Assessment of the Accuracy and Reliability of GNSS Measurements in RTK mode, Performed with Inclined pole, Applying Fuzzy Logic

Gintcho KOSTOV, Bulgaria

Key words: GNSS measurements, inclined pole, Fuzzy logic

SUMMARY

Satellite navigation systems are subject of continuous significant improvements, which reflects on the quality and reliability of the geodetic measurements, done with contemporary equipment.

The overall quality of the results from the satellite measurements is a topic of significant importance to be discussed, especially when the case is about geodetic activities, performed in specific conditions.

Nowadays, a number of producers of GNSS equipment provide hardware to the end user, able to perform measurements via inclined pole. This technical ability opens new horizons for the geodesists. The possible applications are significantly increased, where geodetic measurements could be conducted in this way.

This paper studies the quality results from GNSS measurements, done in RTK mode, performed via inclined pole and assesses them applying Fuzzy logic. The quality criteria, calculated by the GNSS system were treated as input data in a geodetic software - Vienna_fuzzy (for assessment of the overall quality of geodetic measurements and determinations). In the field a number of measurements were conducted to ensure the redundancy of the gathered data.

In this specific case the input parameters in the application for assessment of GNSS measurements were: $\sigma N, \sigma E, \sigma Z, PDOP,$ satellites used. These parameters were processed, using the relevant rules in Fuzzy logic.

The reliability of the performed geodetic measurements was assessed done by two independent ways: human and Fuzzy logic.

The final results, calculated by Vienna_fuzzy – i.e. the rating of each measured point were analysed. Conclusions and proposals for future geodetic activities were given in the paper.

Assessment of the accuracy and reliability of GNSS measurements in RTK mode, performed with inclined pole, applying Fuzzy logic

Gintcho KOSTOV, Bulgaria

1. INTRODUCTION

Nowadays GNSS technology continues to improve its technical parameters. In particular, the modernization in the receivers is comprised of and is not limited to: number of channels, battery life, weight and others. The improvements in the hardware and software lead to new possible ways for performing of geodetic measurements. Currently, using contemporary GNSS equipment the geodesist benefits from a number of improved hardware abilities like: tracking of several satellite systems, possibility for measurements via inclined pole, etc.

GNSS technology is constantly upgraded, which gives better: performance, overall quality and reliability of the results from the geodetic measurements. Another important result from the modernization of this technology is the possibility to be obtained good quality results from certain measurements – in this specific case performed via inclined pole.

The technical possibility for conducting of GNSS measurements via inclined pole is described in several literature sources: https://www.southinstrument.com/company/details/id/401.html, https://leica-geosystems.com/products/gnss-systems/smart-antennas/leica-gs18-t/gnss-setting-out-with-no-need-to-level-the-pole-vertically, http://www.terrisgps.com/product/stonex-s900-gnss-receiver/, https://geomax-positioning.com/SFTP/files/GeoMax/Downloads/GeoMax%20Zenith35%20PRO%20BRO%20849552%201118%20enus%20LR.pdf and http://www.foif.com/news/auto-data-collection-and-incline-measurement-foif-a30-0.

There are a number of publications for tilt compensated GNSS measurement and here are listed some of them: https://www.gpsworld.com/true-tilt-compensation-gnss-presented-by-leica, https://www.xyht.com/surveying/full-tilt/, https://eprints.usq.edu.au/43139/12/Smouha_J_McAlister_Redacted.pdf and https://www.fig.net/resources/proceedings/fig_proceedings/fig2018/papers/ts04e/TS04E_luo_schaufler_et_al_9407.pdf

In the above-mentioned papers it was also studied the quality of the obtained results, e.g. "How Precise?". Here, one different approach will be given. In this study the overall quality assessment of the results from the measurements, performed via inclined pole was done using one single number – rating, calculated applying Fuzzy logic.

Based on the given above information and the current technical parameters of the satellite systems, several topics are discussed in this paper, applying the theory of Fuzzy logic:

- What are the overall accuracy results in case the geodetic measurements are performed via inclined pole;
- How much is the eventual difference in the quality of a point, determined in various angles of inclination of the pole.

In this specific case the results from the geodetic measurements were assessed via Fuzzy logic – independently from the "human expert". It should be noted that the measurements in this study were performed in the open field, away from any passive disturbers in vicinity.

