



MEASUREMENTS SIMULATION FOR OPTIMISATION OF TRIGONOMETRIC NETWORK MONITORING

Milivoj VULIĆ¹, Dušan SETNIKAR²

ID 078

¹ University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Geotechnology and Mining, Ljubljana, SLOVENIA

² Geodetski zavod Celje, Celje, SLOVENIA

milivoj.vulic@ntf.uni-lj.si

ABSTRACT

Environmental impact monitoring often also consists of measuring the displacements in trigonometric network on inflicted areas (changes on landfills, above subsiding mining areas, ...). Here presented measurements simulation is based on the model of 2D adjustments by parameter variation², made with the NTF method, which enables traceability of changes caused by changing the input data. The aim is to control data with MS Excel through entire process of adjustment of those displacements in the most transparent and automated way. Through introducing a switcher we gain the opportunity to improve the final results by excluding bad single or groups of measurements from the input data set. It also gives us the option to define the measurement points as either known or unknown. Once the specific data has been switched off/on, this affects all the other subordinate data in the adjustment. In combination with other calculative tools, i.e. the mean square error, we can evaluate the influence of the specific data on the adjustment results and reliability of the trigonometric network, be it either real or simulated.

Key words: adjustment by parameter variation, simulation, MS Excel, switching off/on measurements.

INTRODUCTION

Previously, when adjusting a trigonometric network, specialised programmes were used. However, they tend to be expensive and above all they function on the basis of the "black box," in which the data is entered and, from this, the results are returned. In such a case, we have no insight into the actual performance and thus cannot check the accuracy by any means other than by a reference calculation. Due to the fact that we know their true function, with proper programming tools, we created our own application in MS Excel, which enables full insight in to the calculation process. Moreover, we offer it freely to all users wanting to know the actual influences on calculation accuracy.

Measurements simulation presented here is based on the model of 2D adjustments by parameter variation², made with NTF method. This method uses an MS Excel environment because of an option to introduce user defined functions (UDF), flexibility in procedure determination, easy data scanning and traceability of changes, caused by changing the input data. Through introducing a switcher (0 or 1; see blue fields in the enclosed case), we gain the opportunity to improve the final results by excluding bad single or groups of measurements from the input data set and also highlights measurements with coarse errors. It also gives us the option to define the measurement

points as either known or unknown. Once the specific data has been switched off/on, this affects all the other subordinate data in the adjustment. In combination with other calculative tools (ie. the mean square error), we can evaluate the influence of the specific data on the adjustment results and the reliability of the trigonometric network, be it either real or simulated. Due to lack of space, only a simple imaginary trigonometric network consisting of five measurement points is presented. The core of this article is an analysis of the influences of variable input data on final results and evaluation through standard quality parameters (mean square error, ..) The practical case of adjustment² is available for download on the internet⁴.

As stated², the model enables calculation of an extensive trigonometric network

- in several periods
- on optional locations
- merely by entering field measurements

In this article this model is upgraded by introducing an option for the simulation of the influence of various input data. A new approach is referred to as the ‘switching off/on the data of single measurements or a group of measurements of the same sort’ or shortly as off/on measurements. This enables us to exclude bad measurements from the set of data, thus giving us the option to achieve more reliable results. When excluding a larger number of measurements, it is fairly easy to overlook the unintentional isolation of measurement point(s) of trigonometric network due to disconnection of all measurements on a specific point. Often it also happens that we leave only one connection of this point on the network, therefore creating offshoot of a traverse. In both cases is essential to notice such irregularities, which was enabled and now in case of such irregularity notice appears beside that point. This way we achieved further automatisation of adjustment, while still preserving full overlook on data process.

WHAT IS A UDF?

Using MS Excel is a compromise solution, using both an individual procedure and user defined functions (further in the article referred to simply as a “UDF”), which are actually specialised sub-programmes for defined calculative operations, which are again part of an adjustment procedure as a whole. UDFs are still small black boxes, but their algorithms are presented in previous articles and visual presentations⁵ of UDF use, available at <http://www.ntfgeo.uni-lj.si/mvulic/gradiva>, thus making this model acceptable also for a lower level of theoretical knowledge.

A UDF functions as an add-in in the MS Excel programme tools platform. It is virtually a part of MS Excel and is simply called to attention from the function line. This additional function enables faster work and adds to table transparency. An optional number of UDFs can be added, although it is recommended to add only those used in the task in order to achieve a higher processing speed. UDFs are similar to macros, but with a less complex code. Their benefits are:

- creating a complex or custom mathematical function
- simplifying formulas that would otherwise be extremely long “mega-formulas”
- custom text manipulation
- an advanced array formulas and matrix functions
- a UDF's programme code can be locked, preventing its unauthorised alteration
- an add-in is available without the need to open a new worksheet

ADJUSTMENT BY PARAMETER VARIATION WITH THE USE OF A UDF

The basis for calculation is presented by the adjustment theory¹. The setting out method is used and distances and directions are measured. Field measurements or their simulations are used in UDFs to acquire matrices of equation coefficients, and to eliminate dz through a Gaussian elimination in order to get residuals equations.

The adjustment consists of two separate parts. First we acquire the design matrix of the equation coefficients by assuming the sought-for coordinates. In the second part, we use the field measurements and actually perform the Gaussian elimination. The matrix of normal equation coefficients, as well as the matrix of unknowns is formed. The result is the residuals equation

$$v = Ax + f;$$

where v is the vector of the residuals, A is the design matrix of the observation equations, x is the vector of unknowns parameters and f is a vector of absolute terms.

