A convenient procedure for the calibration and check of GNSS systems by using the relative static positioning method

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Abstract—Recent development in the area of GNSS-based measurements consists of combination of methodologies and modern manufactured antennas and receivers, which are able to provide coordinates of sub-centimeter accuracy. In order to succeed this, it is necessary that the measurement system (base and rover antennas- receivers and their ancillary equipment) to be calibrated and functioning properly, as the manufacturer defines. Therefore a full methodology that ensures the proper function of GNSS systems is indispensable. This paper describes a convenient procedure for the calibration and check of GNSS systems, using the relative static positioning method. Each one of the calibration or the check procedure can be applied individually. The appropriate statistical checks were carried out in both procedures in order to conclude with reliability about the proper function of the systems being checked. The methodology succeeds the results by using efficient number and type of observations and simple mathematical models. So it is convenient to be used by professionals in order to improve and to ensure their products. More over it could be a new supplement of the ISO 17123-8, which deals only with the real time kinematic method and informs the user only for the precision of the base system which is being checked and not about the accuracy of the measurements. An external control base of 2km length is used for the data acquisition. The control base is located at an optimum position in order to minimize the errors due to the elevation variance, the multipath effect and atmospheric conditions. Also the appropriate series of measurements are carried out in order to take into consideration the change of the satellite geometry. Consequently the proposed procedure provides an over all illustration about the status of the checked GNSS systems under any random environmental conditions. This estimation interests every professional in order to ensure the reliability of his products. Moreover it concludes not only about the precision of GNSS systems under check but also about the accuracy that they provide by the comparison to the ″ true″ values of the measured parameters.

Index Terms—check, calibration, GNSS system, ″Relative Static″ positioning, external control base, network adjustment, nominal values, scale of the system, uncertainty, statistical analysis

1 Introduction

The relative static is the most accurate GNSS positioning method and it is used in advanced and demanding applications such as networks’ adjustments and points’ coordinates determination providing sub-centimeter accuracy. [1],[2]. Nowadays GNSS positioning systems are widely used for both conventional and high accuracy applications, in geodesy [3]. Thus the calibration and check of GNSS systems is indispensable. Here it is worth to clarify that as GNSS system is defined together the antenna, the receiver as well as the software, which is used for the data processing.
The check procedure of a GNSS system is included in the 8th part of ISO 17123, entitled "Field Work for controlling geodetic and surveying instruments: GNSS field measurement systems in real-time kinematic (RTK)". The purpose of ISO 17123-8 is to define a procedure for the evaluation and determination of the uncertainty of the base system provided data, using the real time kinematic positioning method (RTK). During this check procedure, one system is placed at a fixed point (base-reference) and the other consecutively at two different points (rover). The system which remains fixed throughout the check procedure is the one which is tested [4].
Most countries worldwide adopt and implement the proposed provisions by the International Standards Organization (ISO). Very few exceptions regard countries that adopt the processes of standards by adding some conditions to their implementation. As the validity of ISO standards is advisory, countries can apply them either in this way or in the form of laws to consider them binding [5].
As the above mentioned methodology is not adequate for all the needs of the geodesist worldwide, it is useful to make an overview on the changes and supplements to the ISO provisions, suggested by some countries.
In Europe most of the countries are members of the ISO Organization, and thus apply the ISO standards by incorporating them with laws in their constitution. EU Members also compete in the creation of new standards as well as in the renewal and modernization of existing ones. [https://www.iso.org/members.html]. In addition, some countries like France are responsible for the creation and management of institutions that explain key components of the Calibration, Control and Traceability Systems of the International Organization of Measures and Weights. However, there are some researches in Germany, which choose through measurement procedures to isolate some of the error-input operators with GNSS systems and analyze them thoroughly. For example, an absolute antenna graduation of a single system can be carried out using a robot [6],[7]. Most of these investigations are referred to laboratory tests that analyze the

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GNSS receiver as a complex electronic device and by using suitable electronic circuits which can conclude about the proper operation of receivers [8]. Therefore, in these cases no measurements are made as regards satellite observations or the export of coordinates, nor statistical checks are applied. [9]. Therefore these procedures, regarding the GNSS systems as electronic devices, do not conclude on the check or calibration of them, but on the proper functioning of their electronic components.

