Atmospheric corrections for topographic monitoring systems in landslides

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Key words: deformation measurement, engineering survey, network calibration adjustment, risk management, EDM, atmospheric corrections, total station

SUMMARY

New automated "long range" total stations are actually available for monitoring landslides, dams, structures etc. The use of total station is consolidate within some hundred meters of distance and with a supervisor. But the long range (up to 3 km) measurements are not still completely investigated in operating condition. When the accuracy and the precision required are important, seems to be necessary to investigate the atmosphere influence on distance measurements. The research deals with the study of a landslide topographic monitoring system: the Collagna Landslide (Reggio Emilia, Italy) monitoring system. It consists of an automated long range total station acquiring about 36 prisms ,every 4 hours, since 2009. The idea was to test how atmospheric corrections could improve the measurements precision and accuracy to exploit the system capabilities. Some tests on the total station EDM (Electronic Distance Measuring) system are presented in operating conditions. Particularly attention was paid to the long distances dependence on atmospheric conditions (temperature, pressure and relative humidity). Two kinds of corrections were applied, that of the instrument and one of the literature. Some differences were found on atmospheric corrections calculated with the two different methods. But it seems that atmospheric corrections can really improve the final result accuracy.

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1. INTRODUCTION

New automated "long range" total stations are actually available for monitoring landslides, dams, structures etc. The use of total station is consolidate within some hundred meters of distance and with a supervisor. But the automated long range (up to 3 km) measurements are not still completely investigated in operating condition. When the accuracy required is important or indispensable, it is necessary to investigate the atmosphere influence on distance measurements (Marini et al., 1973).

The research deals with the study of a landslide topographic monitoring system: the Collagna Landslide (Reggio Emilia, Italy) monitoring system. It consists of an automated long range total station acquiring every 4 hours, since 2009, a network of about 36 prisms, 6 of control outside the landslide and of 30 inside the body. Actually exist total stations with a very long range and with declared high capability of precision (angle: 0.6"; distance : 1mm+1ppm, standard), such as the Leica TM30, here installed (Leica TPS1200 Technical Reference Manual, v. 7; Leica TS30/TM30 User Manual, v1.0). Thus, it is important to consider the real operative conditions that influence the precision and the accuracy of the final result, such as the atmospheric conditions, particularly when the goal is to detect movements with the magnitude of the centimeter (or less).

The Collagna Landslide, reactivated since 2008, is a risk factor for an infrastructure of great importance, the National Road 63 "Passo del Cerreto", already affected by the landslide in 1973. For this reason, since 2009, the rock slide is the subject of study and monitoring using a robotic station (Bertacchini et al., 2010). The system works continuously and observations are post-processed in real time trying to find and eliminate errors due to external conditions such as rain, fog, etc, with "geometric" corrections: some points coordinates are given as reference coordinates, and the geometric correction is calculated from the variation between the reference coordinates values and these measured at each time. The post-processing of such measurements is computed by the commercial software by means of reference points' coordinates. The most precise and accurate these coordinates are, the best final solution on displacements should be reached. But at the moment, no atmospheric corrections are computed.

The idea was to test how atmospheric corrections could improve the measurements precision and accuracy to exploit the system capabilities. Some tests on the total station EDM (Electronic Distance Measuring) system are presented in operating conditions. Particularly attention was paid to the long distances dependence on atmospheric conditions (temperature, pressure and relative humidity). As a consequence, control prisms were installed on special mounting adaptors in order to perform network adjustment both for GPS (Global Positioning System) and total station surveys (Bertacchini et al., 2011).

Two periodic campaigns were conducted with the total station (April and October 2010) involving the same reference points' network. Observations were obtained measuring each point with respect to the others and taking into account or not, atmospheric corrections algorithms. Two kinds of corrections were used, that of the instrument and one of the literature. After, some comparison were analysed: the first was between the corrected and the incorrected slope distances observations; the second one, between the adjusted corrected coordinates and uncorrected ones and the third was between the different campaigns. Some differences were found on atmospheric corrections calculated with the two different methods. But it seems that atmospheric corrections can really improve the final result accuracy. For example, if the temperature is of about 20°C, the barometric pressure of 918 mbar and the relative humidity of 50%, there's a difference of about 4 cm (40 ppm - part per million) between the ”correct” and the ”uncorrect” slope distance. This is why attention has to be paid to seasonal changes, and the same networks adjustment has to be re-computed for each season. In order to double check those resulting coordinates, GPS surveys have been contextually planned.