The paper studies the quality results from RTK measurements, using four satellite navigation systems: GPS, GLONASS, GALILEO and BeiDou. In this case Fuzzy logic was applied and application Vienna_fuzzy was used, details are given in chapter 5.

The aim of the study is to be obtained one single value as a quality assessment result for each occupation of the chosen point.

2. FUZZY LOGIC AND ITS POSSIBLE APPLICATIONS IN GEODESY

The foundations, also the principles for application of Fuzzy logic could be found in e.g. [Wieser, 2001] and https://www.sciencedirect.com/science/article/pii/S1674984717300101. The so-called fuzzy set contains in itself several values of a given variable "X" and also the corresponding values of the characteristic function $\chi(X)$. This function has values in the closed interval [0,1], showing its degree of "membership". For example, if $\chi(X) = 0$, this means that there is no existing "memberhip". If $\chi(X) = 1$ this indicates full "membership".
Based on the numerical values of the "membership" (also called *rating*) one could assess the overall quality of a given system – how much it's good, respectively bad. The general scheme of the fuzzy system is:

input of the data → fuzzification → conclusion → defuzzification

In the beginning of the data processing the values of the relevant parameters must be input. The numerical data is then processed by the relevant procedures by the so-called controller. These set of steps are called fuzzification. The system performs the relevant conclusion and obtains the final result. The last step is to be obtained one single number – *rating,* fig. 1, which tells what is the quality of the system under assessment. The process is called defuzzification.

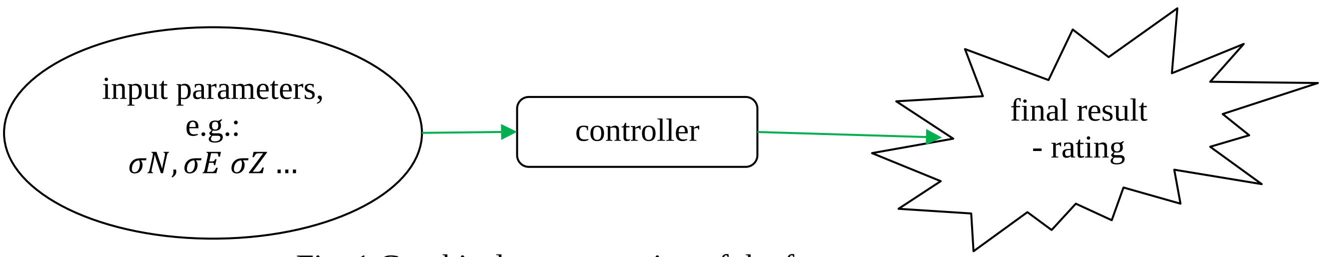

Fig. 1 Graphical representation of the fuzzy system

In general, using Fuzzy logic it could be assessed a system which parameters /numerical values/ are both small and big numbers. The assessment is done via user-defined rules, describing the relations between the parameters in the system.

In Internet there are a lot of publications in the area of Fuzzy Logic, especially for geodetic purposes (GNSS, data processing. etc.), e.g. [Kostov, G., 2009], [Kostov, G., 2012], [Wieser, A. 2003], and https://www.sciencedirect.com/science/article/pii/S1674984717300101.

According to the certain requirements of the tasks more applications in geodesy could be found. Here, in this study is given one other possible usage of Fuzzy Logic, especially to assess the results from GNSS measurements. The attention is focused on the assessment of the accuracy and reliability of the results from the conducted geodetic measurements, performed via inclined pole. In this specific case one single number was used - the rating. The input data /parameters/ for Fuzzy logic here are: $\sigma N, \sigma E, \sigma Z, PDOP, satellites\ used$.

In our case if $\sigma N\ and\ \sigma E\ and\ \sigma Z$ are small numbers, then the system has good quality. Here $\sigma N, \sigma E, \sigma Z$ are input parameters for the system as shown in fig. 1. In some cases, the geodesist uses only the first two criteria to assess the achieved accuracy. For other specific tasks, the third quality criterion is also taken into account. In case if required reliable, precise and overall quality assessment of the results from the field work not only the "human expert" decision should be taken into account. Another, independent assessment should be done with the mentioned above five parameters and using Fuzzy logic, is shown in chapter 5.