In Canada, no changes or annexations to the conditions described in ISO 17123-8, is proposed. However, due to the particular location and the extents of the country, there are guidelines that help the engineers make measurements with the best possible precision and accuracy. These instructions concern both the stage of preparation and the duration of the measurements. It also identifies the common sources of errors for all modern satellite positioning methods. [10]

On the other hand, Australia has created guidelines related to the use of GNSS systems in geodetic applications in order to adapt to the elements of the international standard ISO 17123-8. A verification network is used for testing GNSS equipment for geodetic applications. The aim of these is to encourage all users to use a coherent approach when testing their equipment so that the results achieved provide a reliable verification. Also initial tests are implemented regarding the proper function, relating to the receiver's electronic circuits. After that, the verification procedure can be carried out either at an EDM baseline, where the distances between the pillars are known by a total station's measurements, or at a larger control base where a network adjustment is implemented using several pillars placed at different places [11]. The choice about the positioning method to be used at the check procedures is made through the decision about the overall length of the control base. If the procedures are carried out at the EDM Baseline all the kinematic methods can be applied, as the distances between the pillars are approximately 1km. However when the large control base is used, the guidelines propose the use of the static positioning method. Also these guidelines refer to all processes, as the choice of time between the different control phases and the mathematical model used for measurements processing. [12]

China is one of the fast and largely developing countries. High technological development has led to enormous data need for all infrastructures. Most of these data are provided by GNSS measurements. GNSS systems, because of their large number, are divided into two categories. The first category includes small size and low cost systems and the second one includes commercial systems which are used around the world. Therefore, several experiments have been developed for check the operation of all receivers' types [13]. More specifically, it is proposed to create a control field at a high building, including pillars and pedestals where the system under study is placed. Also fixed reference stations involved in the process. At least one system, which is part of a continuously operated reference station network, is needed. A specific number of observations are carried out, using the relative static positioning method, in order to conclude about the proper operation of the system.

Therefore, the scope of this paper is to propose a convenient procedure, which can be implemented by any professional user, for both the calibration and check of GNSS systems by using the relative static positioning method. This procedure can ensure that the used instrumentation meets the standards of the manufacturer.

The calibration procedure reveals the proper operation of the GNSS systems, by calculating their systematic and random errors through direct comparison of measured baselines with their reference values. The check procedure reveals the suitability of the GNSS systems for a geodetic application by determining the coordinates' uncertainty and by its comparison to the manufacturer's nominal accuracy. For both procedures the appropriate statistical tests are carried out in order to ensure the robustness and reliability of the calculations. Each procedure can be applied independently but also the same measured data can be used in both procedures via a different mathematical analysis. The overall procedure provides safe results about the proper operation of the GNSS systems under check with an easy process.

2 CALIBRATION MATHEMATICAL MODEL

Under the consideration that the "true" (reference) baseline length is known and the same baseline is measured by the under check GNSS systems then the following equation 1 can be formed.

$$D_i = a \cdot d_i + b \tag{1}$$

By using this equation the comparison of the measured baseline [d_i] to the reference "true" value [D_i] of the baseline is feasible.

The true lengths of the baselines can be provided by a first order total station with accuracy less than ±1mm. The implementation of points for the baselines definition should be stable in order to ensure the unique set up of different instrumentation (total station, prism, GNSS systems).The more convenient is to use pillars with forced setting and centring facilities in order to eliminate all these errors.

