13th FIG Symposium on Deformation Measurement and Analysis
4th IAG Symposium on Geodesy for Geotechnical and Structural Engineering

LNEC, LISBON 2008 May 12-15

SOFTWARE TO OPTIMIZE SURVEYING NETWORKS

Antonio Simões SILVA[1], Henrique Lima BAIÃO[1] and Verônica Maria Costa ROMÃO[2]

[1]*Universidade Federal de Viçosa – BRAZIL- asimoes@ufv.br*
[2]*Universidade Federal de Pernambuco – BRAZIL – vcosta@ufpe.br*

Abstract: This paper shows the implementation of a software using the language Java, to apply the concepts of optimization of surveying monitoring networks and to propitiate the user the interaction possibility with the program, in way to optimize a two dimensional surveying network according to the analysis of the criteria of precision, in that it should look for the minimum variance for each point of the network and reliability criteria to evaluate the number of redundancy and with this the influence of the blunders in the adjusted parameters. The software is capable to perform the adjustment of the observations using least squares method to a set of horizontal coordinates, distances, azimuths and angular observations. It optimizes through the change of observations of the network, with increment of observations or if it is the case reduction of these.

The concept of reliability of a surveying network is related to the capacity that this has to detect blunders such small as possible. And this can be evaluated through the numbers of redundancies. The sum of the partial redundancies of the observations of a surveying network indicates the degree of freedom of the network. Therefore each added redundant observation increases in a unit the sum of the partial redundancies, independent of the observation. In this work is intended to apply the idea of the more homogeneous the values of the partial redundancies, more reliable the network is considered. In other words, it is looked for to minimize F, such that $F = (Rmm)^2$ is minimum. Through that minimization of the sum of the squares of the partial redundancies a better distribution of values is sought reducing the amount of unreliable observations.

It was obtained software capable to improve a surveying network suggesting observations to improve the precision and the redundancy of the parameters and observations of the network. The software uses the least squares method using the approach of observation equation. In the aspect of the reliability it uses the concept of redundancy matrix. To each change of the observations of the network the precision and redundancy of the parameters are recomputed, warning whenever some essential observation in the computation of the network be excluded. Some tests have been done and it evidenced that the software reached its objective.

1. INTRODUCTION

As new types of instruments become available it is sometimes convenient to do new observations to improve the quality of the coordinates or of the existing networks. But it raises questions about the type and the way that those measurements should be done. To answer these questions mathematical models are used based in optimization criteria. These

criteria of optimization of horizontal surveying networks have as base the precision and the reliability, in such a way that:
a) criterion of precision: the a posteriori variance of each point must be minimum;
b) reliability criterion: the redundancy number must be the maximum and the influence of the undetected gross error on the parameters of the network must be the minimum
The precision of the coordinates can be assessed by the *a posteriori* covariance matrix estimated by least squares computation. The reliability is the ability of the network to detect the gross errors.

2. REVIEW OF LITERATURE

2.1. Observation Errors

It is noticed that no matter how much observations are repeated, even in same conditions, different values are obtained. Among other causes, these differences are due to the inevitable observation errors, which can be attributed to the human faults, to the imperfection of the equipment in use, and to the influence of environmental conditions. (Jesus, 2005).
The collecting, recording and management of observations can be affected by several errors, which are classified as systematic, random, and gross errors (Silva, 1997).
Systematic errors are those that vary systematically in sign and magnitude. They are defined as the difference between the functional model and the reality; and are often referred to as bias. It is possible to eliminate systematic errors by refining the mathematical model.
Random errors are unavoidable and are those that remain after all systematic and gross errors have been removed. They are inherent to the nature of measurements. Usually they represent small differences between the observations and their expectations. Random errors are unpredictable and follow statistical rules.
Gross errors or blunders result from the malfunction of either the instrument or the surveyor. Blunders can be avoided through careful observations. However there is no absolute certainty that all blunders are removed.