3. PERFORMED GEODETIC MEASUREMENTS VIA INCLINED POLE. RESULTS AND ANALYSIS

In order to be obtained complete and reliable overall quality assessment results, the following field procedure was performed. One point from the national geodetic network, situated in the open field was measured in two different days, during daylight lime.

It was necessary to have sufficient number of geodetic measurements, performed at various inclination angles. The last were chosen to be approximately 30, 60 and 90 degrees from the vertical line at the geodetic point. It should be noted, that in this specific case under "measurements at 90 degrees inclination angle of the pole" is understood pole situated closest as possible to the ground, but not put to lie on the ground.

The pole was also oriented approximately in the four world directions. In this way a control was performed for any discrepancies between the results from the measurements, derived from inclined and vertical pole. Another control was performed for existence of large errors in case of inclination angle over 30 degrees. Detailed results are given in: chapter 4 and chapter 5.

The geodetic measurements were done in RTK mode using GNSS permanent network and processed in the controller with "inclined pole" option activated. The quality results and the number of common satellites /parameter "satellites used"/ were exported from the controller and listed in table 1 and table 2.

N	σN	σE	σZ	PDOP	satellites used	Tilt [deg]
573	15	12	27	1.4	29	00:45
1	16	18	26	1.19	30	24:49
2	17	28	26	1.19	30	42:38
3	21	38	29	1.29	28	68:29
4	21	12	27	1.24	29	23:38
5	31	14	33	1.27	28	52:13
6	40	16	37	2.06	27	77:45
7	15	18	27	1.24	29	25:56
8	17	29	30	1.24	29	52:07
9	20	36	34	1.27	29	80:49
10	21	13	27	1.24	29	29:53
11	29	15	30	1.4	28	56:06
12	34	17	31	1.4	26	74:43

Table 1 Quality results from first part of the measurements

The values of the parameters (which later on were input in Fuzzy logic) from the first part of the measurements are given in table 1. From this table it could be summarized the following facts:

1. σN quality criterion has its lowest and almost similar values in case the measurements were done via vertical or up to 30 degrees inclined pole. The results are valid for first measurement and measurement N 1. It was observed almost the same accuracy for pole, inclined up to 60 degrees (measurements NN 2, 7 and 8). Significant change/deterioration in the quality of the point determinations was observed in case the pole was close to the ground (measurements NN 6 and 12).

2. σE quality criterion has low values in case the pole was in vertical position (first measurement) and the inclination of the pole was up to 30 degrees – measurements NN 4 and 10). In all other cases it was observed significant loss of quality. The worst determination was measurement N 3 – accuracy of 38 mm. It could be seen one exception – measurement N 12, done via pole next to the ground has quality of σE=17 mm.

3. σZ quality criterion in some geodetic tasks is neglected, since the job requires information only in certain map projection. In our specific case, the values of σZ were between 26 and 37 mm. This quality criterion was with lower value than σN for measurement N 6 and almost similar to σE, compared in measurement N 9. These quality results show the possible variations of the height error in our case.
4. PDOP criterion – for all measurements, except N 6 (pole positioned next to the ground) the values are less than 2 and could be classified as excellent.

5. Satellites used parameter– in the open field, without any disturbers in vicinity were used between 26 and 30 common satellites. It could be clearly seen that even in case the pole was next to the ground (measurement N 9), the number of the used satellites was the same as if the pole was vertical.

The same measurement procedure was performed once again. The results from the second part are given in table 2 below.

N	σN	σE	σZ	PDOP	satellites used	Tilt [deg]
573	15	12	25	1.35	30	00:39
1	15	27	25	1.35	30	22:22
2	17	41	25	1.35	30	44:49
3	26	52	31	1.88	27	78:45
4	20	12	25	1.48	30	20:43
5	28	13	26	1.35	30	48:51
6	36	15	30	1.35	28	80:16
7	16	15	26	1.35	30	22:36
8	17	25	29	1.35	30	52:50
9	19	32	33	1.5	29	81:31
10	20	14	26	1.39	30	26:36
11	27	15	28	1.45	30	49:09
12	36	17	32	1.4	27	73:35

Table 2 Quality results - second part of the measurements

Based on the numerical results in table 2 it could be noted:
1. σN quality criterion has its best values for measurements (NN 1 and 7), performed via vertical and up to 30 degrees inclined pole. There are two exceptions for this quality criterion:

- for measurement N 4 is observed value of σN=20 mm, which is worse quality than almost all others. In this case the pole was inclined up to 30 degrees;
- for measurement N 9 the value of σN=19 mm, which is much better than all other measurement, performed via pole next to the ground;
Poor quality was observed for measurements NN 6 and 12, done via pole next to the ground.