Also in order to eliminate the errors caused by atmospheric conditions and the satellites' geometry [14], two series of measurements should be carried out within at least 90 minutes time interval. For each baseline length the mean value, of the two series is used for the calculations.

As regards the error factors, the geometrical distribution of the satellites during the observations is crucial. Thus the DOP values ought to be less than 3 [15] as well as the elevation mask about 15°. Moreover the orientation of both antennas should be identical in order to eliminate the error of the antenna's face center definition.

If more than two baselines are involved then a least square adjustment is carried out considering all the observations equally weighted [16]. The goal is to calculate the values of the unknown parameters a, b and their standard errors σa, σb. Parameter (a) represents the "scale" of the system, namely the grade of the GNSS's measurements identification with the reference values and their regularity. Also (b) represents the systematic error and σ_0 of the adjustment refers to the random error. [17],[18] In order to obtain reliable results, as there are

two unknown parameters, a minimum number of four baselines, is suggested to be measured.
Since the calculated parameters are statistically significant, the accuracy σcalibration of the GNSS systems under calibration results as the total error which is given by equation 2.

$$\sigma_{calibration} = \pm\sqrt{\sigma_0^2 + b^2} \quad (2)$$

3. CHECK MATHEMATICAL MODEL

The initial data provided by a measured baseline between the points i and j when GNSS systems are used are the DX_{ij}, DY_{ij}, DZ_{ij}. Thus the following equations 3 can be formed.

$$DX_{ij} = X_j - X_i,\ DY_{ij} = Y_j - Y_i \text{ and } DZ_{ij} = Z_j - Z_i \quad (3)$$

Each baseline vector produces three equations (DX_{ij}, DY_{ij}, DZ_{ij}) and every system's position creates three unknown parameters (X_i, Y_i, Z_i).Thus If more than three baseline are measured a network adjustment [19] may be carried out by using the linear equations described previously in order to calculate the best values of the unknown parameters.
For the adjustment, one system's position is considered fixed. The provided results are the geocentric coordinates (X_i, Y_i, Z_i) for each point and their uncertainties, s_{X_i} s_{Y_i}, s_{Z_i} which are given by the variance covariance matrix of the adjustment.
For reliable results at least 5 baselines should be measured, which are formed by 4 different pillars.
In order to make the magnitude and the direction of the resulted errors comprehensive by any user, it is better to express these uncertainties in a local plan projection system (E, N, Up).
Moreover it is underlined that the nominal accuracies σ_E, σ_N and σ_{Up} which are given by the manufacturers for each type of GNSS system are also expressed in a local plan projection (E, N, Up). So this transformation is indispensable, in order to compare the outcome results to the nominal systems accuracies.
For the transformation of $s_{X_i}, s_{Y_i}, s_{Z_i}$ to the corresponding s_{E_i}, s_{N_i}, s_{Up_i}, the equation 4 is applied.

$$\hat{V}_{E,N,Up} = R^T \cdot \hat{V}_{X,Y,Z} \cdot R \quad (4)$$

Where:

- $\hat{V}_{X,Y,Z}$: the variance-covariance matrix of the adjustment for the geocentric coordinates
- R^T: the inverse rotation matrix
- R is the rotation matrix of the transformation, which is formed as described in equation 5. [20]

$$\begin{pmatrix} -\sin\lambda & \cos\lambda & 0 \\ -\cos\lambda\cdot\sin\varphi & -\sin\varphi\cdot\cos\lambda & \cos\varphi \\ \cos\varphi\cdot\cos\lambda & \cos\varphi\cdot\sin\lambda & \sin\varphi \end{pmatrix} \quad (5)$$

- φ,λ: the mean latitude and longitude of the pillars which participate to the adjustment

The s_E, s_N, s_{Up} are provided by the diagonal elements of the variance – covariance matrix $\hat{V}_{E,N,Up}$ and the maximum values, $\max s_E$, $\max s_N$, $\max s_{Up}$ among them are used for the check.

