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On the third dimension in robustness analysis

Mevlüt Yetkin *1, **Muhammed Ali Aytemür** 1, **Ömer Bilginer** 1

[1]Izmir Katip Celebi University, Faculty of Engineering and Architecture, Department of Geomatics Engineering, Izmir, Turkey

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ABSTRACT

Robustness analysis is a combination of Baarda's classical reliability analysis and geometrical strength analysis that is based on strain. It measures the ability of a geodetic network to oppose deformations caused by the maximum undetectable biases that are obtained from internal reliability analysis. The virtual deformations originated from undetected biases might be portrayed as displacements. The application of robustness analysis to geodetic networks depends on the dimension of the network. There are some discrepancies among the robustness analysis of levelling networks, horizontal control networks and three-dimensional networks. As well known, heights can be determined precisely in a levelling network using trigonometric heighting or differential leveling methods. Nevertheless, horizontal coordinates are generally approximately known in these types of networks. Therefore, it is needed to concentrate on the vertical displacements. In the present study, we discuss the robustness analysis of one-dimensional networks. Furthermore, some numerical examples are given.

1. INTRODUCTION

Traditionally, the quality of a geodetic network is measured by precision, reliability and economy. Additionally, sensitivity for deformation monitoring networks may be considered. On the other hand, as an augmentation of Baarda's reliability criterion, robustness analysis combines the criteria of reliability and geometrical strength. It is based on strain technique and measures the network ability to resist virtual deformations caused by the maximum undetectable biases. Robustness primitives, displacements and strain invariants are calculated in order to evaluate the robustness of each network point (Krakiwsky et al., 1993).

Outliers may deteriorate the least squares method's results. So, they should be determined and eliminated using an appropriate technique such as Baarda's data snooping approach. However, Baarda's test may not be successful for outlier diagnosis. There are two reasons for this: 1) insufficiently controlled observations, i.e., low redundancy numbers and 2) the effect of the power of the test, i.e., type II error. The influence of undetected biases may be evaluated using reliability analysis. Nevertheless, classical reliability analysis is dependent upon the choice of network datum. Since robustness analysis only reflects the network geometry, it is preferred (Vaníček et al., 2001; Berber, 2006).

Robustness analysis method was first developed by using Baarda's classical reliability criteria analysis approach that is based on one single outlier. However, Knight et al., (2010) presented the reliability criteria that should be used in the case of multiple outliers. Thereupon, Yetkin and Berber (2013) changed the robustness analysis by using the reliability criteria developed for multiple outliers. Naturally, the robustness of the network gets worse as the number of outliers increases.

The application of robustness analysis depends on the dimension of the network. It is generally applied to 2D networks, i.e., horizontal control networks and 3D networks such as GPS networks. However, 1D networks that are measured utilizing trigonometric levelling or geometric levelling techniques have a crucial role in Geomatics Engineering. They are vital tools to determine vertical deformations. For example, these methods may be applied in monitoring vertical crustal movements. But, undetected biases in observations may cause

* **Corresponding Author**

*(mevlut.yetkin@ikcu.edu.tr) ORCID ID 0000 – 0003 – 3438 – 1801
(m.aliaytemur@gmail.com) ORCID ID 0000 – 0002 – 2819 – 5706
(omer.bilginer@ikcu.edu.tr) ORCID ID 0000 – 0001 – 5789 – 7929

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improper deformation interpretation. Thus, the robustness of a 1D network should be assessed using robustness analysis. In this paper, robustness analysis of 1D networks have been studied and some numerical computations have been performed.

2. ROBUSTNESS ANALSIS OF 1D NETWORKS

The displacements in the vertical direction should be considered in a 1D network. The displacement of a point P_i is

$$\Delta x_i = [\Delta z_i] = [w_i] \tag{1}$$

where w_i is the displacement in the z direction. It is external reliability criterion. Then, the tensor gradient with respect to position (strain matrix) is

$$E_i = \left[\frac{\partial w_i}{\partial z}\right] \tag{2}$$

The estimation of the strain matrix E_i can be found in Berber (2006). It should be noted that only dilation may be defined in a 1D network. The remaining robustness primitives cannot be calculated. Dilation shows deformation (or robustness) in expansion. Some problematic cases for a 1D network should be taken into account (Berber, 2006). In robustness analysis, one may move from displacement field (external reliability) to strain field (strain matrix). However, it is possible to move from strain field to displacement field. Thus, vertical displacements for each point in the network can be computed using this procedure. The details of the computation of displacements may be found in Berber (2006).

3. NUMERICAL RESULTS

Three examples are given to illustrate the application of robustness analysis to the 1D networks.