The “weighed least square method” is used. When product $v^T P v$ (v is a vector of residuals, P a matrix of weights, acquired on the basis of the expected measurement accuracy) is the smallest, the result is optimal for the data entered. A vector of unknown parameters is then added to the assumed coordinate data, thus iterating its value until we reach satisfactory results, but - of course - always according to the accuracy of our field measurements.

Simulation principle

Further along, the way we approach simulations is presented. Due to lack of space, only a small set of imaginary network defining data used for a simulation is presented in table 1 and some results in tables 2 and 3. The network situation is presented in figure 1.

	A	B	C	D	E	F	G	H	I	J
1				measurement			accuracy			ponder
2	station	visure	o	'	"	o	'	"		md[rad],m[m]
3	direction	T	MT_1	0	0	0	0	0	5	2.42407E-05
4		T	MT_2	270	0	3	0	0	5	2.42407E-05
5		T	MT_3	216	52	10	0	0	5	2.42407E-05
6		T	new*	171	52	11.6	0	0	5	2.42407E-05
7	distance	T	MT_2	499.99		0.005		0.400008		
8		T	MT_3	500.01		0.005		0.399992		
9		T	new*	707.106		0.005		0.282843025		
10		T	MT_1	500.02		0.005		0.399984001		

Table 1.: The imaginary data set for the network adjustment

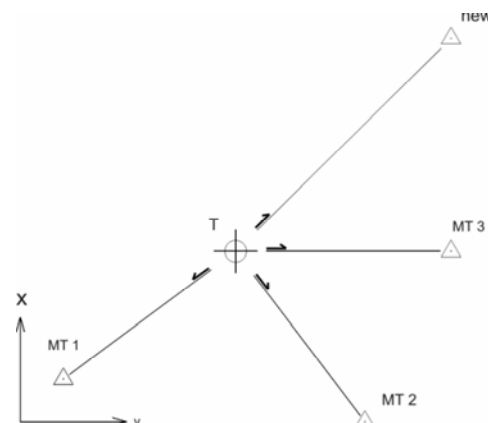


Figure 1.: The trigonometric network and points

new*....a known point additionally introduced to improve results (with every new known point included, the coordinate accuracy of the unknown point improves)

new*....dodatno uvedena datumska točka z namenom izboljšanja rezultatov (z vsako uvedbo nove datumske izboljšamo natančnost določitve koordinat neznane točke).

	A	B	C	D	E	F	G
12	points/	y	x	Dy	Dx	y	x
13	coordinates	[m]	[m]	[m]	[m]	[m]	[m]
14	MT_1	100	100	0	0	100	100
15	MT_2	800	0	0	0	800	0
16	MT_3	1000	400	0	0	1000	400
17	T	500	400	0.0055	0.0013	500.0055	400.0013
18	new*	1000	900	0	0	1000	900
19				$\chi^2 = 3.24E-05$			

Table 2: The initial and calculated points coordinates and mean square error for T point coordinates

Simulation can be used for different purposes. We may use simulation for theoretic optimization of proposed trigonometric network (enough points, proper angles,...) before we perform field measurements. Sometimes we can improve network characteristics solely by introducing new points in the proper places. The other option is manipulation with already acquired field data in such way that we evidently identify bad/best data. Such identification is the basis for final evaluation of displacements inside the network and the quality of network itself. On such a basis we can add new points in a network and improve results in the next period.

The aim is to automatising adjustment and having enough control data to evaluate results in the shortest time possible. With the afore-mensioned switches (0;1) we control every input datum, but we also want to know what effect they have on network quality and final results. In cases when all measurements at all network points are included we fairly simple performe this task by calculating matrixes $[A_{full}]$ $[N]$ and $[Q_{xx}]$ and vectors (x) . It becomes more complicated, because we want to have dynamic network, where all points and all measurements can be used while having an option to exclude measurements or points. Namely in a rigid system calculation stops if we exclude one point out, upgrade one point from free to datum point or when excluding single measurement on that point. In all those cases of matrix N the determinant is zero. To overcome this situation we add a complementary identity matrix D to matrix N and enable an inversion of matrix N ($\det \neq 0$) and calculating the elements of covariance matrix Q_{xx} .

With excluding a single or group of measurements there is an option that we isolate one or several network points (free or datum). One of tasks in the process of automatisation is also noticing such events. Therefore we introduced standard MS Excel function Sign, which returns simple values of 1 or 0 accordingly to whether the sum of squares of matrix $[A_{full}]$ vectors for each point gives a positive value or value 0. In case value of $Sign(a^T * a) = 1$, then that point is included in network and in adjustment, otherwise not.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
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3																									
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Table 3.: Introductory overview of input elements and some control data for simulated case.

For every point in network we track:

- whether point actually is part of adjusted network, which means noticing its isolation due to excluding all of the measurements on this point
- whether point is attached to the network solely with one measurement (offshoot of a traverse)

An additional result of performing adjustment with MS Excel is an option to export data in CAD environment for graphical presentation of results (e.g. parameters of confidence ellipse for each network point).

CONCLUSION

When adjusting a trigonometric network, we operate with lot of data. The aim of proper results evaluation is to have full insight into calculation procedure, while maximally automating the procedure. Here such an approach, using MS Excel, is presented. A model made this way, enables us:

- to operate with large data sets,
- to simulate virtual and evaluate real network characteristics and perform network quality assessment,
- to exclude bad measurements from calculation or introduce new additional field measurements and
- monitoring the procedure through overview of every calculation step and by simultaneous calculation of network quality control parameters.

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