplay/tabid/223/Article/109195/gps-iif-4-successfully-launched-from-cape-canaveral.aspx], [http://www.space.com/21192-gps-satellite-launch-atlas-5.html], [http://gpsworld.com/category/gnss-system/gps-modernization/], http://www.gps.gov/systems/gps/modernization/ and many others. Also, the following words could be added: "GPS III satellites will deliver three times better accuracy" as stated in [http://www.examiner.com/article/next-generation-gps-system-advancing-fast].

Additionally, a lot of publications for the next satellites' launches could be found at [http://www.geoconnexion.com/uploads/publication_pdfs/int-v13i2-A-better-place.pdf] and [http://www.gps.gov/multimedia/presentations/2013/11/USTTI/kim.pdf]. Publication for GLONASS status and progress could be read in [http://www.glonass-center.ru/aboutIAC/GLONASS%20STATUS%20and%20PROGRESS.pdf].

It is known, that GPS measurements in static mode should be conducted at clear horizon, with no active or passive disturbers in the vicinity of the site, etc. in order to obtain results with the expected high quality, also to avoid a potential damage of the equipment. These conditions, also the occupation time for the relevant lengths of the baselines are described in [MRD, 2011].

Based on the mentioned above, it should be noted, that the parameters of the system (i.e. cut-off angle, length of the session and record rate) could be altered to certain values. The aims could be, and are not limited to:
-adherence to the regulatory requirements for GNSS measurements;
-conducting experiments;
-improvement of the final results from the measurements;
-to obtain productivity in the process of performing of the geodetic measurements.

The tasks of this experiment are:
- to conduct GNSS measurements in static mode - explicitly in an open field environment, based on the regulatory requirements given in [MRD, 2011];
- to process and analyse the results with specialized own geodetic software (the important advantage of the last is its ability to analyse various sets of data);
- to link the results and conclusions of the current experiment with previous author's work.

The measurements, subject of this study are done using certain values of the parameters (cut-off angle, length of the session and record rate) in the system, see chapter 3.

2. PRACTICAL IMPLEMENTATION OF THE EXPERIMENT

In this paper, the following study methodology was applied:

2.1 Type of the Conducted Geodetic Measurements

Static method for GNSS measurements was used. Three spatial chords (baselines) were subject of geodetic measurements and overall quality assessment. All points were situated in open field environment with clear horizon, out of the urban areas.

The points of the spatial chords were chosen very carefully, according to the following circumstances and rules:

2.1.1 Reference station

One and the same reference point was used in this experiment.

2.1.2 Rovers

The stations for the rovers were points from the national geodetic network.

2.1.3 Lengths of the baselines

The distances between the reference point and the rovers were selected to be as follows: up to 10 km, from 10 km up to 20 km and over 20 km - according to [MRD, 2011].

2.1.4 Regulatory requirements

In this experiment were strictly applied the requirements for: lengths of the baselines, environmental conditions, cut-off angle, occupation time and record rate, as noted in [MRD, 2011].

2.2 Previous Author's Experiments

This study was linked to other results and conclusions, given in [Kostov, 2009], [Kostov, 2010]. Along with the explicit requirements, the paper also uses cut-off angle 0 degrees, length of the session 10 min. in the GNSS system, based on the cited literature.

3. CONDUCTED EXPERIMENTAL GNSS MEASUREMENTS IN STATIC MODE, APPLYING BOTH THE REQUIRED AND PROPOSED VALUES OF THE PARAMETERS IN THE SYSTEM

In this study, as noted three baselines were subject of measurements and analysis. They were named as follows: "*up to 10 km", "from 10 up to 20 km" and "over 20 km"*. The measurements for each spatial chord were divided into 3 sessions (conducted consecutively) and performed during daytime. The cut-off angle was set to 0 degrees, i.e. it was given the possibility all visible satellites to be tracked. The work of the controller was observed during the measurements and it was noticed that the relevant noisy signals of the satellites were excluded from the measurements, see also [Kostov, 2010].

3.1 Procedure for baseline "up to 10 km":

a) The first session was chosen to last for 15 min., according to the requirements, given in [MRD, 2011].

b) The second session was performed right after the first one, without change in the parameters, except the length of the occupation time, which was doubled (set to 30 min.).

c) The last (third session) was conducted for 10 min., according to the results and conclusions in [Kostov, 2009] and it was started after the second one.

