



## **TESTING: AN APPLICATION FOR MOTORIZED TACHEOMETERS**

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**Abstract:** The measurement of the observables is affected by observation errors, which arise from several causes, such as the measurement equipment, the operative methods, the atmospheric conditions, and the operator's skill. Experience has shown that developing observing procedures and performing tests to control the errors during or right after the measurements is not only a reasonable procedure to minimize the effect of the errors but might also have a high economic impact.

The tacheometer (i.e., total station) Leica TCA2003, with automatic target recognition (ATR), has an ATR accuracy that can reach levels similar to manual pointing. For this reason, in some of the high precision geodetic monitoring systems, where angle and distances are measured, TCA2003, along with the onboard software *Monitoring*, can be applied. This software, also from Leica, was designed to perform repeated automatic measurements to predefined points. But, after the first campaign, it became obvious that the lack of control on the data was leading to longer measurement periods because these had to be repeated several times, only way to be able to, latter, reject those measurements that clearly includes errors. To avoid long periods of observations and the uncertainty on the quality of the data, it would be important to include the control of errors during the measurements.

TCA2003 belongs to the Leica instruments family that can be loaded with software applications developed by the user, according to his needs. This paper presents an application called *Testing*, developed using the programming language GeoBASIC from Leica. Although it has some similarities with the application *Monitoring*, the onboard software *Testing* has some very unique properties since it can perform tests in real time, to validate the data measured, and alerts the observer whenever it detects an error, allowing the user to undertake the most adequate procedure. The paper describes the limitations of software *Monitoring*, when applied in very specific applications, the solution used to surpass the shortcomings - the development of a new onboard software, *Testing* – and the main features of this one.

### **1. INTRODUCTION**

The Applied Geodesy Division (AGD) of LNEC has a motorized tacheometer Leica TCA2003 that has been used for the monitoring of displacements of structures. When high precision results are required, it becomes essential to materialize the points of the geodetic monitoring system, namely the stations and the targets. This causes the measurements to differ very little amongst themselves, unless there are high displacements. Because of the differences between the measured values in different epochs doesn't differ that much it becomes possible, in these situations, to use measurement equipment that incorporates a



pre-programmable automatic aim system. For this reason, in the observation systems where points are materialized by targets reflectors it's possible to use tacheometers like Leica TCA2003 and an application called Leica *Monitoring* (Leica, 1998). This application, which is installed in the tacheometer, allows precise automatic aims, angles and distances measurements and recording all measurements in an external memory card, following a sequence and periodicity pre-defined by the user.

When is necessary to respect sub-millimetric uncertainties, is essential to perform the quality control of the measurements. Among the causes of errors that affect the measurements, stands out the effect of the atmospheric refraction, which can be minimized by taking the measurements in the periods of the day that have appropriate observation conditions. These periods have a reduced time span. For this reason is desirable that the control is accomplished in real time, during the measurements, repeating these immediately, if necessary. The application *Monitoring*, developed by Leica, that can be applied in measurements for monitoring effects, , presents some limitations; the most important one is that it doesn't allow the quality control of the measurements.

The equipment TPS (TPS - Total Stations System) of Leica, a equipment series that includes the tacheometer TCA2003, allows the installation of user developed applications in the internal memory, making it possible to program the equipment for specific tasks. In this communication the application Testing developed in AGD is presented. In the first part of this communication it is presented the application *Monitoring* of Leica and the limitations found in face of its use in specific tasks. In the second part of the communication is presented the application Testing.

## 2. APPLICATION MONITORING

The application *Monitoring*, loaded in tacheometers of the series TPS1000 equipped with systems for automatic target recognition (ATR - Automatic Target Recognition), is applied in the measurements of angles and distances in repeated way according to a sequence determined by the user. This sequence can be established in the field, or before, in the office, for instance, using a computer and transferring the data to the external memory of tacheometer.

The tacheometer has servo-motors to aim and for target recognition. It is also equipped with multiple processors to control various components: ATR, a distancemeter, angles measurements, compensator, modules for reading and writing data into memory, etc.. Besides the unit of external memory, where data is recorded as files, TCA has also a unit of internal memory, where applications and the data needed for the corrections of the measured values are installed. To run the application *Monitoring* is necessary to have a file, in the external memory of tacheometer, with the data needed to perform the aims: angles.

The tacheometer TCA2003, together with the application *Monitoring*, have been used in the observation of some systems, for example, in all precision traverses measured by teams from the AGD. Dozens of campaigns undertaken and hence thousands of measurements made, enabled to notice the high accuracy in automatic pointing, provided that the conditions reported by the manufacturer are satisfied (Leica, 2000): short distances, light and constant dark background, clean target and properly oriented to tacheometer, stable atmosphere and, of course, use of the most precise targets.

