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Metrological comparison between instruments for status monitoring of buildings after earthquake

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Abstract **– This paper aims to investigate the possibility of using measuring instruments to obtain objective indications of the state of a building following an earthquake, to facilitate the planning of interventions in safe conditions and to design provisional structures. The use of such tools would also be useful for monitoring both buildings and provisional structures over time. In particular, a Laser Scanner and a Total Station are examined and compared from a metrological point of view, to evaluate the possibility of using them in emergency situations, which present particular criticalities for measurements, if the reliability of the results has to be guaranteed. The façade of a historical building is used as a test case, and is subjected to measurement campaigns, distributed over time, with the aim of evaluating repeatability and reproducibility of results. Furthermore, applying known thicknesses to the monitoring points, the systems measuring thresholds are evaluated. This work would like to represent a first step towards the standardization of procedures for the adoption of Laser Scanner and Total Stations by rescuers in emergency situations.**

Keywords – Validation, measurement uncertainty, calibration, Total Station, Laser Scanner, building monitoring, technical rescue, Sustainable cities and communities.

I. INTRODUCTION

In the context of rescue in the emergency conditions following an earthquake, it is important to make some preliminary assessments of the state of the concerned buildings as objective as possible, so as to be able to plan in the most appropriate and safe way interventions, and to design provisional structures, which should preserve the buildings over time.

To make the assessments as objective as possible, it is convenient to use measuring instruments that, through rapid data processing, such as, for example, determining the slope of a façade, allow to evaluate the accessibility of the structure in safe conditions. These instruments could also allow the monitoring of structures over time, if they have resolution and uncertainty requirements sufficient to detect even small movements [1, 2].

For this purpose, two types of instruments have been identified, Laser Scanner (LS) and Total Station (TS) [3-5], which possess good requirements in terms of accuracy, resolution, ease of use, acquisition speed, possibility of operating at a safe distance, cost.

In addition, TS and LS are suitable for outdoor use, thanks to the easy installation and real-time output, wide range of operating temperatures and robustness with respect to environmental conditions.

Other alternative technologies like infrared thermography [6], 3D reconstruction techniques based on Unmanned Aerial Vehicle (UAV) tilt photography [7-11], multi-scale morphological profiles with multi-structuring elements from satellite imagery [12], Synthetic Aperture Radar (SAR) techniques [13-14], are time-consuming, or do not inspect with sufficient level of resolution and accuracy the structural characteristics of buildings.

Naturally, it is necessary to develop procedures of use that take into account the particular measurement conditions that an emergency situation entails in terms of: need to operate quickly, minimizing the number of acquisitions; possibility of accidental or voluntary movement of the instrument; impossibility of acquire some points due to the interposition of people and vehicles; non-optimal location of the instrument with respect to the building; unfavourable environmental conditions.

These conditions and the simplification need should also be considered in the calibration phase, in order to correctly estimate the metrological performances of the instruments in the conditions of actual use, and to guarantee the validation and the trustworthiness of the results [24-26]. This approach is not usual in the literature on the subject, where calibration is generally performed under laboratory conditions [15-24].

Standards are also available, concerning the validation of measurements carried out with TS (ISO 17123 – 5: 2018) and LS (ISO 17123 – 9), which present simplified and complete measurement procedures, to consider different operating situations. A standard series is also provided by VDI/VDE, where three different test methods are presented to investigate the accuracy of terrestrial LS under laboratory conditions (VDI/VDE-Richt-linien 2634, part 1-2-3:2002).

Anyway, the number of contributions to the uncertainty is so high [27], and there are so many possible ways to calibrate the system, that obtaining a quantitative evaluation of the measurement uncertainty, with reference to the specific application of interest, is not a trivial task.

In this work the metrological characteristics of a LS and a TS will be evaluated, as a preliminary study for the development of simplified procedures for quick assessments of the state of buildings in technical rescue operations.

The paper illustrates the preliminary results of the tests carried out in a real scenario. The analysis of repeatability, systematic errors, measurement threshold of the techniques are carried out, with the aim of evaluate the capability of these techniques to monitor the behaviour over time of the building under examination, and to begin to understand the aspects that most influence the results.