3.2 Procedure for baseline "from 10 up to 20 km":

a) The length of the first session for this baseline was set to 40 min., as required in [MRD, 2011].

b) The second session was started, as already noted consecutively after the first. The occupation time was doubled from 40 to 80 min. No other change in the system's settings was done.

c) The third session was conducted for 10 min., based on the same principle as given in point 3.1c.

3.3 Procedure for baseline "over 20 km":

a) The occupation time of the first session was set to 60 min., based on the requirements in [MRD, 2011].

b) The next session was conducted consecutively after the first one. The length of the session for these GNSS measurements was set to 120 min.

c) The third session was done for 10 min., according to 3.1.c and 3.2.c.

4. USED CRITERIA FOR OVERALL QUALITY ASSESSMENT OF THE PERFORMED GEODETIC MEASUREMENTS

Within this study, the following criteria were applied:
-Quality in the position M_P;
-Quality in the height M_h;
-Elements of the co-variance matrix of the spatial chord: Q_{11}, Q_{22} and Q_{33};
-Number GDOP(max);
-Number PDOP(max);
-Number HDOP(max);
-Number VDOP(max).

The numbers: GDOP, PDOP, HDOP and VDOP are part from DOP factor for accuracy, described in details in [Wellenhof et al., 2002].

5. NUMERICAL RESULTS FROM THE EXPERIMENTAL GEODETIC MEASUREMENTS. ANALYSIS

Tables NN 1-3 contain information from the post-processing of the GNSS measurements, using *cut-off angle of 0 degrees*. Respectively, tables NN 4-6 summarize the post-processing results of the baselines for *cut-off angle set to 15 degrees*.

The values of the quality criteria (described in details in the previous chapter) in tables NN 1-6 are used later on as input variables in the specialised geodetic software Vienna_Fuzzy (based on the fuzzy logic controller). The application calculates the rating value of each measured baseline and gives the geodesist additional useful information for the overall quality of the system, subject of analysis (in our case – each baseline). In this way the quality assessment of the measured baselines is *independent* from the so called "human factor". For our specific case, the bigger the rating value, the better the overall quality of the system.

According to the previous experiments, done by the author, the system was subject of detailed quality assessment, using explicit values for two parameters (cut-off angle of 0 degrees and occupation time set to 10 min.).

occupation time	length of the baseline - up to 10 km, *cut-off angle 0 degrees*								
	criteria								
	Mp [mm]	Mh [mm]	Q11	Q22	Q33	GDOP max	PDOP max	HDOP max	VDOP max
10 min.	0.7	0.9	0.00000078	0.00000049	0.00000107	1.4	1.3	0.8	1.0
15 min.	0.5	0.7	0.00000066	0.00000034	0.00000045	1.6	1.4	0.7	1.2
30 min.	0.4	0.5	0.00000027	0.00000017	0.00000027	1.6	1.4	0.8	1.2

Table 1

occupation time	length of the baseline - from 10 up to 20 km, *cut-off angle 0 degrees*								
	criteria								
	Mp [mm]	Mh [mm]	Q11	Q22	Q33	GDOP max	PDOP max	HDOP max	VDOP max
10 min.	0.5	0.9	0.00001679	0.00000843	0.00001345	1.7	1.5	0.8	1.2
40 min.	0.3	0.5	0.00000346	0.0000021	0.00000336	1.7	1.5	0.7	1.3
80 min.	0.2	0.3	0.00000204	0.00000113	0.00000218	1.5	1.4	0.9	1.1

Table 2

occupation time	length of the baseline - over 20 km, *cut-off angle 0 degrees*								
	criteria								
	Mp [mm]	Mh [mm]	Q11	Q22	Q33	GDOP max	PDOP max	HDOP max	VDOP max
10 min.	0.5	1.0	0.00002364	0.00000842	0.00001752	1.7	1.5	0.8	1.2
60 min.	0.3	0.5	0.00000352	0.00000152	0.00000291	1.7	1.5	0.8	1.3
120 min.	0.2	0.3	0.00000181	0.00000059	0.00000136	1.7	1.5	0.8	1.3