For a certain confidence level (95%), the zero hypothesis H_0 (the systems work according to the manufacturer's standards) will apply if equations 7 and 8 are simultaneously valid.

$$\max s_{E,N} = \pm\sqrt{\max s_E^2 + \max s_N^2} \quad (6)$$

$$\max s_{E,N} \le \sigma_{E,N} \cdot \sqrt{\frac{\chi^2_{0,95}(r)}{r}} \quad (7)$$

$$\max s_{Up} \le \sigma_{Up} \cdot \sqrt{\frac{\chi^2_{0,95}(r)}{r}} \quad (8)$$

Where:
$\max s_E$, $\max s_N$, $\max s_{Up}$: the maximum among the calculated uncertainties by the adjustment
σ_E, σ_N, σ_{Up} : the nominal uncertainties as are provided by the manufacturer
r : the freedom degree of the system

4. STATISTICAL TESTS

In order to ensure the reliability of the results the following statistical tests are applied to both procedures. The first test is applied by using the a-posteriori standard error σ_0 of each adjustment, and assumed to be the zero hypothesis H_0 (no gross error), as long as the equation 9 remains valid [21].

$$\frac{\hat{\sigma}_o^2}{\sigma_o^2} \le \frac{\chi^2_{r,(1-a)}}{r} \quad (9)$$

Where:

- a: the confidence level of the overall test
- r: the freedom degree of the adjustment
- σ_0: the standard error of the unit weight
- $\chi^2_{r,a}$: the value of the x^2 distribution for a certain degree of freedom and a confidence level.

Moreover the Baarda test should be applied, for each observation to be sure that no gross errors are involved in the adjustment [22]. The zero hypothesis H_0 (no gross error) is true if equation 10 is valid.

$$w_i = \left|\frac{\upsilon_i}{\sigma_{\upsilon_i}}\right| \le z_{(1-a_o/2)} \quad (10)$$

Where:

- a: the confidence level of one-dimensional check
- υ_i :the residuals of each measurement
- $\sigma_{\upsilon i}$: the standard deviation of the residual (Elements of the diagonal of the residuals matrix)
- z: limit values for the normal distribution

5. EXPERIMENTAL APPLICATION

An application was carried out for both the calibration and check procedures at an external EDM control base, as described in Figure 1, which consists of fixed pillars. Five pillars are involved, where the distances between them are from 160m to 2000m. It is pointed out that these are the most common distances of baseline vectors, which are created at the

majority of geodetic applications and surveys. The pillars are placed in a straight layout with zero inclination. The first order Leica TM30 Total Station [23] is used to measure the certified (reference or true values) distances between all the pillars, with accuracy of ±1mm.
The GNSS systems under check are placed successively at the same concrete positions as the total station by using forced centering facilities. Thus baselines, which will be measured by the GNSS systems, can be compared directly to the reference distances between the pillars, without any reductions or corrections. Ten baselines is the maximum number, which are formed by the combination of the five pillars by two. Two GNSS systems Trimble 5800 are used. The nominal horizontal (σ_E=σ_N=±5mm±0.5ppm) and vertical accuracy (σ_{Up}=±5mm±1ppm) for the relative static positioning method is defined by the manufacturer [24].

