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# SOME SOLUTIONS IN THE CREATION, MEASUREMENTS AND ANALYSIS (USING CLASSICAL AND GNSS IT) FOR A GEODETIC NETWORK IN INDUSTRIAL URBAN ENVIRONMENT

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# НЯКОИ РЕШЕНИЯ ПРИ ПРОЕКТИРАНЕ, ИЗМЕРВАНИЯ И АНАЛИЗ (ЧРЕЗ КЛАСИЧЕСКА И GNSS IT) ЗА ГЕОДЕЗИЧЕСКА МРЕЖА В ИНДУСТРИАЛНА ГРАДСКА СРЕДА

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**ключови думи**: Геодезия, хибридна мрежа, GNSS, RTK

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## SUMMARY

In some specific cases from the geodetic practice it is necessary the geodetic measurements (both classical and positional) to be conducted in extremely hard urban conditions. This imposes that the geodesist should take in mind a number of circumstances and conditions, which influence both the conduction and the results from the measurements.

This paper is focused on the creation, measurement, processing and analysis of a geodetic network, especially constructed for performing of detailed measurements of situation in industrial urban area. For the conduction of the geodetic measurements were used both GNSS system and total station. The created geodetic network was adjusted and the results from the classical and GNSS measurements were analysed. The necessary decision for the usage of certain measurements was taken, in order to be produced maximum reliable results for these terrain conditions.

Based on the derived information and the used literature conclusions were done. Proposals for future work are also given.


## 1. Introduction

A number of practical tasks in surveying require performing of classical measurements in industrial urban environment. In the general case this necessitates the usage of existing national geodetic network in order to obtain the results in the official coordinate and height system, according to the requirements.

On one hand, a possible way to complete the survey task is to use existing national network points, which are checked for accuracy. Unfortunately, in some industrial regions the national geodetic network does not exist (i.e. it is destroyed) or it is not suitable for performing of the necessary measurements.

On the other hand, it is known that for conduction of either classical or satellite measurements, the environment should respond to certain specific requirements (line of sight, open horizon, etc.), in order to obtain quality and reliable results.

This paper studies the practical implementation and the technical issues (also the ways the surveyor could avoid them), which might appear in the creation, measurements, processing and analysis of a hybrid (created using classical and GNSS IT) network, situated in the specific environment of an industrial urban area. The paper is also a continuation and extension of the experiment, described in [Kostov, 2012].

## 2. Creation and usage of a hybrid geodetic network in hard industrial urban environment

Due to various reasons like construction activities, malicious people, etc. in some regions of the country the condition of the geodetic network is not as good as expected, see fig. 1, 2 and 3.

Fig. 1 Unusable triangulation point

Fig. 2 Inclined point from the national geodetic network

Fig. 3 Unusable triangulation point from the national geodetic network

As it could be seen, in various places parts of the national geodetic network are already unusable. In the worst case the points are missing on the terrain. Another technical issue is the lack of convenience for conducting of the specific measurements, required for a certain project. This imposes that the surveyor should construct *own hybrid geodetic network* in order to complete the required task in a *technically convenient and productive way*.

Documents, dealing with the requirements for the creation of the classical and GNSS networks in Bulgaria can be found for instance at [http://www.cadastre.bg]. Information for the creation and types of networks, used in Australia are available at [http://www.lacendservices.sa.gov.au/5publications/surveying-drafting_manuals_and_guidelines/cadastral_survey_guidelines/2002v2sec2.asp] and [http://www.sa.gov.au/upload/franchise/Housing,%20property%20and%20land/LSG/CSG/CSG_full.pdf].
Details for the characteristics and design of the vertical networks, especially in urban areas could be found at [https://www.cbeps-cceag.ca/sites/default/files/BCS1979.pdf].

The term “hybrid geodetic network” is used in several literature sources, e.g. [http://siteresources.worldbank.org/INTIE/Resources/P_Desjardins.pdf], [http://gse.vsb.cz/2004/L-2004-2-11-18.pdf], etc. Here it will be used in the light of the *contemporary IT, used nowadays in the 3D geodesy*.

