ASSESSING OF THE OVERALL QUALITY OF GNSS DETERMINATIONS, USING SPECIFIC VALUES OF PARAMETERS

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Abstract

This paper studies the variations of the quality of the results from GNSS (GPS and GLONASS) geodetic measurements, using: specific length of session time, cut-off angle and changed record rate of the observations. For performing of the experiment, fast static geodetic measurements were done. Seven spatial chords were subject of geodetic measurements and quality assessment. The post-processing was done with the GNSS firmware. The values of the derived quality criteria: $M_{3D}, Q_{xx}, Q_{yy}, Q_{zz}$, GDOP *and* PDOP *- quality in position and height, elements of the co-variance matrix for the chord, number GDOP and number PDOP were used for further calculations. These quality criteria were treated as input data in the application Vienna_Fuzzy (using the theory of Fuzzy logic). For the calculation of a rating value specific rules, defined by the user were applied. According to the derived results, conclusions are given and proposals for future work are done.*

1. INTRODUCTION

Nowadays the Information Technologies, applied into the geodetic GPS equipment make possible the reception of the signals from more than one global navigation satellite system (e.g. GPS, GLONASS and the available in the future GALILEO and COMPASS). The possibility for use of the last two GNSS systems should make step forward in the overall improvement of the satellite measurements.
As it is known, see [http://facility.unavco.org/], [Wellenhof et al., 2002], the fast static method for geodetic satellite determinations is one of the most precise ones when high accuracy is required.
In this paper an experiment is performed aiming to determine the possible differences in the overall quality of determined spatial chords, when using specific: length of session time, cut-off angle value and record rate for the geodetic satellite measurements.
The overall quality of the spatial chords is assessed with the mathematical instrument of Fuzzy logic - the application Vienna_Fuzzy [Kostov, 2005].

2. FUZZY LOGIC – THEORETICAL FOUNDATIONS

The so called fuzzy multitude consists of values of a given variable " X " and the relevant values of the characteristic (membership) function $\chi(X)$, abbreviated as MF. Its values are in the closed interval [0, 1], indicating its degree of "membership". When $\chi(X) = 0$, there is no membership, and for $\chi(X)$ =1 there is full membership. The idea of the fuzzy variables is linguistic – "small", "big", "very big", etc. Example: the number 0.1 can be treated as small, 0.6 as big and 0.99 as very big. Using the values of the membership – the so called rating it can be assessed the quality of a given system. The general principle of a fuzzy controller is:

Input>Fuzzification>Inference>Defuzzification

In the beginning exact values of the variables are entered, which are then fuzzified, this means with the relevant MF they get their value for the degree of membership. When performing the inference, the weights and the relevant operator ("and", "or") are applied. The last part - defuzzification is used to obtain an exact value - the rating. A number of methods exist to perform this final part of the calculation, but the most appropriate and commonly used one is the centroid method of defuzzification.

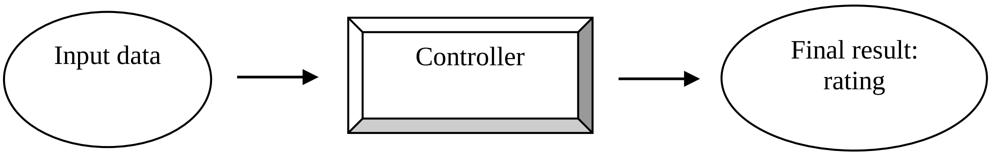

Figure 1. Graphical example of the system

For example, if GDOP or PDOP (see chapter 6) are small numbers, then the measured chord is well determined. Generally, using Fuzzy logic the user can assess a system, which consists of both very small or large values. The assessment is done using the so called "rules", defined by the human.
For instance, if „a" and "b" are small numbers, then the system is good (well) determined. Here with „a" and "b" are denoted the relevant input variables.
The general structure of a rule is: input variables, resulting MF, weight, logical operator ("and (1)", "or (2)"). For example, if the user defines "a" and "b" as input variables, the rules may look in the following way:

Table 1. Example and description for three rules in numerical format

a	b	resulting MF	weight	logical operator
-1	0	1	0.22	1
1	0	2	0.50	2
0	1	2	0.88	1

When the calculations are performed, a value for the rating in the interval [0,1] will be produced. This value tells what the quality of the assessed system is. In our particular case, if the rating is 0.22, the system is not well determined, but if the value is 0.75 the chord has good quality.

3. APPLYING FUZZY LOGIC FOR ASSESSMENT OF THE OVERALL QUALITY OF MEASURED SPATIAL CHORDS

A number of publications exist, describing the applications of Fuzzy logic in geodesy: [Haberler, 2003], [Kostov, 2005], [Wieser, 2001].
Another possible application of Fuzzy logic in space geodesy, using Vienna_Fuzzy will be given in this paper – for assessment of the overall quality of measured spatial chords, using GNSS technology and equipment. The measured chords are determined using session length of up-to 5 min., cut-off angle set to 0 degrees in the firmware and record rate of the observations consecutively set to 1 sec., 15 sec., 30 sec. and 60 sec.
Some publications, treating the record rate could be listed here: [Yeung, 2006], [Grigoriadis et al., 2004] and [http://www.geo.bv.tum.de/images/stories/lehre/docman/GPSBasics_en.pdf]. One different study on the influence of the record rate on the results from the measurements will be given in this paper.
To eliminate the subjective factor from overall assessment of the quality of measured chords, Fuzzy logic was used. As input data in the last are used the following variables: $M_{3D}, Q_{xx}, Q_{yy}, Q_{zz}$, GDOP (max) and PDOP (max), described in details in chapter 6.