2.2. Precision

The network design requires a specified precision of some or of all the estimated coordinates. The precision is assessed through the *a posteriori* covariance matrix $C_{\hat{x}}$ of the estimated coordinates. This matrix is a main component of the precision criteria.
The purpose that a network will serve is critical for the determination of the required precision. For example, when planning a geodetic network for setting out an engineering structure, quite special requirements may be needed. For general purpose networks, the requirements for precision cannot be established so easily. In such cases some concepts of optimal network might be necessary. These optimal precision criteria can either be based on theoretical results such as isotropic and homogeneous criterion matrix, or they can be achieved from empirical studies. This kind of criterion matrix has a Taylor-Karman structure (Grafarend, 1982), which results in circles as point standard ellipses in a plane network. A criterion matrix is a variance-covariance matrix which has an ideal structure representing an optimal situation in the designed network.
For a surveying network it is not always necessary to establish a criterion matrix. As sometimes only some points have to be monitored, point standard ellipses or trivial ellipsoids

are used as precision criteria. These error ellipses are not invariant in relation to the datum. For this reason, the positional precision of one point relative to another (relative errors ellipses) is an important indicator of relative precision (Silva, 2004).

2.3. Reliability

Reliability of a network is the ability to detect gross errors in the observations and to estimate the effects of the undetected gross errors in the parameters estimated from the observations.
Traditionally, the quality of a network has been described by the measure of its precision, whose major component is the covariance matrix of estimated coordinates. This matrix is datum dependent quantities and neglects the aspect of reliability. The observations and derived functions such as coordinates can be judged on precision and reliability by using statistical approach. The concept of reliability makes to have a good assessment of blunders and systematic errors possible.
If a set of observations has any bias it can lead to wrong conclusions. In such observations, without any other error, measures of precision will indicate a good result, even though the result is biased and unreliable.
The reliability of a network depends on the configuration of the network and on the weight matrix of the observations rather than on the observations. Because of this, the reliability should be examined at the design stage. A reliable network should ensure the detection of gross errors as small as possible and the effects of the undetected gross errors on the estimated parameters should be minimized. The main criteria for the reliability of a surveying network are internal reliability and external reliability.
Internal reliability, of a surveying network, is its ability to allow the detection of gross errors by tests of hypothesis made with a specific confidence level ($1-\alpha$) and power ($1-\beta$)
External reliability, of a surveying network, is related to the effect of undetected gross errors on estimated parameters and on functions of them.

2.4. Accuracy

The accuracy can be defined as the combination among the precision, and the reliability (Baião, 2006). In spite of the terms precision and accuracy seem synonymous, the precision is related just to random effects, in other words, to the dispersion of the values around the most probable value, while the accuracy is linked to the random and systematic effects that are evaluate using the reliability procedures.

3. MATERIALS AND METHODS

The language Java was adopted to make possible the use of the software as a free one, besides maintaining the advantages of the oriented-object programming and of the great availability of libraries (Deitel, 2003).
A planning of the structure of the program was accomplished, taking advantage of the oriented-object programming to try to create software easily expandable and adaptable.
The approach used enables the program to be applied to any set of observations where the adjusted observations can be expressed as a function of the adjusted parameters.
The mathematical model for implementing the software is the following:

The largest undetectable gross error ∇l_i is given by the formula,

$$\nabla_{l_i} = \frac{\delta_o}{\sqrt{r_i}} \sigma_i \tag{1}$$

Where,

∇_{l_i} is the largest gross error which will remain undetected in the observation l_i

σ_i is the standard deviation of the i^{th} observation;

δ_o is the lower bound for the non-centrality parameter;

r_i is the redundancy number of the i^{th} observation.