Case I: Dilations are computed in a geometric levelling network. The network includes 4 points and 6 observations. The datum of the network is provided by minimal constraints, i.e., only one point (A) is fixed (Ghilani, 2010). The non-centrality parameter δ_0 is 3.61 ($\alpha_0 = 0.05, \beta = \beta_0 = 0.05$). The redundancy numbers, internal reliability (MDB: Minimal Detectable Bias) and external reliability criteria are shown in Table 1, Table 2, and Table 3, respectively. The external reliability are for points B, C and, respectively.

Table 1. Redundancy number

Observation Number	Redundancy Number
1	0.6549
2	0.3294
3	0.5092
4	0.1877
5	0.4326
6	0.8862
	∑=3

Table 2. Internal reliability (m)

Observation Number	MDB
1	0.0265
2	0.0252
3	0.0253
4	0.0250
5	0.0220
6	0.0460

Table 3. External reliability (m)

1	2	3	4	5	6
0.0092	-0.0053	-0.0038	-0.0148	-0.0097	0.0029
0.0067	0.0116	-0.0108	-0.0159	-0.0046	0.0052
0.0040	0.0006	0.0016	-0.0203	0.0027	0.0018

The dilations are shown in Table 4. The geometry of the network is highly uniform. Thus, dilations for any observation is the same in each point.

Table 4. Dilations of points for 6 observations (ppm)

Observation Number	B	C	D
1	492.025	492.025	492.025
2	562.423	562.423	562.423
3	-681.396	-681.396	-681.396
4	*-961.068*	*-961.068*	*-961.068*
5	-433.238	-433.238	-433.238
6	325.765	325.765	325.765

As can be seen from Table 4, the maximum dilation is due to observation 4. It has lowest redundancy number (See Table 1). Accordingly, it causes maximum deformation in the network. Furthermore, it has the lowest standard deviation.

Case II: Robustness analysis has been performed in a geometric levelling network for multiple outliers. The network has 5 points and 6 observations. There are two fixed points. The data (standard deviations of observations, internal and external reliability criteria) of the network can be found in Knight et al., (2010). The computed dilations for one undetectable bias are shown in Table 5.

Table 5. Dilations of points for one undetected outlier (ppm)

Observation Number	P2	P3	P5
1	2985.47	4440.24	227.48
2	-1941.50	-2598.61	6693.15
3	*22453.21*	*33662.08*	*6693.15*
4	3541.19	6021.11	551.30
5	4046.08	4550.73	4851.85
6	1694.88	2902.87	2006.79

The observation 3 has largest controllability value (see Knight et al., 2010). Therfore, it led to the maximum dilation.

As known from Knight et al., (2010), the external reliability values for some observation pairs are infinite. If we use these reliability analysis results then maximum dilation will be infinite. Thus, the network is not robust. The network is broken due to two undetected biases.

Case III: Robustness analysis of a trigonometric levelling network has been performed. The network consists of 4 points and 5 observations. The data of the network can be found in Demirel (2005). The redundancy numbers and internal reliability criteria are shown in Table 6. On the other hand, external reliability criteria are shown in Table 7.

Table 6. Redundancy numbers, standard deviations and internal reliability

Redundancy Number	Standard Deviation (mgon)	MDB (mgon)
0.7763	1.5	6.1458
0.8478	1.5	5.8809
0.7573	1.5	6.2226
0.3914	0.75	4.3279
0.2272	0.75	5.6803
∑=3		

Table 7. External reliability (cm)

1	2	3	4	5
7.7447	3.6659	8.1684	-10.7915	15.4327
3.7727	-1.5609	3.9791	4.5948	22.3509

Dilations of points 32 and 34 are shown in Table 8.

Table 8. Dilations (ppm)

Observation Number	32	34
1	3977.60	7991.92
2	6567.96	8428.07
3	4195.21	8429.15
4	*-19334.31*	*-24810.00*
5	-12839.57	-4662.83

Displacements of points 32 and 34 are shown in Table 9.

Table 9. Displacements (cm)

Observation Number	32	34
1	2.0	-1.0
2	2.6	-2.0
3	2.2	-4.05
4	*-7.5*	*5.86*
5	0.94	2.58

As can be seen from Table 8 and 9 maximum dilation and displacement are due to observation 4. It may be remedied by improving the network geometry and/or observational accuracy.

4. CONCLUDING REMARKS

Dilation and vertical displacement of any point in a levelling network are computed for each observation utilizing robustness analysis. The maximum of these is kept as the robustness criterion at that point. If we have calculated the displacements, we can make an evaluation by comparing with threshold values. However, the calculation of threshold values is not included in this study. Certainly, we can refer to traditional precision analysis for threshold values. This subject may be recommended as a future work.

The network geometry (redundancy numbers) and the accuracies of the observations play a crucial role in the network robustness. Additionally, the number of undetected outliers affects the robustness analysis results. The robustness of the network naturally worsens as the number of outliers that cannot be determined increases.

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