But, why to spend time for atmospheric corrections? The hydro-geological risk and the instability of the slope as well, in fact, are serious problems that unfortunately characterized the entire country, along with the Northern Apennines area. The consequences of landslides are sometimes severe. Departments of Civil protections and Regions are facing increasingly disaster and emergency situations that directly affect the population. Topographical monitoring systems along with more established borehole instrumentations can reduce the risk for people and infrastructures linked to this kind of natural hazard. Actually, the Geomatics with state-of-the-art instrumentations and techniques shall be an important support for planning and mitigation of risk. The Collagna Landslide was aperfect sites to test the different techniques and their possible application. This work has been carried out under the scientific and technical collaboration of the University of Modena and the “Servizio Tecnico di Bacino degli affluenti del Po” (Reggio Emilia division). In fact, today, more and more Public administrations are investing in innovative monitoring systems, in collaboration with Universities.

2. THE COLLAGNA LANDSLIDE TOPOGRAPHIC MONITORING SYSTEM

2.1 The Collagna Landslide

The Collagna Landslide is located in the Northern Apennines of Italy, in the Emilia Romagna Region (Figure 1). In December 2008, after high precipitation rates, a landslide interrupted the National Road 63 “Passo del Cerreto”, in proximity of Piagneto, Collagna (Reggio Emilia). In order to restore the traffic circulation, the old road layout was reopened. The old road was closed in the early 1970s as a result of another landslide. At that time the path affected by the landslide in 2008, was designed and created and the landslide risk appeared bypassed, till 2008. Therefore, the National Road 63 “Passo del Cerreto”, in proximity of Piagneto is carachterized by a certain level of risk. A topographic monitoring system was installed in 2009 in order to reduce the risk factor and to monitor the landslide and the neighboring areas.

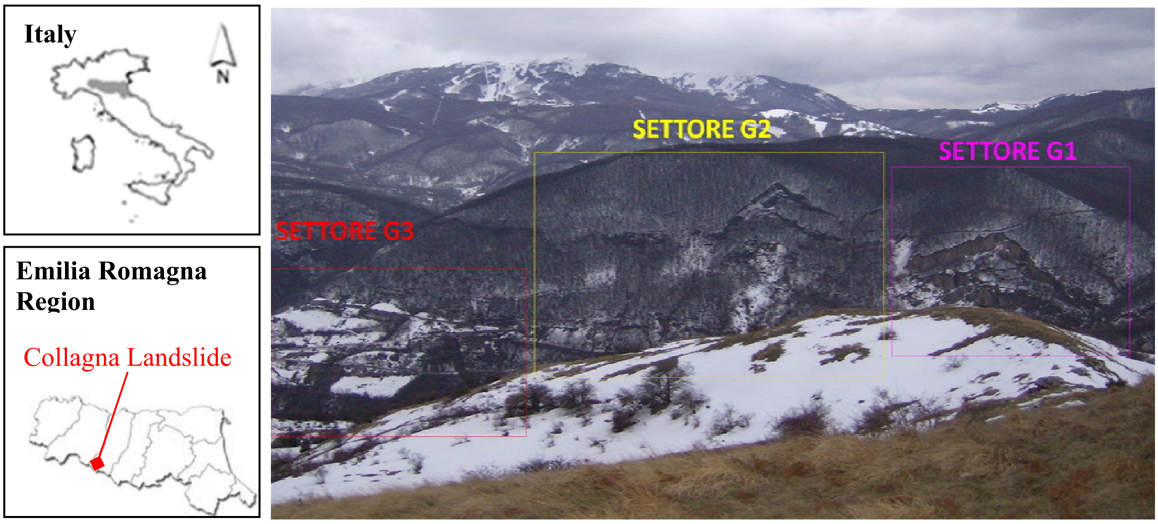

Figure 1: Geographical location and picture (October 2009) of the Collagna Landslide

