74 Motorized Tacheometres Aiming at 5350 Prisms in Amsterdam: The Largest Topometric Continuous Real Time Monitoring System in the World?

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SUMMARY

When a specific area has to be monitored, one may survey a geodetic network and repeat the observations at various epochs. In specific cases, automatic systems (motorized tacheometers) are required for continuous data acquisition and thus specific softwares are required for data processing.

IGN has designed its own system of automated acquisition. A type of software called TACT (standing for Targets Acquisition with Controlled Theodolite) has been developed with SolData Company. Each total station has to be connected to a PC where the software is installed. Before the autorun, the system has first to be taught about the targets it has to detect and one must define how the measurements must be done (for instance, two acquisitions in both circles on each target).

IGN has developed its own tridimensional compensation system called COMP3D, least squares adjustment in a local system. It is used for micro-geodesy applications (e.g. a few kilometers).

For a small network, sometimes it is not possible to provide enough references. In this case, we use several motorized tacheometers combining target references as usual, and other references shared between several stations. Using least squares adjustment software the whole system can be calculated as a group composed by all the observing stations, the reference targets for one or more observing stations, and all usable information.
This system is already being used on several areas, but the main example is the city of Amsterdam where 74 motorized tacheometers and 5 350 prisms are processed continuously, for the construction of a metro line.

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1. PRESENTATION

This document presents the automatic monitoring system that IGN has developed in co-operation with SolData. Automatic total stations can provide measurements with a frequency and density that manual measuring would never have been able to reach. Besides, the manufacturers supply instruments whose functionnalities configurations can more and more be defined by the user by the way of a piloting system.

Thanks to these automatic instruments, the idea of an automatic monitoring system in real time has naturally appeared. From this automatic data acquisitions by tacheometers, the coordinates of the observed points located in the region that is supposed to move have to be computed automatically. Therefore, it becomes possible to describe the movement of each monitored point in real time.

The coordinates automatic computation becomes problematic when several tacheometers have to monitor a unique site in the same local reference system and when some of the points can only be observed by tacheometers installed in the moving area and thus their position have also to be processed automatically.
This study is made up of three main axes:

- Data acquisition
- Data organisation or group definition
- Data processing

These three axes are developed in this document that is illustrated by the example of Amsterdam where this monitoring system has been set up during the works for the subway construction.

2. AUTOMATIC DATA ACQUISITION

IGN and SolData have developed their own system of acquisition: TACT standing for Target Acquisition by Controlled Theodolite. The configuration possibilities of this piloting system are quite numerous and make the acquisition compatible with the measuring state of the art. As every piloting system, a learning phases is compulsory for each automatic total station that is equipped with such a system. Then, the automatic acquisition can run.

2.1 Initialisation and Learning

A first series of parameters has to be registered in order to configure the system. Some of them are quite typical for such a system as the name and coordinates station, the instrument height and the reference orientation. The system has got also an access to the compensator, that is always switch on for most of the applications in monitoring. The communication parameters between the total station and the PC (such as baudrate, COM...) have also to be defined.

It is important to point out the fact that the system accepts equally Zeiss and Leica automatic total stations. Then the user is free to use either the one or the other instrument, even both for the same site.

Then, the targets that have to be observed are manually learnt : horizontal and vertical angles and distance are recorded for each target. In the same time, the search window size is specified if necessary. This option is useful in the case of aligned targets.

At the end of this first step, the network can be visualized.

2.2 Observations Configuration

All the learnt targets can be organised in pointsets that are associated with one or more timers. A pointset is defined by sorted targets, for instance by increasing horizontal angles. The timer is defined by its date of validity and its frequency of activation. Therefore, the user can distinguish the rate of acquisition depending on the type of points (more frequent observation of sensible areas) or on the time of observation (only during the night to reduce refraction influence).
The export format has also to be defined depending on the processing that will follow this acquisition.

Furthermore, classical topometric procedures are implemented and can be chosen by the user in order to eliminate or to reduce the consequences of instruments errors and to reduce the random error of the measurements. Two types of characteristics exist: those concerning the targets, and those concerning the cycles.

Indeed, for each target, are user-definable:
- The number of successive shoots,
- The tolerance between successive shoots,
- The time between successive shoots,
- The number of attending shoots before abandoning,
- If the total station has to move out of touch with the target after each shoot...

For a cycle, are user-definable:
- The aperture and closing target,

- The tolerance for closing cycle
- If the cycle has to be reduced
- Both circles readings in a raw or one cycle with left readings then one cycle with right readings
- If all the measurements, their means or their medians are saved and exported.

In addition to these targets and cycles characteristics, temperature and pressure can also be measured if total station are fitted with sensors and introduced in the processing. The measurements can be recorded at the beginning or/and at the end of a cycle so that the inclination measurements.

At this point, all the total stations are able to observe automatically the whole network. They are completely independant to each other, acquiring observations and exporting them to the PC that processes the data.
In most of the cases, the network geometry requires several tacheometers to compute the coordinates. Therefore all the observations have to be organised to be processed together: the group has to be defined.