The environment (in our specific case - industrial urban area with administrative buildings, trees and tall bushes) around the object, subject of measurements imposed several key details, which had to be *carefully considered*, concerning the creation of the hybrid geodetic network. They are as follows:
- very difficult to choose a priory suitable places for the points of the network, i.e. the last was created in real time, according to the specific needs for measurements of terrain points;
- the area around the object fell in an environment, hard for both classical and GNSS measurements;
- the classical measurements were hard to conduct due to the tall bushes;
- GNSS measurements were done with difficulties in an environment of passive disturbers.

According to the environment around the object, all points, but one – N 110004 were situated in the available places with "open" horizon around the object. Due to the requirements of the project and the necessity for performing of classical measurements, one of the points from the network was placed in very hard terrain conditions.

Based on the existing situation around the object and the requirements for measurements of detailed points, a hybrid geodetic network was created. It was measured, processed and analysed (details given later on in the paper).

## 3. Conducted geodetic measurements

For the needs of this project both classical and GNSS measurements were conducted and processed in order the practical task to be completed. The classical measurements (bearings and distances) in the network were done, using high-accuracy total station. All possible bearings and distances between the points in the network were measured. Control points were created and used in order to be obtained reliability for the geodetic network.

The points were coordinated by GNSS equipment using RTK mode. Based on the requirements for productivity, also taking in mind the hard environmental conditions it was decided that the usage of fast static mode was not applicable. A reference station was placed near to the object in a site with open horizon.

A key moment was followed, i.e. *all possible* classical and GNSS measurements were performed in order to be obtained enough redundant measurements.

## 4. Processing of the classical geodetic measurements. Results. Analysis

The classical geodetic network was adjusted, using the applications PhDPolarSurvey and Heights-Network [http://www.bulgarian.geozemia.com/GeodeticSoftwareBG.html]. The software calculated the adjusted coordinates of the new-determined points and also the following parameters:
- Tr (Q) – the trace of the co-factor matrix;
-M number – value, function of the normal matrix, see [Faddeev et al., 1963];
- N number - value, function of the normal matrix, see [Faddeev et al., 1963];
- Tod's number – function of the dimension of the normal system and its maximal element;
- condition number= $\varepsilon \cdot cond(N)$ - described in details by [Konstantinov et al., 1987];
- $\mu$ - posterior variance factor;
- $Mar$ - Mean arithmetic error for the whole network;
- $Msq$ - Mean square error for the whole network;

The above parameters were used here for the necessary analysis.
The numerical results from the adjustment of the geodetic network are given below:

**Mathematical processing of the geodetic measurements**

Adjustment of geodetic network in the plane
**Application PhDPolarSurvey**

The data are from classical measurements
residuals:

Min V= -23.42
Max V= 13.93

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control sums:

PFF.U=16136.48
PVV= 16136.48
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[VV]=1265.31

Tr (Q) = 0.43

M number of Turing 4047.20
N number of Turing 128.47
Tod's number 75032.93

Condition: 3.42307594002284E-13

density of the normal system: zero/all elements 0.3333
density of the normal system: non-zero/ all elements 0.6667
zero elements of the normal system = 48

posterior variance factor = 64;

mean square error for the whole network 17 [mm]
mean arithmetic error for the whole network 16 [mm]

**Adjustment of trigonometric levelling**

**Application Heights-Network**

Results from the adjustment:
residuals:

Min V= -0.89 [mm]
Max V= 29.20 [mm]
=======================================
control sums:
[PVV]= 129.921
PFF.6= 129.921

assessment of the accuracy:
posterior variance factor = 7
mean square error for the whole network = 14 [mm]
mean arithmetic error for the whole network = 17 [mm]
Tr (Q) = 39.02

M number of Turing = 2064.57
N number of Turing = 112.47
Tod's number= 181.14

Condition: 1.49838649517574E-0013

From the numerical values of the quality criteria it could be noted the following.
- The overall network quality could be optimized, due to the value of condition criterion. In case of well-posed system it has generally value at about 1e-16;
- Both mean square error and mean arithmetic error for the whole network have good values;

As a results it could be summarized, that the network has the necessary quality for its purpose (determination of heights of the terrain and situation details – needed for creation of a project).