4. SOURCES OF ERRORS, INFLUENCING THE QUALITY OF GNSS DETERMINATIONS

In case the geodesist plans to use GNSS technology, then several factors concerning the quality of the satellite determinations should be carefully considered. According to [Minchev et al., 2005], the main sources of errors in satellite measurements and data processing are: errors from synchronizing of clocks in satellites and receiver, satellite orbit, troposphere refraction, ionosphere refraction, variations in the phase center of the antenna, multipath.
Another information about the sources of errors in GNSS measurements and possible ways for their mitigation can be found also in [Wellenhof et al., 2002] and [Valev et al., 1995].

5. PERFORMED GEODETIC MEASUREMENTS

In order to study the overall quality of the performed geodetic satellite measurements, using GNSS equipment in fast static mode, experiments are done.
In this paper subject of assessment are seven spatial chords, with lengths as follows:
– up-to 5 km.;
– from 5 km. up-to 10 km.;
– from 10 km. up-to 15 km.;
– from 15 km. up-to 20 km.;
– from 20 km. up-to 25 km.;
– from 25 km. up-to 30 km.;
– over 30 km.
The record rate of the satellite signals was set consecutively from 1 sec. to 60 sec., as stated in chapter 3.
Measurements were done with occupation length of up-to 5 min., taking in mind the results and conclusions in [Kostov, 2009].
The occupied points were situated in open areas, without interference sources in vicinity.
The value for the cut-off angle was set to 0 degrees in the firmware.
The time interval was planned and chosen short enough as to provide similar conditions for conducting of the geodetic satellite measurements.

6. USED CRITERIA FOR ASSESSMENT OF THE OVERALL QUALITY OF THE MEASURED SPATIAL CHORDS

In this study the following quality criteria were used:
– Quality in position and height M_{3D};
– Elements of the co-variance matrix of the measured chord Q_{xx}, Q_{yy} and Q_{zz};
– Number $\mathrm{GDOP(max)}$;
– Number $\mathrm{PDOP(max)}$.
The numbers GDOP and PDOP are part from DOP factor for accuracy, described in [Wellenhof et al., 2002].

7. NUMERICAL RESULTS

The recorded raw data from the satellite observations was imported in the firmware for post-processing. The mentioned in the previous chapter quality criteria were calculated for each measured spatial chord.
Based on the data – the parameters (see chapter 6), the rating value for the chords, subject of assessment was calculated for each session. It should be noted, that in this specific case, the bigger the rating value, the better the overall quality of the chord. The numerical results for the rating values are given in the tables below:

Table 2. Chord N 1

Spatial chord – length up-to 5 km.				
	Record rate			
Variables	1 sec.	15 sec.	30 sec.	60 sec.
M3D	0.0002	0.0011	0.0012	0.0023
Qxx	0.00000043	0.00000683	0.00001475	0.00003403
Qyy	0.00000017	0.00000239	0.00000492	0.00001109
Qzz	0.00000046	0.00000665	0.00001421	0.00003494
GDOP	1.8	1.7	1.6	1.5
PDOP	1.6	1.5	1.4	1.3
Rating	0.50	0.37	0.63	0.71

Table 3. Chord N 2

Spatial chord – length from 5 km. up-to 10 km.				
	Record rate			
Variables	1 sec.	15 sec.	30 sec.	60 sec.
M3D	0.0003	0.0013	0.0023	0.0031
Qxx	0.00000043	0.0000067	0.00001429	0.00003391
Qyy	0.00000016	0.0000024	0.0000049	0.00001117
Qzz	0.00000036	0.00000593	0.00001302	0.00003185
GDOP	1.6	1.6	1.6	1.6
PDOP	1.4	1.4	1.4	1.4
Rating	0.80	0.74	0.70	0.70

Table 4. Chord N 3

Spatial chord – length from 10 km. up-to 15 km.				
	Record rate			
Variables	1 sec.	15 sec.	30 sec.	60 sec.
M3D	0.001	0.0019	0.0031	0.0045
Qxx	0.00000053	0.00000706	0.00001446	0.00003208
Qyy	0.0000002	0.00000271	0.00000533	0.00001134
Qzz	0.00000042	0.00000586	0.00001244	0.00002838
GDOP	1.6	1.6	1.6	1.6
PDOP	1.4	1.4	1.4	1.4
Rating	0.80	0.73	0.63	0.63