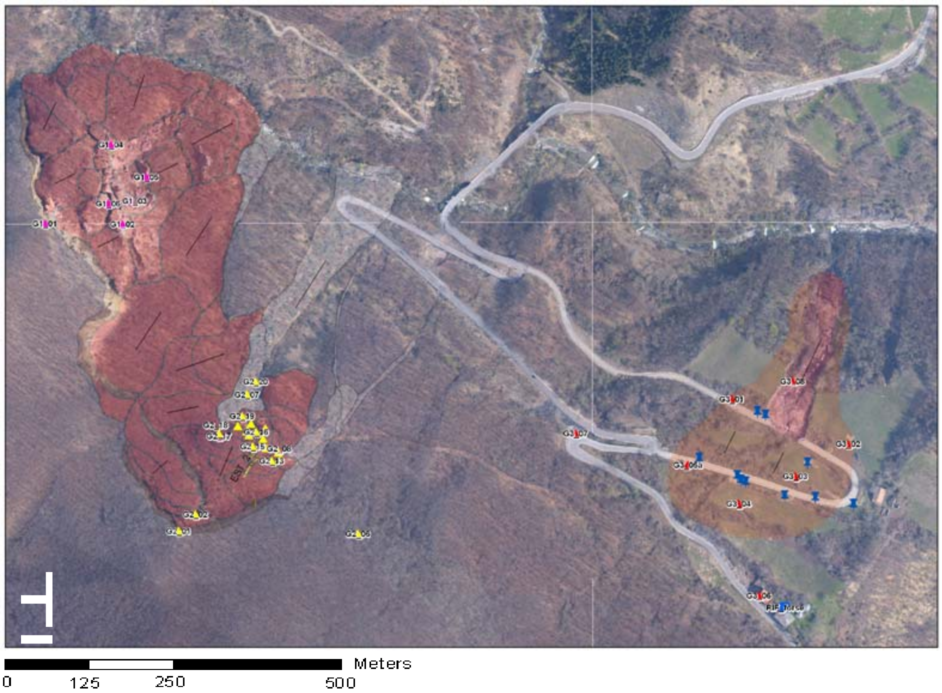

Figure 2: Hydrogeological risk map on the orthophoto 2010

An hydrogeological risk map (Figure 2) was created from the analysis of aerial photos, a detailed LIDAR (Laser Imaging Detection and Ranging) DTM (Digital Terrain Model), different measurements campaigns, along with the total station monitoring system. In Figure 1 and Figure 2 (in red) the three main sub-assemblies identified (sectors G1, G2 and G3) are represented. In Figure 2 their sub-units are represented too: sectors G1 and G2 have sub-units separating each block of rock, or group of rocks with similar movement. The figure reports also deposits of earth and debris flow (in white). The sector G1 doesn't involve the National Road 63, but it's delimited by the Biola creek, already affected by landslides and rock failures in the past. The sector G3 affects directly the National Road. In detail, in Figure 3, some picture of this sector.

Figure 3: Details of the street interruption in sector G3 (November 2010).

2.2 The total station monitoring system

The Collagna Landslide monitoring system (Figure 4) is composed by an automated total station (Leica TM30), able to work up to 3 km. For the Collagna Landslide the medium range distance is about 1 km. The total station and the monitoring equipment (modem, industrial pc, etc) are inside a wooden artifact, thought to protect the systems. Since September 2009, the total station measures 36 prisms every 4 hours. 30 prisms are monitoring prisms, in the body landslide and 6 are of control, outside of it. The total station monument is located near Cava Riva Rossa. From this location it is possible to measure group of prisms installed on the different sectors of the landslide. The monitoring system can be remotely controlled by the office. Thus it is possible to control in real time the status of the sensor, the observations and the acquiring parameters. The remotisation has rapidly evolved through years leading to fast and non expensive internet communication protocols that make quite easy data transfer.

For these type of monitoring systems, the accurate centering of instruments and reflectors over the monument reference marks is a critical procedure for collecting deformation measurements. It is very important how the monument is created, in particular for the instrument permanent location. If rock are presents, these are ideal sites. But, if not, an adequate monument must be projected and realized. A reinforced concrete pilaster, with a foundation of three micro-poles long more than 13 m, was built for the Collagna Landslide monitoring total station. Reference points should be thought in the same way, but when not feasible, it is possible to create “less stable” monument. The conditions of stability of these points should be controlled over time as a guarantee of a correct interpretation of the whole landslide behavior. Generally, the total station pilaster should be equipped with a bi-directional clinometers. But, the instrument tiltmeter, even if less accurate, should replace the clinometers very well, thanks to a good monumentation work of the pilaster. The Collagna total station bi-dimensional tiltmeter has never gone out of range. This means that the starting leveling of the instrument has been kept over time. In fact, the total station wasn’t re-leveled at any time. This kind of control doesn’t gives information on the vertical behavior, but no movements on the horizontal plane should mean no vertical movements.

In Figure 5, there are some examples of prisms monuments. Different types of prism mounting were used: that on the left, for a reference point, can rotate around the vertical and the horizontal axis without changing the prism centre position; the others are special fixed mounting, for monitoring prisms. This special mounting was useful because was cheap and easy to install on rocks, houses, artifacts etc. But it is not created with a forced centering device.