The ∇x_i, which is the effect of an observational error on the estimated parameter is:

$$\nabla X_i = \left(A^T PA\right)^{-1} A^T P \nabla l_i \tag{2}$$

The variance-covariance matrix of the adjusted parameters is:

$$C_{X_a} = \left(A^T PA\right)^{-1} \tag{3}$$

The redundancy number matrix is given by:

$$R = I - (A(A^T PA)^{-1} A^T P) \tag{4}$$

The adjustment of a set of observations by the least squares method using the parametric approach is an iterative process, whose rule of decision on finishing the processing will be the evaluation of a convergence criterion. This is fulfilled when all the values, in module, of the elements of the vector of the parameter corrections (X) go smaller than a value of acceptable convergence.

As the reliability of a network is defined by the precision of the observations and for their redundancies, it was used the matrix of redundancies as the criterion for the reliability improvement of the network observations.

The sum of the partial redundancies indicates the degree of freedom of the surveying network. Thus, each added redundant observation increases in a unit the sum of the partial redundancies, no matter the measured observation. So, the more homogeneous the values of the partial redundancies are, the more reliable the network is considered. Therefore, it is reached by minimizing F, such that:

$$F = \sum (R_{mm})^2 \tag{5}$$

or

$$F = (RY)^T RY \tag{6}$$

In that Y is a matrix column filled out only with values 1.

A better distribution of values is sought through that minimization of the sum of the squares of the partial redundancies, thus minimizing unreliable observations.

For the optimization of the network, it is used the simulation method, by analyzing each observation at once and verifying the results.

4. RESULTS

As the result of this work it was obtained software, capable of improving a surveying network, and suggesting observations to improve the precision and the reliability of the network.
The observations are showed separately, making possible either to increase or to exclude some observation in an easy way. The figure 1 shows a typical window of the software.

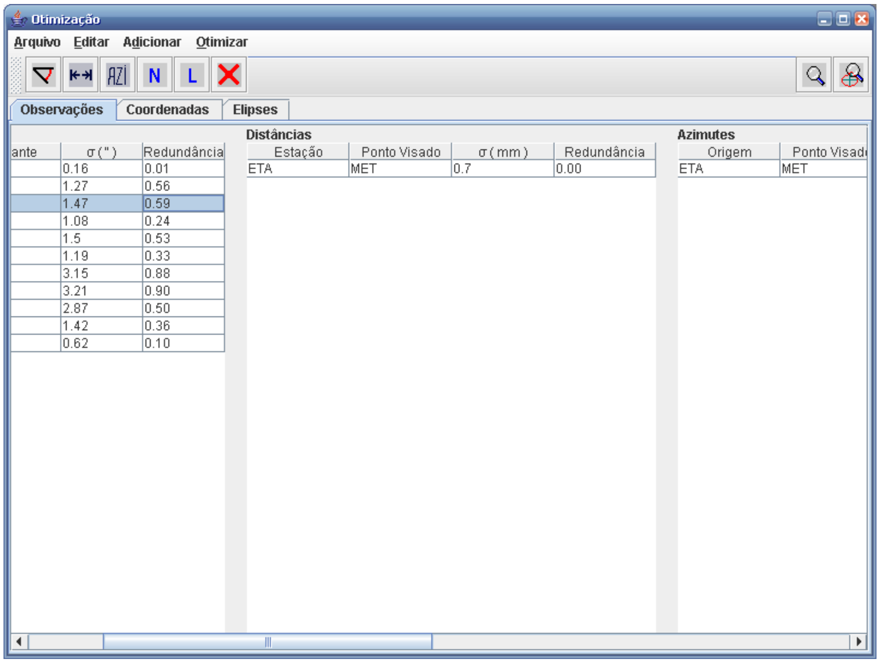

Figure 1 - Window of the observations

To each alteration in the data of the network the precision and redundancy numbers of the observations are recomputed, informing whenever some essential observation in the calculations of the network were excluded.
In order to easy the visualization, the error ellipses are showed in a panel containing the scale of the ellipses (figure 2). The scales and the colours of the panel are changeable.