Table 3

occupation time	length of the baseline - up to 10 km, cut-off angle 15 degrees								
	criteria								
	Mp [mm]	Mh [mm]	Q11	Q22	Q33	GDOP max	PDOP max	HDOP max	VDOP max
10 min.	0.6	0.8	0.0000008	0.00000049	0.00000126	1.9	1.6	1.0	1.3
15 min.	0.5	0.7	0.00000067	0.00000034	0.00000047	1.8	1.5	0.8	1.3
30 min.	0.4	0.5	0.00000029	0.00000018	0.00000028	1.8	1.5	0.8	1.3

Table 4

occupation time	length of the baseline - from 10 up to 20 km, cut-off angle 15 degrees								
	criteria								
	Mp [mm]	Mh [mm]	Q11	Q22	Q33	GDOP max	PDOP max	HDOP max	VDOP max
10 min.	0.6	0.9	0.00002351	0.00000891	0.00001545	2.1	1.8	0.9	1.5
40 min.	0.3	0.5	0.00000374	0.0000023	0.00000358	1.9	1.6	0.8	1.4
80 min.	0.2	0.3	0.00000263	0.00000127	0.00000259	4.3	3.6	2.4	2.6

Table 5

occupation time	length of the baseline - over 20 km, cut-off angle 15 degrees								
	criteria								
	Mp [mm]	Mh [mm]	Q11	Q22	Q33	GDOP max	PDOP max	HDOP max	VDOP max
10 min.	0.5	1.1	0.00002751	0.00001049	0.00002095	1.9	1.6	0.8	1.4
60 min.	0.2	0.4	0.00000382	0.00000165	0.00000311	2.3	1.9	0.9	1.7
120 min.	0.2	0.3	0.00000212	0.00000065	0.00000157	2.4	2.1	0.9	1.9

Table 6

5.1 Analysis of the Results for Baseline "up to 10 km"

The measurements, processed with cut-off angle set to either 0 degrees or 15 degrees , see table 1 and table 4 could be characterized with "*ideal*" and "*excellent*" (according to [http://en.wikipedia.org/wiki/Dilution_of_precision_(GPS)]) values of DOP factor.

It should be noted that the tripled time for occupation of this spatial chord did not lead to substantial improvement of the quality in the position of the new-determined point (0.7 mm vs. 0.4 mm), see table 1. The accuracy in the height component was increased with step of 0.2 mm, if occupation time was extended.

In case of altering of the cut off angle to 15 degrees, a very slight improvement of the quality in the position (from 0.6 mm up to 0.4 mm) and height (from 0.8 mm up to 0.5 mm) was observed, see table 4.

5.2 Analysis of the Results for Baseline "from 10 km up to 20 km"

The numerical values of the relevant criteria for this chord indicate continuous improvement of the quality in the position and height for prolonged length of the session (starting from 10 min. up to 80 min.). However, it should be noted that the improvement in the position is just 0.3 mm, respectively 0.6 mm in the height for 8 times much occupation time. DOP values for this baseline (data processed with cut off angle of 0 degrees) are less than 2, i.e. "*excellent*", see table 2.

Slight increase in DOP values was observed in the session with occupation time set to 80 min., see table 5. It should be noted that the lowest value of rating was calculated for the longest occupation time and cut-off angle of 15 degrees, see table 10. Possible reason for the derived low overall quality of this baseline could be the value of GDOP criteria. Same values for M_P and M_h were calculated for doubled and tripled length of the session, if applied cut-off angle 0 and 15 degrees respectively.

5.3 Analysis of the Results for Baseline "over 20 km"

As it could be seen from table 3 and table 6 the quality in the position of the new-determined point increases from 0.5 mm up to 0.2 mm – i.e. at about 2 times. However, the length of the session was increased from 6 up to 12 times. The quality of the height component was improved starting from 1 mm up to 0.3 mm for cut-off angle of 0 degrees, see table 3.

DOP values for this baseline (if used cut-off angle of 0 degrees) were less than 2 – linguistically expressed as "*excellent*", see [http://en.wikipedia.org/wiki/Dilution_of_precision_(GPS)].