2. σE quality criterion could be characterised with excellent values (better than σN) in case of measurement via vertical pole and inclination of up to 30 degrees (measurement N 4). Slightly worse quality values were calculated for measurements NN 7 and 10, respectively 15 mm and 14 mm. It should be noted, that even via inclined pole – up to 30 and 60 degrees the same value - 15 mm for σE was calculated, which is valid for measurements NN 7 and 11.

3. σZ quality criterion has much more stable values, starting from 25 mm (vertical pole) and reaching lowest quality of 33 mm for measurement N9, done via pole next to the ground. It is important to be noted, that there was not a significant difference in the error if the pole was inclined up to 60 or 90 degrees, which is valid for almost all measurements.

4. PDOP criterion could be characterised with stable and excellent values, less than 2. It could be noted, that almost all values of PDOP fall below 1.5. Only for measurement N9 was calculated value of 1.5. Maximum value, but still excellent for PDOP was observed for measurement N 3, having PDOP=1.88.

5. Satellites used parameter – for almost all of the measurements were used 30 common satellites. Their number slightly decreases in case of pole next to the ground - measurements (NN3 and 12). For these specific measurements the number of used satellites was 27.

Here in the second part of the measurements were studied again the values of: $\sigma N, \sigma E, \sigma Z, PDOP, satellites\ used$. The values vary and this could be clearly seen in table 2. It would be hard to be assessed the overall quality of the measured point and determine "how much" it has been degraded if e.g., the pole was inclined up to 60 degrees. In this specific case, in order to have a reliable quality assessment and reasonable answer of "how accurate" is the point a study using Fuzzy logic was done, which details are given in chapter 5.

Taking in mind the given information in this chapter (various values of five parameters) it would be almost impossible to be done conclusion, based on the "human expert" for the overall quality and reliability of the measurements, performed via vertical and inclined pole.

Based on the measured coordinates of the point graphical representations of the results are given in fig. 2 and fig. 3. In black colour are given the measurements' names (in this case as numbers) and in red colour - the calculated discrepancies between the "true" position (vertical pole) and the positions, determined via inclined pole. The arrow shows which one is the point, measured via vertical pole.

4. GRAPHICAL ANALYSIS OF THE RESULTS FROM CONDUCTED GNSS MEASUREMENTS

From the graphical information on fig. 2 it could be noted the following facts:
-the biggest discrepancies have values of 32 mm and 38 mm, situated in approximately perpendicular directions. Measurement N6 has the biggest error in the height component, compared with all other results from the same day. This specific measurement was performed via pole positioned next to the ground;
-slightly better results were obtained for measurement N1 (pole, inclined up to 30 degrees). It could be accepted, that the difference of 6 mm between the both discrepancies might be neglected, according to the specifics of the performed measurements.
-the value of 6 mm, given above shows, that there is almost no practical difference if the pole was inclined up to 30 degrees or positioned just next to the ground.

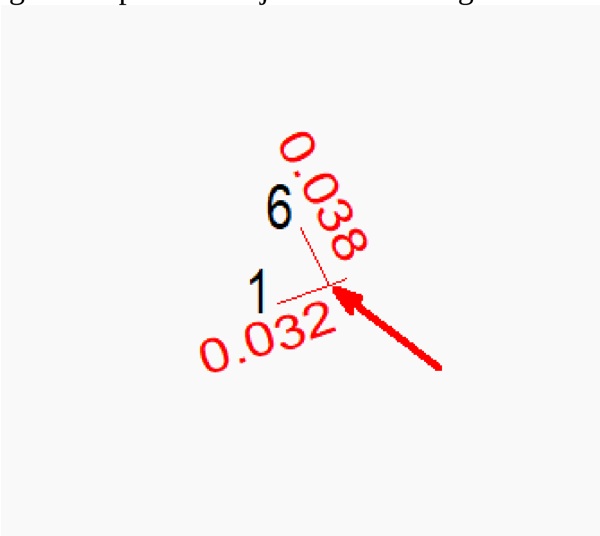

Fig. 2 Calculated discrepancies in the plane for the first part of the measurements