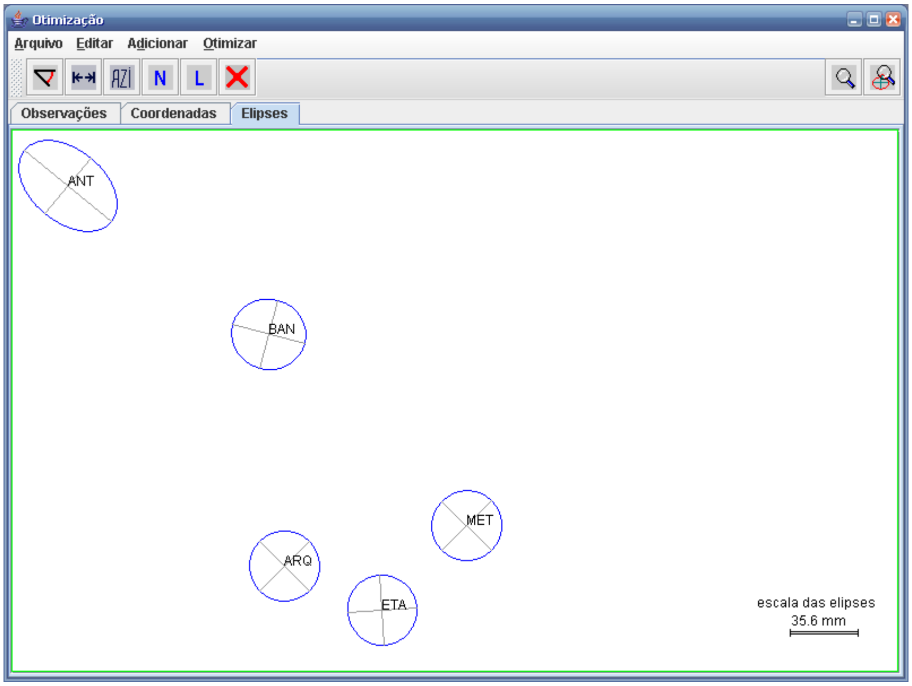

Figure 2 – Error ellipses

When requested, the program informs the user which observations provide better contributions to the precision, or to the redundancies number of the observation of the network.