If the cut-off angle was changed to 15 degrees, the rating decreased to 0.5, see table 12. In case of setting this parameter to 0 degrees, it was observed significant improvement of the overall quality of the system. The rating values started from 0.57 and increased up to 0.76 for occupation times 10 min. and 120 min. respectively, see table N 11.

length of the baseline - up to 10 km, *cut-off angle 0 degrees*	
occupation time	**rating**
10 min.	0.53
15 min.	0.52
30 min.	0.52

Table 7

length of the baseline - up to 10 km, cut-off angle 15 degrees	
occupation time	**rating**
10 min.	0.33
15 min.	0.49
30 min.	0.51

Table 8

length of the baseline - from 10 up to 20 km, *cut-off angle 0 degrees*	
occupation time	**rating**
10 min.	0.58
40 min.	0.68
80 min.	0.78

Table 9

length of the baseline - from 10 up to 20 km, cut-off angle 15 degrees	
occupation time	**rating**
10 min.	0.58
40 min.	0.68
80 min.	0.56

Table 10

length of the baseline - over 20 km, *cut-off angle 0 degrees*	
occupation time	**rating**
10 min.	0.57
60 min.	0.67
120 min.	0.76

Table 11

length of the baseline - over 20 km, cut-off angle 15 degrees	
occupation time	**rating**
10 min.	0.57
60 min.	0.50
120 min.	0.50

Table 12

6. CONCLUSION. RECOMMENDATIONS. FUTURE WORK

This experiment studied the results from the post-processing and the rating of three baselines with various lengths, following the current regulatory requirements, also using certain values of the parameters from previous work of the author.

In tables NN 7-12 are listed the various calculated values of the rating for each baseline. The last denotes the obvious difference in the overall quality of the measured baselines, subject of assessment.

In the case – analysing spatial chord of up to 10 km at 0 degrees cut-off angle, the rating is almost one and the same – valued to 0.52 and 0.53 for observation times from 10 up to 30 min., see table 7. These results show that at short distances, if using for instance cut-off angle of 0 degrees and length of the session 10 min., the final results would have similar overall quality, regardless to the occupation time. A change of the cut-off angle to 15 degrees would decrease the quality of the results, see table 8, compared to table 7.

According to the middle range distances – the baseline "from 10 up to 20 km", it could be summarized that results with highest possible overall quality could be obtained, if doubled observation time was applied, as required by [MRD, 2011] and *cut-off angle of 0 degrees* was used, see table 9.

The analysis for the long-range distances (the spatial chord "over 20 km") show, that maximum overall quality was obtained for occupation time 120 min. at 0 degree cut-off angle, see table 11. The change of the cut-off angle to 15 degrees, see table 12 was the possible reason for the low value of the rating.

Nevertheless, based on the numerical results, given in table 3 it could be summarized that the relative difference in M_P and the longest session was just 0.3 mm. Also, an improvement in the position of the new-determined point of only 0.1 mm was achieved for doubled occupation time (from 60 min. set to 120 min.).

Based on the calculated numeric values of the used quality criteria, also the rating of each measured baseline it could be concluded with the following recommendations:
-if cut-off angle of 0 degrees is applied, with the usage of nowadays GNSS status, the results from the post-processing of the baselines would have highest overall quality;
-the extension of the session's length does *not* necessarily leads to (substantially) improvement in the accuracy of the determination of the baseline, see tables NN 7 and 12;
-a prolongation of the occupation time would cause significantly *decrease of the productivity*, which is essential for the geodetic practice;
-the improved quality (e.g. in the position of the new-determined point) of all baselines under assessment was maximum 0.3 mm (derived experimentally, see tables NN 1, 2 and 3), which might not be of significance for the geodetic applications.

Future work - this study and its experimental results could be used for an update of the current regulatory requirements, according to the technical possibilities nowadays and the continuous improvement of the GNSS status.

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Used Software:

1. Geomax Geo Office;
2. GNSSTransformations;
3. Vienna_Fuzzy.

BIOGRAPHICAL NOTES

Gintcho Kostov graduated in UACEG, Sofia in 1998. He works in "GEO ZEMIA" Ltd. since 2001. In TU Wien, Austria he completed and defended a scientific project, entitled "Assessment of the Quality of Geodetic Networks Using Fuzzy Logic". He has teaching activities in UACEG, Sofia. Dr. Kostov holds the following licenses: for performing of activities in the area of geodesy, cadastre, investment design and privatization. He holds: diploma for membership in the Union in Scientists in Bulgaria, Chambers of the Engineers in Geodesy, Chambers of the Engineers in Investment Design, diploma for best presentation as a young scientist. He is a member of the Union of Surveyors and land Managers in Bulgaria, Union in Scientists in Bulgaria, Chamber of Engineers in Geodesy and Chamber of Engineers in Investment Design. He is a member (in part Geodesy) of the Councils of Experts in Municipalities: Stara Zagora and Opan.

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