Furthermore, the effect of reducing the number of monitoring points is investigated, in order to study simplified procedures, to be used after an earthquake.

II. MATERIALS AND METHODS

In this work, the following instruments are analysed:

1. A Leica RTC360 3D Laser Scanner (Fig. 1.a), and the Leica Cyclone 3DR software for the point cloud analysis.
2. A Total Station Leica Geosystems (Fig. 1.b), model TS16 Imaging, and the Leica SafeR software, for the management of the acquired data.

The two instruments have been placed next to each other, about 5 m away from the building.

13 monitoring points (MP) on the façade of an historic house have been chosen, and targets (100 mm x 100 mm) (Fig. 3.a) have been placed in these positions using epoxy resins, to delimit reference areas, easily identifiable, on which to impose known displacements, by gluing thicknesses of 4.00 mm.

7 prisms (Fig. 3.b) have been used as reference points, to fix a stable reference system even in the case of instrument movements, according to an optimal configuration [28].

The following acquisitions have been carried out:

1. For the LS: 6 points clouds have been acquired, 3 before and 3 after the application of the thicknesses. Based on the acquired points clouds, repeatability analysis and comparison between points before and after the placement of the thicknesses, are carried out.
2. For the TS: 20 repeated measurements have been acquired for each monitoring point, and the measurements have been repeated after a few days and after a year. Furthermore, 20 measurements have been carried out after applying the thicknesses to the monitoring points.

Both the instruments provide the x, y and z coordinates of the monitoring points for each measurement. Since the y axis, in both cases, is perpendicular to the wall of the building, the variation Δy_i, between points before and after the application of the targets, should represent the thickness of the targets themselves.

a) b)

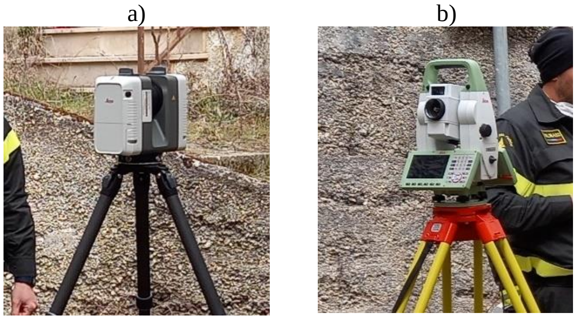


Fig 1. a) Terrestrial Laser Scanner; b) Total Station.

Fig 2. Monitoring points.

a) b)

Fig 3. a) Target used for monitoring; b) Prisms used as references.

III. PRELIMINARY RESULTS

The main results of the measurement campaign can be summarized as follows:

1. For the LS:

Before the placement of the piece with a 4.0 mm thickness:

- Standard deviation between successive acquisitions is in the order of 0.9 mm (repeatability contribution).
- An uncertainty contribution, due to the reference system definition in successive acquisitions, is in the order of 1.6 mm.
- A small variability between points on the same target, in the order of 0.5 mm, is estimated.

After the placement of the piece with a 4.0 mm thickness:

- The mean value of the variation of the y coordinate (Δy_i) for the points on each target is equal to 4.9 mm, with an overall standard deviation among targets of 0.52 mm.

2. For the TS:

Before the placement of the piece with a 4.0 mm thickness:

- Standard deviation of data, in the repeatability tests: 1.4 mm
- Standard deviation of data, in the reproducibility tests: 2.0 mm

After the placement of the piece with a 4.0 mm thickness:

- The mean value of the variation of the y coordinate (Δy_i) for the points on each target is equal to 3.5 mm, with an overall standard deviation among targets of 1.4 mm.

The results of the comparison between points before and after the application of the thicknesses are reported in Fig. 4. The presence of the pieces used as reference thickness is detected by both systems.
As can be seen from the results, the two systems have similar metrological characteristics, from the point of view of overall variability. The differences found between the two instruments are in line with the results available in the scientific literature [29], which indicates differences of the order of ± 2 mm.
The evaluation of the adequacy of these characteristics for the purpose of assessing the safety status of a building is the task of structural engineering experts.