Table 5. Chord N 4

Spatial chord – length from 15 km. up-to 20 km.				
	Record rate			
Variables	1 sec.	15 sec.	30 sec.	60 sec.
M3D	0.0011	0.003	0.005	0.0062
Qxx	0.00001	0.00014768	0.00031112	0.00067631
Qyy	0.00000347	0.00004821	0.00010206	0.00022415
Qzz	0.00000812	0.00012661	0.00026866	0.00058624
GDOP	1.8	1.9	1.9	1.9
PDOP	1.6	1.7	1.7	1.7
Rating	0.80	0.39	0.23	0.20

Table 6. Chord N 5

Spatial chord – length from 20 km. up-to 25 km.				
	Record rate			
Variables	1 sec.	15 sec.	30 sec.	60 sec.
M3D	0.0008	0.0034	0.0051	0.0071
Qxx	0.00000918	0.00012535	0.00022258	0.00053121
Qyy	0.00000357	0.00005082	0.00008755	0.00020572
Qzz	0.00000696	0.00010696	0.00020298	0.00049981
GDOP	1.5	1.6	1.7	1.7
PDOP	1.3	1.4	1.5	1.5
Rating	0.80	0.50	0.24	0.20

Table 7. Chord N 6

Spatial chord – length from 25 km. up-to 30 km.				
	Record rate			
Variables	1 sec.	15 sec.	30 sec.	60 sec.
M3D	0.0007	0.0027	0.0057	0.0082
Qxx	0.00000907	0.00014679	0.00031955	0.0007699
Qyy	0.00000341	0.00005598	0.00012807	0.0003369
Qzz	0.00000897	0.00013342	0.00029853	0.0006292
GDOP	1.7	1.7	1.8	1.8
PDOP	1.5	1.5	1.6	1.6
Rating	0.80	0.76	0.23	0.20

Table 8. Chord N 7

Spatial chord – length over 30 km.				
	Record rate			
Variables	1 sec.	15 sec.	30 sec.	60 sec.
M3D	0.0013	0.004	0.0065	0.0131
Qxx	0.00001203	0.00019945	0.00042628	0.0009984
Qyy	0.00000636	0.00011991	0.00028044	0.0006578
Qzz	0.0000096	0.00015039	0.00031776	0.0007575
GDOP	2.1	1.6	1.5	1.9
PDOP	1.8	1.4	1.4	1.6
Rating	0.51	0.74	0.72	0.47

8. RESULTS AND REMARKS. CONCLUSIONS

In this paper an experiment using the signals from GPS and GLONASS satellite systems was done.
Here could be noted the following facts and conclusions.
Highest rating for the chord with length of up-to 5 km. (Table 2) was calculated when the record rate of the satellite signals was set to 60 sec. The overall quality of the chord was valued to 0.71. Similar result was calculated when the record rate was set to 30 sec. Lower quality, valued to 0.50 was calculated for the measurements, conducted at record rate of 1 sec.
Next spatial chord, subject of quality assessment was with length from 5 km. up-to 10 km. For its overall quality (Table 3) could be summarized: highest quality, valued to 0.80 was calculated when the record rate of the satellite signals was set to 1 sec. Similar quality results were obtained for 15 sec., 30 sec. and 60 sec. record rates – rating in the interval [0.70,0.74].
The spatial chord with length from 10 km. up-to 15 km. (Table 4) has its highest rating value, calculated for record rate of 1 sec. For the other cases – record rates set to 15 sec., 30 sec. and 60 sec. were calculated ratings with similar values in the interval [0.63,0.73].
The next analyzed chord was with length from 15 km. up-to 20 km. (Table 5). Its best overall quality, valued to 0.80 was calculated for the record rate set to 1 sec. The ratings for other cases were significantly worse – values between 0.20 and 0.39.
Similar results were obtained for the spatial chords with lengths from 20 km. up-to 25 km. (Table 6) and from 25 km. up-to 30 km. (Table 7). High overall quality was calculated for record rate of 1 sec. Lower rating values were obtained for: 15 sec., 30 sec. and 60 sec. observation rates.
Exception from the results, calculated at record rate of 1 sec. was observed for the largest measured chord over 30 km. (Table 8). Its best overall quality valued to 0.74 was obtained for record rate set to 15 sec., while for 1 sec. observation rate was produced rating 0.51.
Taking in mind the values of the ratings for each spatial chord, subject of quality assessment it could be summarized:

According to the calculated values of the input variables and the derived rating, the possible reason for the low overall quality of the chord with length of up-to 5 km. for record rate of 1 sec. could be the high values of GDOP and PDOP numbers. The same likely reason for low quality should be valid for the chord with length over 30 km. using record rate of 1 sec.
Based also on the conclusions in [Kostov, 2005] that rating could be used as additional information for geodesists, it could be concluded the following. If no other instructions or rules must be applied to the geodetic satellite measurements, in order to produce results with good overall quality, then record rate for example of 1 sec. and cut-off angle of 0 degrees should be used when conducting fast static GNSS measurements. The IT implemented in the geodetic GNSS equipment controls the quality of the signals from satellites on low elevation angles.

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Used software:
1. Geomax Geo Office;
2. Vienna_Fuzzy.