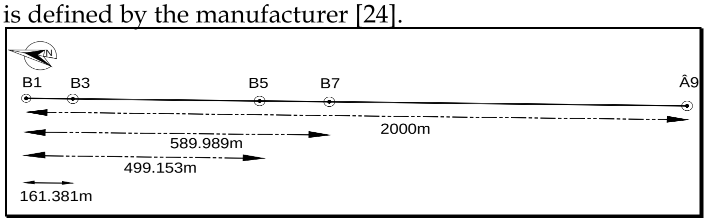

Fig 1. The external control base

Ten baselines were measured namely the B1-(B3-B5-B7-B9), B3-(B5- B7-B9), B5-(B7-B9) and B7-B9 [25]. The occupation time for each baseline ranges from 10 to 20 minutes and was decided after the analysis of the DOP values and the distance between the pillars. The overall time for the measurements was approximately 5 hours. Each of the two different measurement series last about 2 hours as 90 minutes is the time internal between them. The DOP indexes fluctuate from 2 to 3, so are accessed as satisfying. The differences of the calculated coordinates between the two measurements series fluctuates horizontally from ±2mm to ±6mm as vertically from ±5mm to ±9mm.
For the calibration procedure ten baseline distances are calculated by the process of the baselines vectors. A total of 10 observation equations were formed according to equation 1, and the matrices referring to the least-square adjustment were carried out. The freedom degree of the adjustment was 8. The differences between the experimental and the reference values of distances range from ±1mm to ±1cm.
The results are checked for their statistical significance. Then the systematic error (b) and the random error (σ_0) are come out as well as the adaptation equation 11:

$$y = 1.000005 \cdot x - 2.2\text{mm} \tag{11}$$

where $\hat{\sigma}_0 = \pm 1.1\text{mm}$, $\sigma_a = \pm 4.6 \cdot 10^{-7}$ and $\sigma_b = \pm 0.5\text{mm}$. Thus

$$\sigma_{\text{calibration}o} = \pm\sqrt{\sigma^2 + b^2} = \pm 3.1\text{mm} \approx \pm 3\text{mm}$$

The statistical tests are applied successfully as follows

$$\frac{\hat{\sigma}_0^2}{\sigma_0^2} \le \frac{\chi^2_{r,(1-a)}}{r} \Rightarrow 1.2 \le 1.9\text{mm}$$

where r=8, $\sigma_0 = \pm 1\text{mm}$ and $\chi^2_{r,(1-a)} = \chi^2_{8,(0.950)} = 15.51$.

Moreover the Baarda test doesn't detect any gross error. So both systems perform measurements without statistical errors with ±3mm accuracy.
For the check procedure also the same ten baselines between the pillars are used. Thirty observation equations were formed according to equation (3) where twelve unknown coordinates (X_i, Y_i, Z_i) are calculated as the pillar B1 was considered fixed. The freedom degree of the adjustment was r =18. The standard errors of coordinates s_{Ei}, s_{Ni}, of the four unknown pillars fluctuate from ±0.9 to ±1.5mm as s_{Upi} fluctuates from ±0.8 to ±1.6mm. The a-posteriori standard deviation of the adjustment is obtained; $\hat{\sigma}_0$ = ±1.2mm therefore the equation 9 can be applied, where:

$$\frac{\hat{\sigma}_o^2}{\sigma_o^2} \le \frac{\chi^2_{r,(1-a)}}{r} \Rightarrow 1.4 \le 1.6\text{mm} \tag{12}$$

where r=18, $\sigma_0 = \pm 1\text{mm}$ and $\chi^2_{r,(1-a)} = \chi^2_{18,(0.950)} = 28.80$.

Also, the Baarda check is applied successfully. Therefore, no gross errors appear in the observations that may lead to their rejection. The maximum standard errors max s_E, max s_N, max-s_{Up}, are compared to the nominal values set by the manufacturer σ_E, σ_N, σ_{Up}, for confidence level 95%. Where:

$$\max s_{E,N} = \pm\sqrt{\max s_E^2 + \max s_N^2} = \pm 2.2\text{mm} \tag{13}$$

$$\max s_{E,N} \le \pm\sqrt{\frac{\chi^2_{0,95}(18)}{18}} \cdot \sigma_{E,N} \Rightarrow \pm 2.2\text{mm} \le \pm 1.26 \cdot 5\text{mm} = \pm 6.3\text{mm} \tag{14}$$

$$\max s_{Up} \le \pm\sqrt{\frac{\chi^2_{0,95}(18)}{18}} \cdot \sigma_{Up} \Rightarrow \pm 1.6\text{mm} \le \pm 1.26 \cdot 5\text{mm} = \pm 6.3\text{mm} \tag{15}$$

All individual uncertainties for each point satisfy the check conditions as described in equations 13 to 15. So the systems under check can perform observations according to the uncertainties specified by the manufacturers.