However, despite the good conditions of observation, pointing errors occurred occasionally. The detection of these errors was possible due to the fact that there are redundant



measurements: there were always made three measurements for each point, in each position of the telescope. Calculating the standard deviation of these three observations, selecting those that have values above 0.3mgon and calculating the incidence of these, were obtained the percentages of measurements with anomalies shown in Table 1. The observations were performed in the open air and in two galleries. The galleries are located in two different dams.

	<b>Anomalies</b>
Open air	4%
Gallery A	6%
Gallery B	1%

Table 1: Incidence of anomalies in the observations

The high incidence of abnormalities in Gallery A is the result of the failure to achieve one of the conditions specified by the manufacturer, a stable atmosphere. At gallery A, there are thermal amplitudes, not only between the interior of the galleries and the outside but also inside the dam, which produces an almost constant air flow. This air flow occurs mainly near the ends of the gallery, where the accesses to different areas of the dam are located. It is noteworthy that the observations that took place in the central area of the Gallery A, the incidence of anomalies was 1%, exactly the same as occurred in Gallery B, located in a dam very thermally stable.

Although the incidence of anomalies can not be overlooked, there aren't, however, any pointing anomalies in the majority of the measurements, a fact that is good to the progress of the campaign, if the repetition of measurements were performed only when there are abnormal values. In addition, to only the time spent in the observations would be reduced but also the wear of the tacheometer and batteries.

The application *Monitoring* of Leica, that has been used in most of the observations made with the TCA2003, does not perform any analysis of the measurements recorded. Other negative aspects of this application are: doesn't allow the control, in real time, of misclosures; doesn't emits clear warning sign when the target is not detect or when it detects more than one target, as a result of the proximity of points. These restrictions led AGD to consider creating one application to the TCA, which could surpass the limitations of *Monitoring*. Thus an application was developed which was given the name *Testing*.

### 3. TESTING APPLICATION

The development of applications for the equipment Leica TPS1000 series, as well as their test in computers, simulating the procedures of the tacheometer, is performed using the programs Leica GBStudio, GeoBasic1000 (Leica, 1999) and the TPS1000 Simulation. These enable the development of applications and also, with some limitations, the simulation of the tacheometer behaviour. The uploading of applications to the internal memory of the equipment is done through the program PC-Workbench.

Quite similar to Visual Basic, the programming language GeoBasic incorporates some subroutines used to initiate procedures in tacheometer. Rotate the telescope to a given direction, detect the target, initiate measurements, record the measurements on file, get the internal time of the tacheometer, these are some of the subroutines incorporated. This programming language also supports multi-language and use of graphics functions.

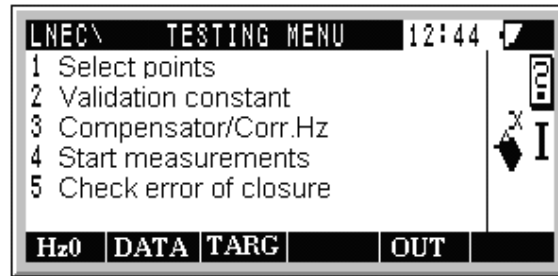


Figure 1 - Testing main menu

After the completion of two measures, *Testing* estimates the standard deviation of the two horizontal angles, of the two zenith angles and the two distances, and tests them, by comparing them with predefined values. If at least one of three tests is rejected a third measurement is made and the tests are repeated. If a second rejection occurs the user is alerted (see Figure 2). The user does not need to establish the values of the test variables each time he begins a new set as they are loaded to the memory when the program starts.

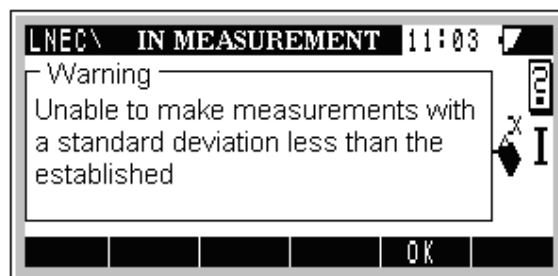


Figure 2 - Advice Window in the case of rejection

Every time the value given by the statistical test is in the critical region, the hypothesis “no errors” is rejected. The user can (see Figure 3): i) introduce new values for the critical region (these can be applied strictly to the data under examination or be used for all subsequent tests accomplish during the set of measurements); ii) repeat the measurements; iii) reject the measurements, action that causes the tacheometer to continue to the next point; iv) finish the set.