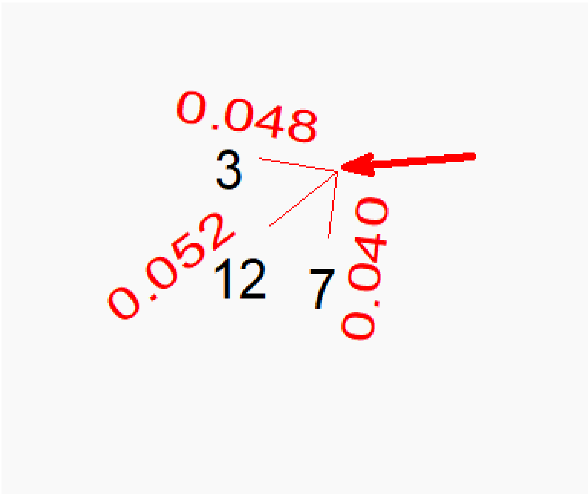

Fig. 3 Calculated discrepancies in the plane for the second part of the measurements

From the graphical data on fig. 3 it could be summarised:
-significant discrepancy of 52 mm was calculated between the positions, determined via vertical pole and pole, put next to the ground - measurement N12;
-measurement N3, performed via pole positioned next to the ground has significant discrepancy of 48 mm from the "true" position. This is bigger value, compared with the results from the first part of the measurements;
-discrepancy of 40 mm was observed in the results from measurement N7, which was performed via pole, inclined up to 30 degrees. The value of this difference from the "true" position could be treated as large for such angle of inclination.

5. ASSESSMENT OF THE OVERALL QUALITY AND RELIABILITY OF THE GNSS MEASUREMENTS VIA INCLINED POLE USING FUZZY LOGIC

The raw data from the geodetic measurements via inclined pole was processed applying the named in the same way menu option "process" in the controller. In this way were calculated the correct coordinates of the point for each measurement. From the controller's software were exported the values of: $\sigma N, \sigma E, \sigma Z, PDOP, satellites\ used.$ These values were used as input parameters required for the quality assessment in Fuzzy logic. The calculations, necessary for the obtaining of the rating value for each single measurement of the point were done using the specialized geodetic software Vienna_fuzzy, which window is given in fig. 4.

The software Vienna_fuzzy calculates a value, called *rating*. The last gives information about the obtained overall quality of the system under assessment. In this study the rating tells how accurate is each result from the GNSS measurements of the point. For this specific case, *the bigger the rating value*, *the better is the overall quality* of the relevant point determination. Detailed information for the application can be found in [Kostov, 2007].