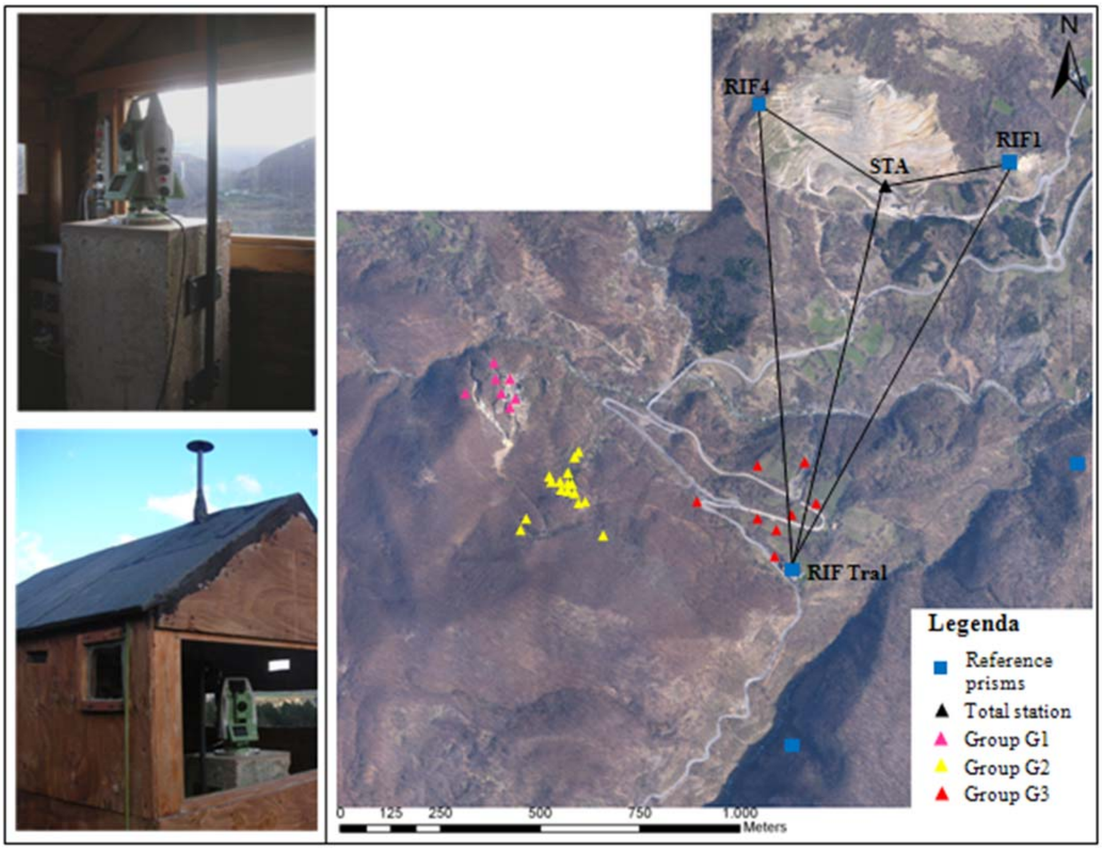

Figure 4: Total station monitoring system: master unit photos, prisms locations and total station network scheme on the Orthophoto 2010

Some reference points (RIF1, RIF4, RIF Tral) were installed and thought for periodic "network adjustment" campaigns with GPS and total station. Thus, there is the possibility to mount on them the total station to measure the others for network adjustment. The GPS antennas can be mounted as well. Therefore, two kind of adjusted reference networks were created, that of total station (Figure 4) and that of GPS.

The reference point RIF1 was installed by means of an aluminum pole (Figure 5) driven into the ground and filled with terrain. A special adaptor was built on his top for the GPS, the total station and the prism positioning. A target for the long range laser scanner was mounted on the pole, too (white 60 cm x 60 cm panel). The total station is working in its local reference systems. But it could be is useful to georeference these information to better understand what is happening. Now, it is possible to visualize the monitoring system observation/results on the local reference system, the total station one, for measurements analysis, behavior interpretation ext; and then to visualize the final results in a GIS (Geographic Information System). The integration with others instruments measurements helped us to understand something more about the landslide. ETRF(European Terrestrial Reference Frame)2000 was the system choose for the geocoding, trying to update the UTM* ED50 reference system of the Emilia Romagna Region.

Figure 5: Examples of prisms monuments

The transformation between the two reference systems, that of the total station and the ETRF2000, needed the double coordinates of almost three points. Thus the networks with GPS and total station with RIF1, RIF4, RIF Tral and STA (derived coordinates for GPS), the master unit was used for the geocoding, too. But, sometimes it was necessary to work in the UTM* ED50 system, so a further transformation was calculated.

3. ATMOSPHERIC CORRECTIONS ON TOTAL STATION MEASUREMENTS

As mentioned before, points (STA, RIF1, RIF Tral, RIF4) were located so that intervisibility fir total station measurments could be obtained. The network geometry was strongly influenced by the morphology of the territory, hence was not an ideal network geometry (Figure 4 and Figure 6).