3. DATA ORGANISATION

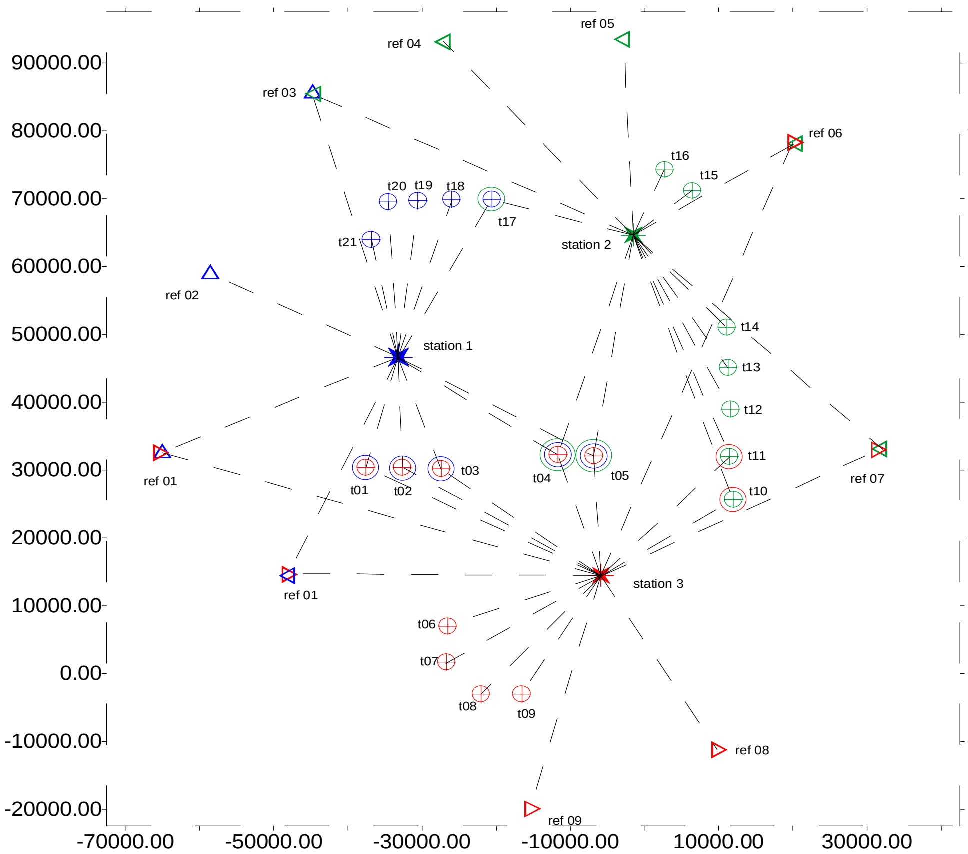
3.1 Group Definition

When the area to be monitored is cluttered, a real network with several total stations and reference points is set up. These reference points are materialized by targets installed in stable area and have to be numerous enough and well located all around the total stations in order to process the instrument coordinates in first step, then the points coordinates. However, it happens that it is impossible to get enough reference targets for each total station because some of the points that have to be monitored require a total station in a place where no reference targets can be seen. It's then necessary to add new constraints to reinforce the network skeleton.

A group is defined by many total stations and all the reference points they can see and additionally what is called « multiple points ». These multiple points are points that are located either in or outside the studied area and that are seen by several total stations. The new constraints it creates make the network more tightened up. There is enough redundancy to calculate the network and ensure the precision of the determinations.
It is obvious that multiple points are generally located in the moving area since this is where they are usually required. Multiple points are also physically multiplied. Indeed, the prisms have to be well oriented when pointed by a total station in order to ensure the instrument precision. Therefore, the prisms of a multiple point have to be carefully installed, that is to say close enough to each other and on a homogeneous entity that can not buckle so that it can be assumed there is no relative movement between the prisms of a multiple point.

When designing the network, it is first of all important to have enough reference points around the monitored area. Then, the multiple points have to be well located and numerous enough to transmit the references. Furthermore, the field constraints and particularly the reciprocal visibilities have to be kept in mind. It is strongly recommended to compute simulations in order to ensure that with the a priori measurement precisions and the geometry of the network, the final coordinates precision is reached. The least squares adjustment let the designer have the final precision in a statistical way.

The following scheme shows such a network.



In Amsterdam, the whole monitoring network has been simulated before being set up. There are 23 groups of 2 to 5 total stations.

3.2 Initial Coordinates

When a group is defined, the coordinates of the reference points have to be determined so that the initial coordinates of all the total stations and all the monitored points. Indeed, the deformation has to be understood as the displacement vectors between the initial state and the running one.

The initial state is determined according to the following steps :

– Determination of the local coordinates system thanks to a geodetic survey between the stations : stations coordinates and orientions are calculated.
– Reference points coordinates are then determined by the automatic total stations installed on the known points. Data of several cycles are averaged.
– Initial coordinates of all the monitoring points are determined in the same time, same way.