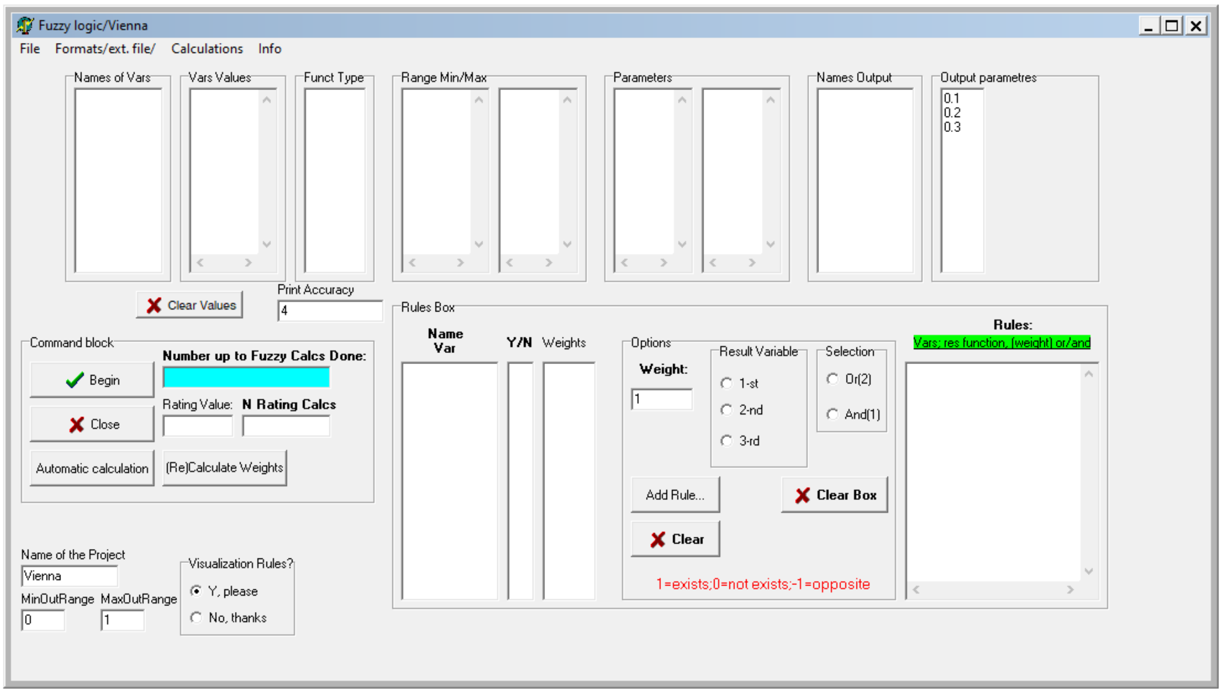

Fig. 4 Application Vienna_fuzzy

In our specific case the software Vienna_fuzzy calculated the rating values, which are given in table 3 and table 4 below. From the results (the values of the rating) it could be concluded:
-the rating is highest /the quality is good/ if the pole is vertical. There is one exception observed for measurement N1 in table 3;
-the rating begins to decrease its values which means, that the quality becomes poor in case the pole is inclined;
-overall quality of each point, measured via pole up to 30 degrees keeps high rating, almost equal to the measurements, done via vertical pole;
-the rating values in general are not the same in case the inclination angle is approximately for example up to 60 degrees;
-in case the pole is positioned next to the ground the rating values are smallest, but are in the boundaries between 0.48 to 0.51. In this case was observed almost one and the same lowest overall quality.

N	inclination [deg]	rating
573	0	0.69
1	24	0.75
2	42	0.59
3	68	0.51
4	23	0.69
5	52	0.51
6	77	0.50
7	25	0.69
8	52	0.58
9	80	0.50
10	29	0.69
11	56	0.52
12	74	0.50

Table 3 First part of the measurements and their rating values

N	inclination [deg]	rating
573	0	0.73
1	22	0.60
2	44	0.50
3	78	0.48
4	20	0.63
5	48	0.54
6	80	0.50
7	22	0.73
8	52	0.63
9	81	0.51
10	26	0.70
11	49	0.55
12	73	0.50

Table 4 Second part of the measurements and their rating values

6. CONCLUSION

This paper studied the results from GNSS measurements, conducted both via vertical and inclined pole. The relevant overall quality assessment was also performed, applying Fuzzy logic.

The study went through several main steps:
-the measured coordinates were processed in the controller of the equipment. In this way the results (coordinates and heights) were reduced to the centre of the geodetic point;
-the values of: $\sigma N, \sigma E, \sigma Z, PDOP, satellites\, used$ were extracted from the controller and further on used as input parameters in Fuzzy logic, via the geodetic software Vienna_fuzzy.
-the calculated rating values of each determination of the point were analysed.

From the final results of this study - the rating value for each position of the pole, given in table 3 and table 4 it could be concluded:
-the extreme values of the rating are: min. 0.48 and max. 0.75;
-one exception from all results was observed for measurement N1 in table 3. This could be explained with the lower value of PDOP and one more used satellite in the point determination, compared to the measurement via vertical pole;
-in the second part of the measurements the variations of the rating between vertical and inclined up to 30 degrees pole are not significant: almost similar values with maximum difference of 0.13;
-significant differences in the overall quality, in the interval [0.10-0.23] were observed in case the pole was inclined at angle up to 60 degrees;
-variations in the interval [0.01, 0.12] in the overall quality were calculated if the inclination angle was changed from 60 to 90 degrees.
-in case the pole was put closest possible to the ground the quality becomes poor, with rating of 0.48, observed in the second part – measurement N3, table 4. All other rating values at the highest inclination angle are similar either 0.50 or 0.51.

Taking in mind the values of the rating, given in table 3 and table 4, also the graphical information on fig. 2 and fig. 3 it could be summarized:
-if errors of 30 mm up to around 50 mm aren’t of importance for the specific geodetic task, the differences in the overall quality between vertical and inclined pole could be ignored;
-if possible, the measurements to be performed via vertical pole in order to be avoided the compromise with the accuracy.