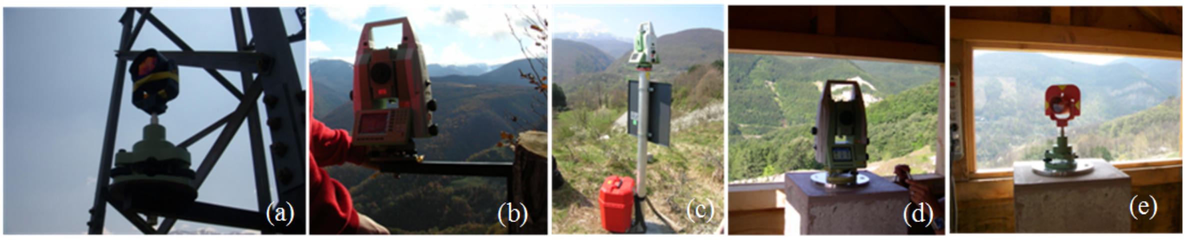

Figure 6: Total station and prisms on reference points: (a) RIF-tral, (b) RIF4, (c) RIF1,(d) and (e) STA

Two periodic campaigns were conducted in April and October 2010. Each network was adjusted with the software Starnet v6.0.36.

Three kind of analysis were done: the first, regarding the slope distance observations, taking into account or not, atmospheric corrections algorithms; the second about the comparison of corrected and the uncorrected adjusted coordinates; the third about comparison of different campaigns coordinates.

The networks were measured following the fundamental roles for total station high precision measurements: forced centering devices were used; the leveling was performed using the electronic bubble of the mounted theodolite (before measurements) because the built-in circular level bubble of the tribrachs is not considered accurate enough; tribrachs, instruments and bubbles calibration was previously verified; extreme care was taken to avoid disturbing the tribrach during the insertion and measurement process; tribrachs were mounted paying attention to the height to consider it constant between the instrument centre and prism centre and among the different campaigns; a 20 minutes warm-up period was kept and multiple (three) face left and (three) face right (direct and reverse) point and reads were made for all targets in all total station works (CECW-EE, 2002). The height of instruments and of targets were measured, too, with respect to the plate at the base of the monuments, between 1 mm of accuracy.

Ideally, total station observations should be limited to days when the weather conditions are fairly neutral (e.g., cloudy day with a light breeze). Days with temperature extremes should be avoided. This is not possible for monitoring systems working in a continuous way. Thus, surface meteorological measurements could be necessary to correct observations.

In order to compute the atmospheric corrections it is necessary to collect meteorological data (air temperature, pressure and relative humidity) on-site: at the instrument stations and at the target station, in a location shaded from the sun, exposed to any wind, at least 1 meter above the ground and away from the observer and the instrument.

Two types of atmospheric corrections were applied.

- Atmospheric corrections directly applied by the instrument, setting, at each time, locals atmospheric air pressure (mbar), temperature (°C) and relative humidity (%) values; output observations were the corrected ones.
- Atmospheric corrections determined in post processing.

Atmospheric Refraction Correction

When observations were post-processed, accordingly with the following method (Rüeger, 1990), barometric pressure, dry bulb temperature and wet bulb temperature should be measured. The meteorological station employed couldn’t measure dry bulb and wet bulb temperature and they were determined indirectly from some simple physics formulas and from a psichrometric diagram, starting from the air temperature and the relative humidity values (Çengel, 1998). The results are a little less precise (some fraction of ppm), but the measurements system much more cheaper. A zero part per million (0 ppm) value for refraction was entered setting standard atmospheric conditions: 1013.3 mbar, 13°C and 60% of relative humidity, when refractive index corrections were calculated in post-processing.

EDM distances should be corrected for the actual refractive index of air along the measured line. Measurement of atmospheric conditions at several points along the optical path should be performed with well calibrated thermometers and barometers in order to achieve the 1 ppm accuracy. If the meteorological conditions are measured only at the instrument station (usual practice), then errors of a few parts per million may occur, particularly in diversified topographic conditions. In order to achieve the accuracy better than 1 ppm, it is necessary to measure meteorological conditions every few hundred meters (200 m – 300 m) along the optical path.

Ppm application for “correct” distances

$$D_{CORR} = [\ (ppm / 1 \cdot 10^6)\ (D_{MEAS})\ ] + D_{MEAS} \qquad [1]$$

Where: D_{CORR} = field corrected distance
ppm = parts per million term
D_{MEAS} = measured distance set with zero ppm

Refractive index correction formulas. Distance reduction calculations for determination of the refraction correction for precise electro-optical distance measurements are briefly presented below.

The refraction correction is as follows:

$$d = (nR / nL)\ d_{MEAS} \qquad [2]$$

Where: d = corrected distance
nL = ambient refractive index
nR = reference refractive index (from the manufacturer's specifications for a given EDM instrument)
d_{MEAS} = measured distance

The reduction is essentially an application of the scale factor (nR/nL) to the measured distance. The scale factor relates the instrument reference refractive index to the refractive index based on ambient atmospheric conditions.