As soon as all the initial coordinates are known, the vectors between the targets of a multiple point can be processed. Each vector is then expressed in terms of three independent components: one distance, one horizontal angle and one vertical angle, called fictitious observations. Each fictitious observation is associated with its calculated precision that should be understood as constraint weight in the Least Squares Adjustment.

The group is in this way interlocked by several types of constraint. First, the reference targets are stable points, installed outside the moving area on undeformable structure. The first type of constraint is then the large constraint on reference points coordinates which define the local coordinates system. As these constraints are sometimes not sufficient to have a solid group skeleton, a second type of constraints has been created. These are large constraints on fictitious observations between targets of multilple points.

3.3 Reference System

At this step, it is possible to monitor the area in the local coordinates system. However, several methods are usually used to monitor an area and the information the topometric monitoring network provides has to be superimposed with information acquired for instance by inclinometers, extensometers, levelling… Then, it is often required to determine the transformation parameters to a global coordinates system which is common to all the providers of data.
The interest is multiple. First, information from different origins can be used as it has been precedently explained. But also, it lets the results be compared and redundant with other one. In this way, the stability of the reference points can be checked by independant measurements like regular campains of manual precise geodetic levelling or geodetic surveying of the reference points.
We should point out that even if the transformation to a global coordinates system exists, all the acquisition of the automatic topometric monitoring system is processed in the local coordinates system since this is better defined. The results are expressed in the global coordinates system afterwards.

As Amsterdam example is concerned, 74 total sations are installed and are monitoring 5350 targets. The total stations are organised in 23 groups of 2 to 5 and 8 local systems cover the whole area. Each local system has parameters which link itself to the Amsterdam Datum.

The definition phasis is now finished : the skeleton of the network is designed, the constraints on reference and multiple points are defined, the local and global reference systems are determined and linked to each other. All this information is implemented in the processing system. The automatic acquired data can be automatically processed thanks to the model described in the following.

4. DATA PROCESSING

4.1 Description

The processing module, COMP3D, has been developed by Yves Egels at IGN. This let the geodetic micro-networks (few kilometers) be computed. The main principle is a compensation by Least Squares processed in a local 3D system.

4.2 Local 3D system

The local 3D system has been defined by considering that geoid has been approximated by a tangent sphere to the ellipsoid at the center of the interesting area.
By assuming that all the projections are locally equivalent, the planimetric coordinates expressed in the local coordinates system are considered as the coordinates in a stereographical oblique projection. The altimetric component is considered to be normal to the sphere.

Therefore, we can express the points coordinates in this local 3D system so that the observations.

4.3 Least squares Adjustment

The principle of Least Squares is to minimize the residuals between the observation measurement and the theoritical value thanks to the redundancy. This adjustment can be described by its functional and stochastic model and its parameters.

The functional model is the observations equations and the constraints equations which are not linear. The observations equations link the real measurements of distances, horizontal and vertical angles to the coordinates and the fictitious observations of multiple points to the coordinates. The constraints equations deals with the reference points.
The stochastic model assumes that :

- measurement errors are normally distributed,
- measurements are independent, reference constraints also,
- weights are inversely proportional to the precision.

Therefore, real observations equations are weighted with respect to the measurement precision, fictitious observations equations with respect to the precision that has been achieved when they have been computed, reference constraints equations with respect to the precision of their determination.
The parameters are all the coordinates points : reference points, total stations and obviously, monitored points.

For real observations, the typical precisions that are introduced are :

- distances : 1mm+1ppm
- horizontal angles : 0.0008 gon
- vertical angles : 0.0008 gon

The constraint vectors have a precision of 1mm to 2mm.
The centering constraints of reference points are 1mm.

To solve this non linear system with respect to the weighting, observations equations are linearized and an iterative procedure is implemented.

4.4 Results

A Least Squares adjustment provides the resulted value for the parameters and also indicators of quality. Therefore, it is possible to know how the calculations went through, if problems occurred like a constraint impossible to follow or a wrong measurement.

For each observation, the result before compensation gives the difference between the observations measurements and the theoretical observation processed with the initial coordinates. Some faults can be generally detected at this step, particularly targets confusions when aligned.

After the adjustment, residuals give the difference between the observations measurements and the theoretical observations processed with the adjusted coordinates. The residuals on reference points and constraints vectors of multiple points let the initial hypotheses be checked. The a posteriori variance factor can be compared with the a priori one. Furthermore, for each point, are given:

- An indicator of redundancy: number of observations and constraints of its concern
- An indicator of quality: quadratic sum of all the standardized residuals of the observations and constraints concerning it.

All these information is required to analyze the compensation results and to modify the initial design if something wrong was appearing.

Finally, the adjusted coordinates are provided. They are associated with a confidence ellipsoid and a displacement vector which can be consider as significant as soon as it points outside the ellipsoids.

5. CONCLUSION

A real complex geodetic network can be observed and processed automatically. Results are good in Amsterdam and wherever it has been set up.
We can add that all but the analysis is automatic. Or something like, it is impossible to make the analysis automatic. It is possible to put automatical warnings about large residuals or flags strange values, but that’s all. A human being is still required to understand what’s going wrong. But if everything is ok (no flag, no warning) that means that the model is ok.

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