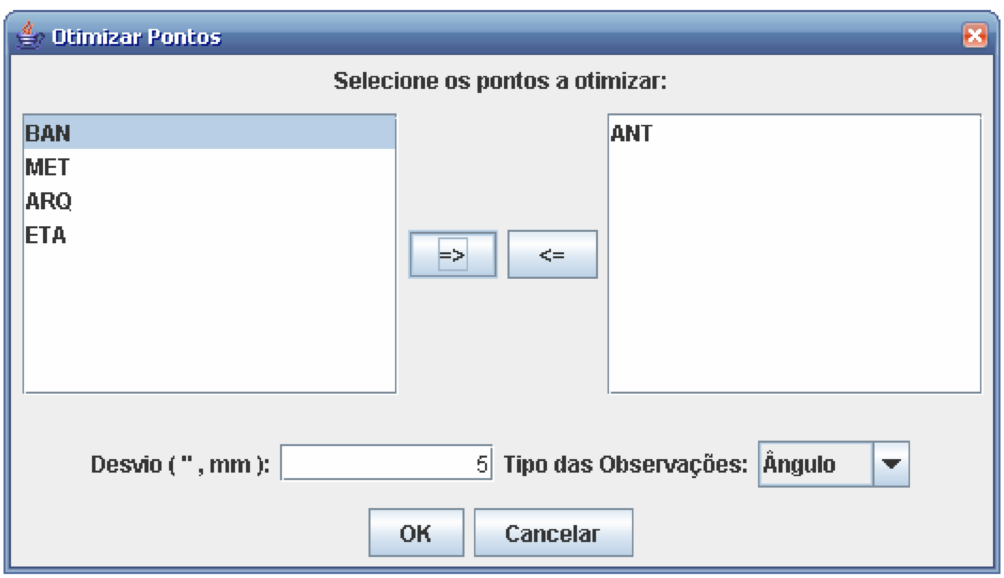

Figure 3 - Choice of the points to be optimized


Sugestões
Observações e novas precisões

Observação	ANT σx (mm)	ANT σy (mm)
Ângulo: BAN - ANT - ARQ	4.5187E1	4.8826E1
Ângulo: MET - ANT - ARQ	4.5739E1	4.9550E1
Ângulo: BAN - ANT - ETA	4.5925E1	4.9734E1
Ângulo: ANT - BAN - ARQ	4.6185E1	4.9946E1
Ângulo: MET - ANT - ETA	4.6371E1	5.0331E1
Ângulo: ANT - BAN - ETA	4.6430E1	5.0286E1
Ângulo: ANT - ARQ - MET	4.6453E1	5.0578E1
Ângulo: ANT - MET - ETA	4.6672E1	5.0406E1
Ângulo: ANT - MET - ARQ	4.6576E1	5.0533E1
Ângulo: ANT - ARQ - BAN	4.6487E1	5.0628E1

Adicionar Cancelar

Figure 4 - Suggestions of angles for the optimization of a point

Two different forms for optimization were implemented in this program:
1 -excluding the observation that less contributes to the precision or to the redundancy number of the network.
2 - adding the observation that more contributes to the precision or to the redundancy number of the network

5. CONCLUSIONS

The software was implemented to optimize surveying networks. Some tests have been done and they prove that the software work properly
The interaction of users and software was looked for, in order to make the optimization of the network the easiest possible. For teaching purposes it was added to the software, a manual for helping the users, which describes the main concepts of optimization of surveying networks, their functions and usefulness; and how to use the software.
It was obtained a program easily to use, which optimizes the precision of the points and the distribution of the reliability of the observations. All the windows and commands are showed in Portuguese.

6. ACKNOWLEDGEMENTS

Acknowledgements to CNPq (Conselho Nacional do Desenvolvimento Científico e Tecnológico) for funding part of the project; making this work possible.

7. REFERENCES

BAIÃO, Henrique Lima; JESUS, Alexandro Campos de; SILVA, A. Simões; IORIO, Vladimir Oliveira Di.(2006) Confiabilidade e Precisão de Redes geodésicas. In: COBRAC 2006 Congresso Brasileiro de Cadastro Técnico Multifinalitário, 2006, Florianópolis. Anais do Congresso Brasileiro de Cadastro Técnico Multifinalitário. Florianópolis: UFSC, 2006. p. 1-9.

DEITEL, H. M. & DEITEL, P. J.(2003) *Java: Como programar*, 4º edição, Bookman, 1386p.

GRAFAREND,E.W. (1982) "Optimisation of geodetic networks." Munchen. DGK, B, 258/III - 69-81

JESUS, Alexandro Campos de; SILVA, A. Simões; IORIO, Vladimir Oliveira Di; ROMÃO, Verônica Maria Costa. (2005) Software para Ajustamento de Observações. In: XXII Congresso Brasileiro de Cartografia, 2005, Macaé - RJ. Anais do XXII Congresso Brasileiro de Cartografia - CD ROM. Rio de Janeiro: Sociedade Brasileira de Cartografia, p. 1-9.

SILVA, A. Simões. (1997) Optimization of Surveying Monitoring Networks. Nottingham UK: University of Nottingham, (PhD Thesis).

SILVA, A. Simões; ROMÃO, Verônica Maria Costa. (2004) Conceitos em planejamento e otimização de redes para monitoramento de deformações. In: I Simpósio de Ciências Geodésicas e Tecnologias da GeoInformação, 2004, Recife. Anais do I Simpósio de Ciências Geodésicas e Tecnologias da GeoInformação, p. 1-9.

Corresponding author contacts

Antonio Simões SILVA
asimoes@ufv.br
Universidade Federal de Viçosa
BRAZIL

Verônica Maria Costa ROMÃO: vcosta@ufpe.br