The ambient refractive index (nL) is:

$$nL = 1 + [\ (A + B) / (1 \cdot 10^8)\ ] \qquad [3]$$

Where: A and B are functions of temperature (dry and wet bulb temperature), instrument carrier wavelength, ($\lambda = 0.658\mu m$), density factor of water vapor, density factor of dry air, partial water vapor pressure, partial pressure of dry air, total atmospheric pressure, partial water vapor pressure, partial pressure of dry air, and of varies constants

Methods and data set

During the periodic campaigns, meteorological data were collected meanwhile measurements were performed. When possible, two meteorological station were used, one in proximity of the instrument and the other close to the target. When this was not possible, only meteorological data next to the total station were recorded. But, in the end, only these data were used for a more appropriate simulation of a potential operating continuous monitoring system.

Measures with standard atmospheric conditions were performed for first, recording air temperature, pressure and relative humidity. Secondly, measures were carried out setting local meteorological values directly into the instrument, in order to have directly corrected observations.

Different data set of observations were analyzed: "uncorrected" observations, "post-processed" corrected observations and "instrument" corrected observations. For the "post-processed" corrected observations, the refractive index correction formulas were firstly computed for the atmospheric ppm calculation (Formulas [2] and [3]). Then the ppm were applied to the slope distances.

Each network was adjusted following the same rules: same kind of observations, same input weight parameters, same pre-analysis, etc.

As expected, the standard deviations of each coordinate, derived from each adjustment were very similar. The slope distance corrections are proportionally to the distance as well (Formula [1]), and if correction are well performed, no gross errors should be introduced and the accuracy of the final result should be the same and the accuracy should improve.

RIF4 had changes in the monument over the considering period. Thus, data regarding this point were consistent for each campaign, but weren't used for the comparison between different campaigns. Because of this problem, RIF4 wasn't used as a station mark, but only as a point of measure, weakening the network.

The centre of the local reference system was located in the total station instrument centre and was oriented along the STA-RIF1 direction.

The air temperature, atmospheric pressure and relative humidity measured are reported in Table 1. For the station STA the medium value between the in and out wooden artifacts conditions were calculated.

	26/04/2010			**29/10/2010**		
ID	**T (°C)**	**P (mbar)**	**U (%)**	**T (°C)**	**P (mbar)**	**U (%)**
RIF1	27.2	933	40	22.1	913	53
RIF Tral	21.3	933	56	18.4	911	61
STA	22.7	933	37	15.65	912	67.5

Table 1: Temperature, atmospheric pressure and relative humidity measured during the campaigns in proximity of the stations of the network

Following some tests and comparisons are explained. The name of the work is given in this way. For example: C10; the letter means Coordinates, the 1 stands for the number of the campaign, and the 0 stands for the type of dataset. The campaign of 26/04/2010 is the 0 campaign, while the 29/10/2010 is the number 1. For the dataset 0 stands for no corrections, 1 for post-processed corrections and 2 for instrument correction.

3.1 Test 1: different corrections approaches.

The first test concerns the comparison of different approaches to obtain slope distances observations corrections. As mentioned before, two types of methods were followed. With the first one, a rigorous method was applied, with a post processing calculation. With the second, corrections were directly applied by the instrument firmware setting each time the local atmospheric conditions.

In Table 2, the slope distances, raw (uncorrected, D0), corrected in post-processing (D1) and corrected directly by the instrument (D2) with a blind method, are shown. The difference between each set of values is reported as well. The magnitude of the corrections is similar. Seems that the instrument applies a correction bigger than that computed with the formulas, and the greater is the distance, the greater are the differences. The formulas chosen for the post processing seem to be a good choice even if some differences between the two method were find. Some further test, in different atmospheric conditions, with higher and lower temperature would be done to confirm these results. Although, for distance of about 1 km, with a temperature of about 20°C, an atmospheric pressure of 913 mbar and a relative humidity of about 50%, the atmospheric corrections are of about 40 ppm, while the difference of the two method, more or less of 5 ppm. There's one order of magnitude of difference.

Station ID-Point ID	D0 meas (m)	D1 form (m)	D2 instr (m)	Δ D1-D0 (mm)	Δ D2-D0 (mm)	Δ D2-D1 (mm)
RIF1- RIF tral	1097.22345	1097.26418	1097.26697	40.73	43.52	2.79
RIF1-STA	269.59065	269.60066	269.60121	10.01	10.56	0.55
STA-RIF1	269.58997	269.59847	269.60002	8.50	10.05	1.55
STA-RIF tral	958.86367	958.89390	958.89928	30.23	35.61	5.38
STA-RIF4	438.24613	438.25995	438.26268	13.82	16.55	2.73
RIF tral-STA	958.86382	958.89686	958.89231	33.04	28.49	4.55
RIF tral-RIF4	1158.85198	1158.89191	1158.88621	30.23	34.23	4.00
RIF tral-RIF1	1097.22248	1097.26028	1097.26514	37.80	42.66	4.86

Table 2: Slope distances uncorrected (D0), post-processed corrected (D1), instrument corrected (D2); atmospheric corrections ΔD1-D0 in mm (ppm), ΔD2-D0 in mm (ppm); comparison between the two corrections ΔD2-D1 (29/10/2010)

With respect to the standard deviation errors derived from the compensation of the network (following examples), it seems that atmospheric corrections could be necessary to improve the accuracy of the method. This is useful when the monitoring system has to detect slow motion, that can be hide under the observation fluctuations due to the atmpsphere: rock slides, dams, structures ecc.