Based on the given results and performed overall quality assessment in this study, it could be concluded, that in case inclined pole is applied, this deteriorates the quality and reliability of the GNSS measurements. However, if the terrain conditions are hard or object is specific, measurements still could be performed with acceptable errors (in the position). Explicit attention should be paid to those results, calculated via inclined pole, regardless to the angle of inclination.

Future work.
-The necessary update of the relevant firmware could be done as the procedure and data processing of the measurements, conducted via inclined pole to be finalized without the required operator's intervention;
-Similar study could be performed in night time.

REFERENCES

Kostov, G., 2009. Applying of Fuzzy Logic for Study of GNSS Detrmination in Various Conditions. International Scientific Conference Stara Zagora 4-5-th of June 2009 entitled: "The Development of the Economy and Society, Based on the Knowledge". ISBN 978-954-9329-45-2. (in Bulgarian).

Kostov, G. 2007. Assessment of the Quality of Geodetic Networks Using Fuzzy Logic. Geowissenschaftliche Mitteilungen Heft Nr. 78, 2007. Schriftenreihe der Studienrichtung Vermessung und Geoinformation Technische Universitat Wien. ISSN 1811-8380, page 4-19.

Kostov, G. 2009. Using of Fuzzy Logic for Some Studies over GNSS Determination in fast Static mode. University of Architecture, Civil Engineering and Geodesy. International Scientific-Applied Conference. UACEG 2009 29-31-st of October 2009. ISSN 1310-814X. (in Bulgarian).

Kostov, G. 2012. Study on the Overall Quality of the Planned fast Static GNSS Measurements, if Certain Values of the Parameters are Applied in the System, Using Fuzzy Logic, 6-10 May 2012 - FIG Working Week 2012 - Knowing to manage the territory, protect the environment, evaluate the cultural heritage, Rome, Italy. ISBN 97887-90907-98-3, 2012, 1-12.

Wieser, A. 2003. Benefitting from Uncertainty. GPS WORLD. March 2003.

Wieser, A. 2001. Robust and fuzzy techniques for parameter estimation and quality assessment in GPS. Dissertation Technische Universität Graz. Shaker Verlag. Graz, July 2001. ISBN 3-8265-9807-5. ISSN 1618-6303, pp 49-80

INTERNET

https://eprints.usq.edu.au/43139/12/Smouha_J_McAlister_Redacted.pdf
https://geomax-positioning.com/SFTP/files/GeoMax/Downloads/GeoMax%20Zenith35%20PRO%20BRO%20849552%201118%20enus%20LR.pdf
https://leica-geosystems.com/products/gnss-systems/smart-antennas/leica-gs18-t/gnss-setting-

out-with-no-need-to-level-the-pole-vertically
https://www.fig.net/resources/proceedings/fig_proceedings/fig2018/papers/ts04e/TS04E_luo_schaufler_et_al_9407.pdf
http://www.foif.com/news/auto-data-collection-and-incline-measurement-foif-a30-0
https://www.gpsworld.com/true-tilt-compensation-gnss-presented-by-leica/
https://www.sciencedirect.com/science/article/pii/S1674984717300101
https://www.southinstrument.com/company/details/id/401.html
http://www.terrisgps.com/product/stonex-s900-gnss-receiver/
https://www.xyht.com/surveying/full-tilt/

USED SOFTWARE

Hi-Survey Road
Vienna_fuzzy

BIOGRAPHICAL NOTES

Gintcho Kostov is Director of "GEO ZEMIA" Ltd. In TU Wien, Austria he completed and defended a scientific project. Dr. Kostov holds the following certificates: for activities in the terms of the law of cadastre, for design - full designer's qualification, for completed course entitled "Support and increasing of the qualification of the certified persons in the area of cadastre". He is a member of: Chamber of Engineers in Investment Design, Municipal Council of Experts on Planning of the Territory - Municipality Opan, Union of Scientists in Bulgaria – Sofia, Union of Surveyors and land Managers in Bulgaria.

CONTACTS

Gintcho Kostov
"GEO ZEMIA" Ltd.
Sofia 1680
41 “Solun” str. et.3 ap.9
Bulgaria
Tel. +359 888 84 96 04
Email: cccc@cccc.email
Web site: www.1111111111.me