6. DISCUSSION

Both the calibration and check procedures are indispensable in order to conclude about the proper operation of GNSS systems, using the relative static positioning method. A significant advantage is that each procedure can be applied individually.
The use of an external control base helps the application of the proposed methodology, providing certain advantages such as the accurate definition of the end points of each baseline and the identification of these points with the total station ones, the existence of the reference values of the baselines lengths and the open horizon. Moreover much time saving is achieved due to the control base facilities and the use of the same measurements for both procedures.
It is well known that there is a plethora of errors that influence the GNSS measurements as the antenna's manufacture, ionosphere, troposphere, multipaths, the number of visible satellites and their geometry during the measurements, clock errors, observation time etc. All these are quite difficult to be

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accurate defined. Thus the proposed procedure doesn't deal with the investigation of all these errors as the main request is the manufacturer accuracy to be succeeded under mean and random conditions.

However, in order to ensure the reliability of the methodology, the measurements are carried out into two different series of about two hours duration for each one. The two series are carried out with a time interval of at least one and a half hour. Moreover during the measurements special care must be given to the orientation of the antennas to be identical in order to eliminate the error of the definition of the antenna's face center. Also the elevation mask should be about 15° in order to avoid gross errors.

The calibration procedure requires reference values of baselines distances as the check procedure does not. However the implementation of the check procedure at a control base is preferred in order to eliminate all the factors that insert errors to the measurements. It is noted that due to the mathematical model, each baseline vector forms only one equation for the calibration procedure, while it forms three equations DX, DY, DZ for the checking procedure. The equation used for the calibration procedure has only two unknowns as for the check each pillar forms three unknowns and at least three pillars must be use, where six unknowns should be calculated by nine equations.

If a systematic error occurs, the check procedure may be successfully completed while the calibration procedure emerges the problem.

In the case that the equation 16 remains valid, that means that the systems work properly and the results of the two procedures are compatible to each other .This occurs at the present application.

$$\sigma_{\text{calibration}} \approx \pm\sqrt{\max(s_{E,N})^2 + \max(s_{Up})^2} \Rightarrow \pm 3.1\text{mm} \approx \pm 2.7\text{m} = \pm 3\text{mm} \qquad (16)$$

7. CONCLUSIONS

The proposed methodology concludes both, about the precision of GNSS systems being checked and the accuracy that they provide by the comparison to the true values.

The calibration procedure provides conclusion about the "external" accuracy of the measurement system. It uses as observations, measured baselines by the two GNSS systems, which are compared to the reference "true" values.

The check procedure provides conclusion about the internal accuracy of the measurement system, namely the provided coordinates precision. It uses as observation the initial components (DX, DY, DZ) of the baseline vector and it provides results to a local plan projection after the transformation of the coordinates' uncertainty (s_E,s_N,s_{Up}). This transformation is indispensable in order to compare these uncertainties to the nominal accuracy set by the manufacturer.

The idea to compare GNSS baselines with accurate measured distances by a modern total station is not quite new. Also the mathematical model is a simple one by a well known approximation. Thus the proposed methodology provides to the professionals a user – friendly and easy to implemented procedure.

The methodology meets the requirements of any professional user as it concludes for the proper operation of GNSS systems, by using efficient number and type of observations and simple mathematical models. So it is convenient to be used by professionals in order to improve and ensure their products. Also it could be a supplement to the ISO 17123-8 as gives more information about the systematic and random error of the GNSS systems as well as their compliance to the manufacturer nominal accuracy by using a more accurate positioning method.