3.2 Test 2: network calibration.

The network adjustment can give information not achivable with the single measure analysys. In this test the comparison of adjusted coordinates of a campaign (29/10/2010) is performed with the aim to create a network calibration. In the following tables the adjusted coordinates and their relative standard deviation errors are reported. The standard deviations of each coordinate in each work are very similar, as expected: probably, measurements procedure didn't introduce gross errors and atmospheric corrections model are supposed to be appropriate.

C10:UNCORRECTED coordinates						
Point ID	**N (m)**	**E (m)**	**El (m)**	***σ (N) (m)***	***σ (E) (m)***	***σ (El) (m)***
STA	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RIF1	269.2515	0.0000	-13.5827	0.0058	0.0000	0.0091
RIF tral	-394.5514	873.5847	-24.3954	0.0120	0.0078	0.0250
RIF4	-326.0884	-277.1268	94.4652	0.0086	0.0090	0.0207

Table 3: uncorrected coordinates (29/10/2010)

The comparison here reported shows the difference between the adjusted coordinates derived from the raw observations (Table 3), from the observations corrected with the rigorous formulas (Table 4) and by the instrument (Table 5), within the same campaign (29/10/2010).

It was not necessary to compute any error propagation: the standard deviations are quite similar, at all. The standard deviation values in Table 3 were arbitrary chosen as reference for thecomparison of results. When the variation is null (for STA and the Est of RIF1) some constraints were applied: the centre (STA) and the orientation of the local reference system on the direction STA-RIF1. In Table 6 the differences between the dataset are shown.

C11: "Post-processed" CORRECTED coordinates						
Point ID	**N (m)**	**E (m)**	**El (m)**	***σ (N) (m)***	***σ (E) (m)***	***σ (El) (m)***
STA	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RIF1	269.2612	0.0000	-13.5831	0.0058	0.0000	0.0091
RIF tral	-394.5682	873.6123	-24.3962	0.0121	0.0079	0.0250
RIF4	-326.0931	-277.1279	94.4620	0.0093	0.0091	0.0208

Table 4: post-processed corrected coordinates (29/10/2010)

C12: "Instrument" CORRECTED coordinates						
Point ID	**N (m)**	**E (m)**	**El (m)**	***σ (N) (m)***	***σ (E) (m)***	***σ (El) (m)***
STA	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RIF1	269.2620	0.0000	-13.5829	0.0058	0.0000	0.0091
RIF tral	-394.5600	873.6169	-24.3762	0.0121	0.0079	0.0250
RIF4	-326.1056	-277.1386	94.4644	0.0093	0.0091	0.0208

Table 5: instrument corrected coordinates (29/10/2010)

	Δ C10-C11			**Δ C10-C12**			**Δ C12-C11**			**C10:** ***uncorrected coord***		
ID	**ΔN (m)**	**ΔE (m)**	**ΔEl (m)**	**ΔN (m)**	**ΔE (m)**	**ΔEl (m)**	**ΔN (m)**	**ΔE (m)**	**ΔEl (m)**	***σ (N) (m)***	***σ (E) (m)***	***σ (El) (m)***
STA	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	***0.0000***	***0.0000***	***0.0000***
RIF1	-0.0097	*0.0000*	0.0004	-0.0105	*0.0000*	0.0002	-0.0008	*0.0000*	-0.0002	***0.0058***	***0.0000***	***0.0091***
RIF tral	0.0168	-0.0276	0.0008	0.0086	-0.0322	-0.0192	-0.0082	-0.0046	-0.0200	***0.0120***	***0.0078***	***0.0250***
RIF4	0.0047	0.0011	0.0032	0.0172	0.0118	0.0008	0.0125	0.0107	-0.0024	***0.0086***	***0.0090***	***0.0207***

Table 6: Comparison between adjusted coordinates (29/10/2010)

The differences between the two methods is lower than the precision of the method (standard deviation). So, even if a little difference in the slope distances, both methods seems to be adequate. The differences between the corrected and non corrected coordinates are bigger than the standard deviation values: differences of some centimeters can occur. Thus atmospheric corrections could be useful to improve the accuracy of the method when the objective is to detect movements of some centimeters or less of magnitude.