## 5. GNSS measurements in RTK mode – results and analysis

The results from the quality assessment of the GNSS measurements are given in table 1. It could be seen, that the values for quality in the position and height – i.e. the criteria Mp, Mh and M3D for all points are about 2-3 cm. For completeness of the information in the table are also given the diagonal values of the elements of Q matrix. According to the criterion M3D, the points from the network are well-determined.

| NT | M0 | Qxx | Qyy | Qzz | Mp [mm] | Mh [mm] | M3D [mm] |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| 110001 | 1.3343 | 0.00007328 | 0.00001708 | 0.00011977 | 13 | 15 | 19 |
| 110002 | 1.6169 | 0.00002774 | 0.00001361 | 0.0000994 | 10 | 16 | 19 |
| 110003 | 2.8981 | 0.00001299 | 0.00000648 | 0.00005265 | 13 | 21 | 25 |
| 110004 | 2.6472 | 0.00004258 | 0.00001306 | 0.00009444 | 20 | 26 | 32 |

Table 1 – Quality assessment of the results from the GNSS measurements

## 6. Ascertained problems. Solutions

In the first cycle of data processing of the classical measurements it was noticed existence of large values of the residuals. This required isolation of the exiting blunders, available in the data from the measurements.

Further processing of the data was done for elimination of the blunders. It was ascertained that one of the points – N 110004 (situated under trees and in proximity to a building) - determined in RTK mode was with incorrect coordinates and height ($\Delta x = 95\,mm, \Delta \mathrm{y} = -288\,\mathrm{mm}, \Delta \mathrm{h} = -1813\,\mathrm{mm.}$), despite of the value of M3D quality criterion– 32 mm. Here with $\Delta x, \Delta \mathrm{y}$ and $\Delta \mathrm{h}$ are denoted the differences between the wrong and correct coordinates and height.

It should be noted that in the literature [http://geoplus-bg.com/geomax/download/ZGP800_User_bg.pdf] there exists a warning for the possibility of existence of wrong measurements in some cases, while in [Minchev et al., 2005] there is information for the high reliability of GNSS measurements in RTK mode.

From *practical* point of view the height of the problematic point was definitely incorrect as its value did not correspond to the existing terrain (in this case - concrete). The wrong determined point was close (due to the specificity of the object) to another point from the network, situated also on a concrete, with no significant change in the terrain.

The following *solutions* could be proposed in order to be eliminated the ascertained technical issues:

- each network point to be coordinated by GNSS technology (e.g. in RTK mode), regardless to the terrain conditions;
- control points to be created in order to provide high level of reliability for the results from the geodetic measurements;
- information from the processing of the classical measurements to be analysed along with the results from the GNSS measurements;
- the derived results should be “*manually*” examined for consistency with the terrain.

## 7. Conclusion. Recommendations

This paper provided information for the classical and GNSS measurements, performed in a hard environment of an industrial urban area. Inconsistency with the results from the GNSS determinations in RTK mode (*despite of the good value for M3D quality criterion*) and the existing terrain were found. The incorrect results were possibly caused by the passive disturbers – leaves, buildings and branches situated around the place of measurements. The blunders were localised and eliminated using the conducted *redundant classical measurements, their processing and analysis*, using the mentioned in chapter IV geodetic software.

It should be noted, that the inevitably usage of a hybrid network and the mentioned IT was due to:
- the environment around the object;
- the requirements for productivity, accuracy and reliability;
- the specificity for performing of classical and GNSS measurements;
- the lack of points from the national geodetic network in the region.

According to the numerical results from the quality assessment given in this paper, especially the values for M3D quality criterion it could be *recommended*:
- in specific cases (e.g. forest, urban environment, etc.) the results from the RTK measurements should be used with explicit attention;
- in order to ensure the necessary control for reliability of the conducted measurements, hybrid geodetic network should be used and analysed with the relevant software. The consistency of the height of each point with the existing terrain should be checked, *regardless* to the value of the quality criterion M3D.

Used software */in alphabetic order/*:
1. GeoMax Geo Office;
2. Heights-Network;
3. PhDPolarSurvey.

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