REFERENCES

[1] Teunissen P. and Kleusberg A., "GPS for Geodesy", Springer, 1998

[2] Bisnath S., "Current State of Precise Point Positioning and Future Prospects and Limitations", IUGG 24th General Assembly, 2009

[3] Hofmann-Wellenhof B., Linchtenegger H. and Wasle E., "GNSS: Global Navigation Satellite Systems – GPS, GLONASS, Galileo, and More", Springer-Verlag, New York 2008.

[4] ISO 17123-8, International Standard Organization, "Optics and optical instruments-Field procedures for testing geodetic and surveying instruments- Part 8:GNSS filed measurement systems in real-time kinematic (RTK) ", 2007

[5] Kanellopoulos N., "Development of a methodology for the checking and calibration of a GNSS receiver using the VRS and Single Base RTK methods ", Laboratory of General Geodesy NTUA, Postgraduate Diploma Thesis, Athens 2017 (in Greek).

[6] Martin S., Wubbena G. and Boetcherr G., "Absolute Receiver Antenna Calibrations with a Robot", Universität of Hannover, Germany 2002

[7] Zeimetz P. and Kuhlmann H., "Validation of the Laboratory Calibration of Geodetic Antennas based on GPS Measurements", University of Bonn, 2011

[8] Pikridas Ch., "Calibration of GPS Receivers - Zero Baseline Test", Aristotle University of Thessaloniki, 2005

[9] Elonsegui P., Park D., Davis J. and Normandeau J., "Multipath characteristics of GPS signals as determined from the Antenna and Multipath Calibration System (AMCS)", 2005

[10] Natural Resources Canada (NRC)., "National Standards for the Survey of Canada Lands", Ministry Of Transportation, Ontario 2014

[11] Hirst B., "Guideline No 9 – GNSS Verification", Surveyor General of Australian Capital Territory, Australia, 2011

[12] Hirst B., " Guideline for Control Surveys by GNSS v2.1", Surveyor General of the Australian Capital Territory, Australia 2009

[13] Yeh T.K., "Calibration of the GNSS Receivers – Methods, Results and Evaluation", Department of Real Estate and Built Environment, National Taipei University, 2008

[14] Dutt S. and Rao G., "Investigation of GDOP for Precise user Position Computation with all Satellites in view and Optimum four Satellite Configurations", Journal of Indian Geophysical Union, 2009

[15] Langley R.B, " DOP Value: Investigation and Research", GPS World, Brunswick, 1999

[16] Hirvonen R., "Adjustment by Least Squares in Geodesy and photogrammetry", Fred & Ungar publications, New York, 1971

[17] Lambrou E. and Nikolitsas K., "A new method to check the angle precision of total stations". Proceeding of FIG Working Week 2015, From the Wisdom of the Ages to the Challenges of the Modern World", Sofia, Bulgaria, May 2015.

[18] Nikolitsas K., Pantazis G., "Development of an integrated and convenient methodology for checking levelling systems", International

ISSN 2229-5518

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[19] Ashkenazi V., "Solutions and error analysis of large geodetic networks", Survey review, Volume 19, Issue 147, 1968

[20] Bomford G., "Geodesy", 4th edition, Clarendon Press, Oxford University, 1980

[21] Kanji G., "100 Statistical Tests 3rd edition", SAGA Publications, London, 2006

[22] Baarda W., "A testing procedure for use in Geodetic Networks ", Delft University of Technology, 1981

[23] Leica Geosystems, "Leica TM 30: Technical Data", Specifications Manual, Switzerland, 2009

[24] Trimble Navigation, "Characteristics of the Trimble 5800 GNSS receivers series", Specifications Manual, 2004

[25] Kanellopoulos N., "Investigation of methodology for checking and calibration of GNSS receivers by using the relative static positioning method", Laboratory of General Geodesy NTUA, Diploma Thesis, Athens, 2015 (in Greek).