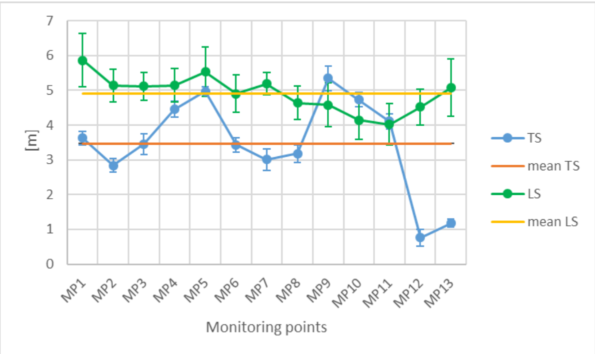
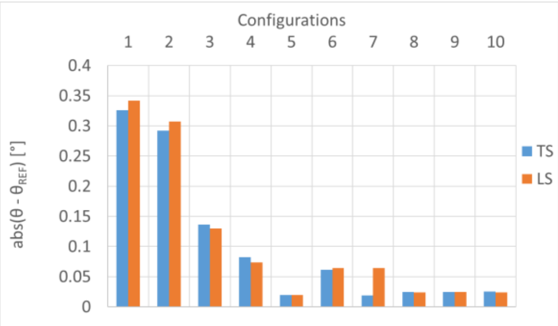


Fig. 4. Δyi in the comparison between points before and after the application of thickness for LS and TS.

On the basis of all the measurements on the targets, obtained by using TS and LS, respectively, the slope of the façade with respect to the horizontal plane has been calculated by means of a least squares regression (first degree polynomial model).

A slope of 89.997° has been obtained by the TS, and a slope of 89.992° has been obtained by the LS, so the difference is of 18". These values are considered as reference slopes, because obtained by using the points of all the targets.

If the slopes are calculated on reduced configurations of the monitoring points, interesting information can be obtained from the point of view of simplifying the measurement procedures. Fig. 5 shows the results in terms of absolute value of the difference of the calculated slope with respect to the reference value.
First of all, it is noted that the measurements provided by the two instruments give a similar trend. Furthermore, it can be noticed that using extreme points only (configuration 10) is the solution that, with the least number of points, allows to obtain a slope closest to the reference one. In general, the choice of points placed at the base and top of the building façade, provides better results (configurations 5-10).



a)

Point configurations		
Cases	Choice of the points	Nr. of points chosen
REF	all points	all points
1	central points	6,7,8,9
2	central rows	5,6,7,8,9,10
3	top row excluded	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
4	bottom row excluded	5, 6, 7, 8, 9, 10, 11, 12, 13
5	top and bottom rows	1,2,3,4,13,12,11
6	left column excluded	2,3,4,7,8,10,6,9,12,11
7	right column excluded	1,2,3,5,6,7,8,9,13,12
8	external columns	1,5,13,4,10,11
9	internal columns	2,3,6,7,8,9,12
10	extreme points	1,4,11,13

b)

Fig. 5. Comparison among points configurations: (a) absolute value of the difference between calculated slope and reference value (REF), for TS and LS; (b) description of the configurations taken into account.

IV. CONCLUSIONS AND OUTLOOK

The metrological characteristics of a LS and a TS have been evaluated, as a preliminary study for the development of simplified procedures for the emergency response planning. For this purpose, the façade of a building has been considered as a test case and has been subjected to a measurement campaign, with the aim of evaluating repeatability of results, system measurement threshold, and systematic errors.

Both the measuring methods meet the requirements for use in the field, with similar characteristics from the point of view of the overall variability. The application of thicknesses of 4.00 mm at the monitoring points has been clearly identified by the systems.

Furthermore, the effect of reducing the number of monitoring points has been analysed, with the purpose of defining simplified procedures, to be used in emergencies. The results show that the choice of points placed at the base and top of the building façade, provides better results in terms of slope.

In future work, the effect of:

- the choice of number and location of the reference points,
- the positioning angle of the instrument with respect to the wall of the building,

will also be analysed, to consider critical operational conditions that could occur in emergency situations.

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