3.3 Test 3: monitoring over time.

In Table 7 and Table 8 the adjusted coordinates and their relative standard deviation errors of the fisrt campaign are reported (26/04/2010).

C00:UNCORRECTED coordinates						
Point ID	**N (m)**	**E (m)**	**El (m)**	***σ (N) (m)***	***σ (E) (m)***	***σ (El) (m)***
STA	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RIF1	269.2458	0.0000	-13.6105	0.0058	0.0000	0.0091
RIF tral	-394.5547	873.5826	-24.4065	0.0121	0.0079	0.0250

Table 7: uncorrected coordinates (26/04/2010)

C01: ”Post-processed” CORRECTED coordinates						
Point ID	**N (m)**	**E (m)**	**El (m)**	***σ (N) (m)***	***σ (E) (m)***	***σ (El) (m)***
STA	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RIF1	269.2552	0.0000	-13.6109	0.0058	0.0000	0.0091
RIF tral	-394.5680	873.6100	-24.4070	0.0121	0.0079	0.0250

Table 8: post-processed corrected coordinates (26/04/2010)

In this third test the attention was directed to the monitoring over time of the network. In this case, too, the standard deviations of each set of coordinate are very similar and consistent with theese of the others campaigns, as a conformation of the goodness of both measurements and the atmospheric correction methods. Results on RIF4 are not reported because not consistent for the comparison, due to a change in the monuments during the periodo of interest.

In Table 9 is shown the comparison between the first and the second campaign, considering only the coordinates corrected with the formulas of the literature. A controlled process would always be preferred to something blind and out of the operator control (the instrumental corrections). The comparison between different campaigns shows no big differences between the two campaigns except for the RIF1 elevation. The point seems to have lowered. The difference from the uncorrected coordinates are similar in both cases, probably due to the very similar atmospheric conditions encountered in the two campaigns. Some more test with different temperature should confirm this first results. But, it is possible to state that something happened to point RIF1 over time. The comparison of these coodinates with the GPS one could help in the interpretation of some displacements.

	Δ C10-C00			**Δ C11-C01**			**C10:** ***uncorrected coord***		
ID	**ΔN (m)**	**ΔE (m)**	**ΔEl (m)**	**ΔN (m)**	**ΔE (m)**	**ΔEl (m)**	***σ (N) (m)***	***σ (E) (m)***	***σ (El) (m)***
STA	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	***0.0000***	***0.0000***	***0.0000***
RIF1	-0.0057	*0.0000*	-0.0278	-0.0060	*0.0000*	-0.0280	***0.0058***	***0.0000***	***0.0091***
RIF tral	-0.0033	-0.0021	-0.0111	0.0002	-0.0023	-0.0308	***0.0120***	***0.0078***	***0.0250***

Table 9: Comparison between adjusted coordinates (29/10/2010 - 26/04/2010)

4. CONCLUSIONS AND FUTURE DEVELOPMENTS

The comparison of slope distances shows a sufficient difference between the raw and the corrected observations (about 40 ppm at 1 km, with 20°C, 913 mbar and 50% of relative humidity). Raw observations are measured with 0 ppm: standard atmospheric condition for

the total station. The two approaches followed, led to similar results, but further investigation are necessary to confirm that similarity and in order to understand the reason of the difference.
As a consequence of the similarity of the two models, on the distances derived from the two methods, adjusted corrected coordinates would be more accurate than the uncorrected one. Furthermore, the formulas for the post processing seem to be a good choice and a better method as well, because controlled. The next step would be the application of the model to all monitoring prisms. A global improvement of the accuracy of the monitoring system would be expected: daily and seasonal fluctuations would reduce. But, a continuous meteorological data acquisition is necessary.

The direct correction of observation operated by the total station could introduce gross errors due to the operator or to the meteorological station bad working. This is a blind process, in which there’s no control of the overall process. If something goes wrong non raw data are available. Even if quite good, it is suggested to apply correction in post-processing.

Meteorological stations should be used in proximity of both total station and reference targets, in an ideal continuous monitoring system. Considering the costs of a certain number of meteorological station, along with the high cost of high precision types, maybe another monitoring system which performs much better that the total station could be built, at the same cost. But with precise model of the atmosphere, the atmospheric correction could be better. But, for long distances, the problem of the atmosphere strongly influence final results of all systems. Distance checks, in the field, could be made by comparing the ppm corrected measurements to the corrected results of other instruments, such as a GPS. Some test on this direction will be performed in the future, along with others total station calibration campaigns with different atmospheric conditions.

The final conclusion is that atmospheric corrections could be useful to improve the accuracy of the total station monitoring system when the objective is to detect movements of some centimeters or less of magnitude.

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BIOGRAPHICAL NOTES

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