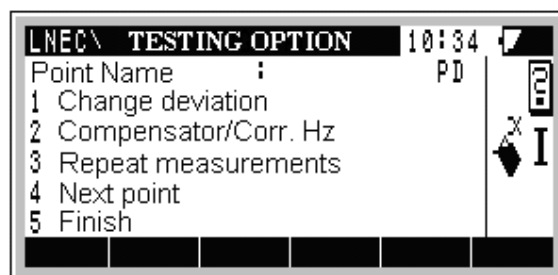


Figure 3 - Menu with the options in the case of rejection

The *Testing* alerts the user whenever an error is detected during the measurements. Failure to detect the target, atmospheric disturbances and the detection of more than one reflecting surface are the most common causes of error messages, according with experience taken from



campaigns already conducted by teams from AGD,. After alerting the user, the application waits for his decision (to repeat the measure or continue to the next point). Besides these three errors, *Testing* detects eleven other errors (error in the calibration of the system ATR, error in the acquisition of the target, precise position of the target not reached within the expected time, etc.), errors that the user is not informed in real time, but are register in the output file.

*Testing* does not require the guidance of the horizontal circle, provided that, at the beginning of the set, the telescope is pointing approximately to the first point of the set. At the end of each set it calculates the misclosure of the horizontal angles and displays the value. The user can choose, before the start of the set, the number of repetitions. The sequence of aims, in one or two positions in the telescope, depends solely on the structure of the input file.

The *Testing* lets you enable, or disable, the compensator of the vertical axis ("electronic level") and the system of correction of horizontal angles (includes corrections of errors of Hz-collimation, ATR collimation, vertical index and tilting axis). It also includes two subroutines, which are frequently used in the application *Monitoring*: i) one allows to establish the constant of the prism (when it is not altered the constant 0 mm is used); ii) other sets the zero of the horizontal circle (Hz0). Contrary to what happens with *Monitoring*, in *Testing* the user is not required to exit the application to perform these operations.

Two results files are created: one containing the measured values, accepted after the testing (Figure 4), another containing the same values plus error messages that may have arisen during the measurements (Figure 5). In the two files one can find also the name of the input file and the values of temperature, atmospheric pressure and relative humidity. These values are supplied by the user before starting the set and at the end of this. The advantage of including the name of the input file is to allow the user to know the name of the station where the set was made, provided that the name of the file includes the name of the station and first target point (origin).

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```
P10_11.GSI
Temp. : 31.5° Pres. : 1040 mBar Hum. : 24%
110000+P11 21.322+39999989 22.322+10006850 31..06+ 906824 19...+09042201 58..16+0
110001+P11 21.322+39999985 22.322+10006858 31..06+ 906823 19...+09042201 58..16+0
110002+PE 21.322+ 3738518 22.322+ 9722050 31..06+ 2008710 19...+09042202 58..16+0
110003+PE 21.322+ 3738518 22.322+ 9722080 31..06+ 2008712 19...+09042202 58..16+0
110004+PE 21.322+ 3738524 22.322+ 9722055 31..06+ 2008711 19...+09042202 58..16+0
110005+P9 21.322+18292217 22.322+ 9995668 31..06+ 798384 19...+09042202 58..16+0
110006+P9 21.322+18292212 22.322+ 9995698 31..06+ 798384 19...+09042202 58..16+0
110007+P9 21.322+18292204 22.322+ 9995673 31..06+ 798384 19...+09042202 58..16+0
110008+P8 21.322+20773482 22.322+ 9998674 31..06+ 1460092 19...+09042203 58..16+0
110009+P8 21.322+20773458 22.322+ 9998639 31..06+ 1460093 19...+09042203 58..16+0
.....
Temp. : 30.6° Pres. : 1040 mBar Hum. : 24%
P11_E.GSI
.....
```

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Figure 4 - Sample of the file with tested and accepted measurements

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P10_11.GSI
Temp. : 31.5° Pres. : 1040 mBar Hum. : 24%
110000+P11 21.322+39999989 22.322+10006850 31..06+ 906824 19....+09042201 58..16+0
110001+P11 21.322+39999985 22.322+10006858 31..06+ 906823 19....+09042201 58..16+0
110002+PE 21.322+ 3738518 22.322+ 9722050 31..06+ 2008710 19....+09042202 58..16+0
110003+PE 21.322+ 3738518 22.322+ 9722080 31..06+ 2008712 19....+09042202 58..16+0
110004+PE 21.322+ 3738524 22.322+ 9722055 31..06+ 2008711 19....+09042202 58..16+0
110005+P9 21.322+-6366198 22.322+-6366198 31..06+ -10000 19....+09042202 58..16+0
410000+001 42....+ERR_8704 POSITION NOT REACHED
110005+P9 21.322+18292217 22.322+ 9995668 31..06+ 798384 19....+09042202 58..16+0
110006+P9 21.322+18292212 22.322+ 9995698 31..06+ 798384 19....+09042202 58..16+0
110007+P9 21.322+18292204 22.322+ 9995673 31..06+ 798384 19....+09042202 58..16+0
410000+001 42....+ERR_1289 INFO: ONLY ANGLE MEASUREMENT VALID BUT ACCURACY CAN NOT BE GUARANTEE
110008+P8 21.322+20773482 22.322+ 9998674 31..06+ 1460092 19....+09042203 58..16+0
110009+P8 21.322+20773458 22.322+ 9998639 31..06+ 1460093 19....+09042203 58..16+0
.....
Temp. : 30.6° Pres. : 1040 mBar Hum. : 24%
P11_E.GSI
.....
  
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Figure 5 - Sample of the file with all measurements (accepted, rejected and errors)

The number of measurements that it is possible to register is limited only by the capacity of the memory card PCMCIA. During the execution of measurements the user is informed of the name of the point that is being observed and also of additional information, such as the number of points to observe and number of sets (Figure 6).

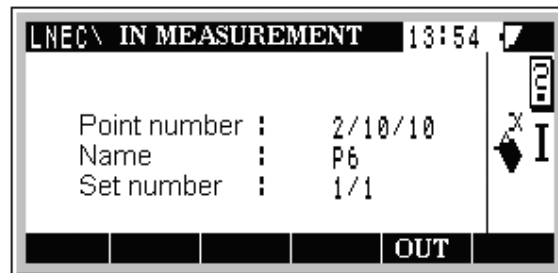


Figure 6 - Information made available by Testing during the execution of the measurements

The *Testing* does not represent, however, a complete change in procedure compared to *Monitoring*. Unchanged: i) the structure of the data, i.e. the data files are readable by both software; ii) the ability to activate or deactivate points, a situation that occurs when the user knows firsthand that one or more targets are not reachable or that the target is missing, and may eliminate those targets from the set.

#### 4. ADDITIONAL APPLICATION

Along with *Testing*, other applications were developed in response to needs in carrying out campaigns. For example, applications to view the data recorded and for the creation of data files in the tacheometer.

The application *Data Testing* is used for displaying data obtained by the program *Testing*. This application informs the user of the total number of measurements registered in the file

and lets him view, for each point, the recorded data, including the date and time the measurement was made.

The application *Convert Testing* creates a data file (input) for the program *Testing*. It is useful when it is not possible to create, by computer, the input file. The creation of this file can be done in office, before the first campaign, if the approximate coordinates of the points of the network and information on the system configuration are available. This application is comparable to the function *Learning of Monitoring*.

The application *Light* was based on *Testing*. The important difference between these two applications is that *Light* does not test the measured values. In *Light* the user defines the number of measurements for each point and also the total number of sets (Figure 7).

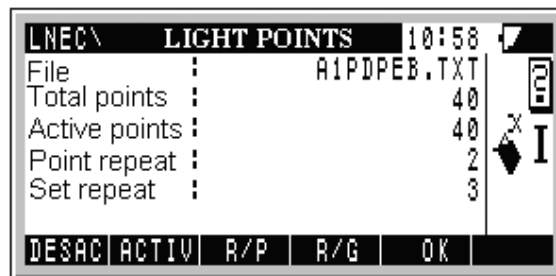


Figure 7 - Light program configuration menu

## 5. CONCLUSIONS

The application *Testing* for the tacheometer of the series TPS1000, such as the tacheometer TCA2003, was developed for the observation of geodetic and topographic networks used for the monitoring of displacements. It has some similarities with the *Monitoring* application with the advantage of safely allowing the reduction of observations by testing the measurements. In addition three separated applications were developed, also intended to be implemented in the internal memory of the tacheometer. These applications and the added capabilities of the final version of *Testing* were developed in response to some deficiencies detected during the campaigns of observation, where the first version of *Testing* was used.

The quality of the results, proved by testing the measurements, and the reliability in use, due to several warnings that arise when anomalies are detected, coupled with the ease of use is in the origin of *Testing* to become in us in all observation campaigns made by AGD teams whenever TCA2003 is applied.





## References

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