Least Squares 3D Algorithm for the Study of Deformations with Terrestrial Laser Scanner

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***Abstract*— The application in question is aimed, in the study of deformations of mountain areas, as well as test the TLS applied to a hilly area in two different eras. For this purpose, it was also tested using the algorithm LS3D "Least square 3D surface matching" that allows both the registration of point clouds produced by scans carried out without using targets but, overall, the estimate of deformations that in this case, compared to other methods, is done directly on the basis of the two data sets acquired in two different periods of time t_1 and t_2.**

***Keywords*— Laser scanner 3D; Least square 3D surface matching; TLS; 3D modelization; Survey; Radiometric data.**

I. Introduction and Study Area

The Faculty of Agriculture of the University "Mediterranea" of Reggio Calabria is built on a hill that offers a specific geomorphology. In fact, after the construction of the Faculty building some problems arose, regarding its stability, the possible deformations through time also because of poor vegetation.

The Laboratory of Geomatics Engineering Faculty of the University "Mediterranea" of Reggio Calabria, used Terrestrial Laser Scanner for monitoring the hill, doing the scans after three years and examining the results obtained. Every era we made two scans, that we found to be sufficient to cover the entire study area.

Fig. 1. Study area.

Fig. 2. A view of the scanner.

Fig. 3. Some views of the scans.

II. Registrations of the Scans

The first operation performed after the relief phase was therefore recording different scans with a procedure based on the algorithm of "Least Squares 3D surface matching" without the need of using targets in data processing, however, present during scanning.

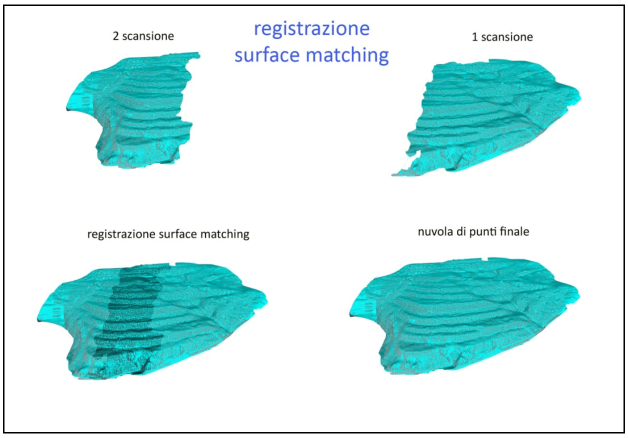

Fig. 4. Schematization of the surface matching with LS3D.

The recording of the entire cloud at each epoch is done so by applying a global matching. The mathematical model used considers the reflection that, at every point of the first surface $f_{(x,y,z)}$ has an exact match with $g_{(x,y,z)}$ and with $e_{(x,y,z)}$ the error vector (random errors).

The matching is obtained by the least squares objective function that represents the sum of squared Euclidean distances between the two surfaces.

$$\sum \left\| \vec{d} \right\|^2 = min \qquad (1)$$

TABLE I.

No	TMP scan no (#)	SRC scan no (#)	No.of TMP points (K)	No.of SRC points (K)	No. of COR points (K)	Inter.	Time (sec)	Sigma naught (cm)
1	1	2	2063	2008	1376	3	1324	0,3

a. Numerical results of the "surface matching" LS3D with the two clouds of point at the time t_1.

Fig. 5. Global cloud of points cleaned after the recording with LS3D of the scan at the time t_1.

Fig. 6. Global cloud of points cleaned after the recording with LS3D of the scan at the time t_2.

TABLE II.

No	TMP scan no (#)	SRC scan no (#)	No.of TMP points (K)	No.of SRC points (K)	No. of COR points (K)	Inter.	Time (sec)	Sigma naught (cm)
1	1	2	1978	2043	1412	3	1342	0,3

b. Numerical results of the "surface matching" LS3D with the two clouds of point at the time t_2.

The matching for the registration of the whole cloud at the epochs t_1 and t_2 presupposes the selection of three points in common on the scans to be joined; by applying the matching several times using different homologous points, the results were validated using the statistical test χ^2.

The variable χ^2 measures the overall difference between observed and expected data according expression:

$$\chi^2 = \sum_{i=1}^{N} \frac{(f_{Oi} - f_{Ai})^2}{f_{Ai}} \qquad (2)$$

The test $\chi^2(p_1,\alpha) < \chi^2 < \chi^2(p_2,\alpha)$ for a risk of error α equal to 5% is verified result.

III. Subsequent Processing - Control of Deformation

Once registered scans for the generation of clouds at two times t_1 and t_2, the "global matching" is re-applied to monitor the deformation.

The procedure involves three steps:

- global matching of the two point clouds over the area selected as stable;
- global matching of all points of the clouds over an area already found stable and searching for areas of possible movement;
- local matching of selected areas to estimate the deformation.

In the first step the algorithm LS3D is applied to areas that we assume as stable, eliminating areas with possible movements; the two clouds (registered) at the two epochs are traced thus in a common reference system.

Fig. 7. Stable area chosen for the global "matching".

TABLE III.

No	TMP scan no (#)	SRC scan no (#)	No.of TMP points (K)	No.of SRC points (K)	No. of COR points (K)	Inter.	Time (sec)	Sigma naught (cm)
1	1	2	487	486	486	2	303	0,3

a. Numerical results of the "global matching" of the clouds of point at the time t1 and t2.

The second step is based on the same matching technique, but drawing the two point clouds, already traced in the same reference system, and considering whole clouds, therefore not only stable areas but also the areas with possible movements.

TABLE IV.

No	TMP scan no (#)	SRC scan no (#)	No.of TMP points (K)	No.of SRC points (K)	No. of COR points (K)	Inter.	Time (sec)	Sigma naught (cm)
1	1	2	2695	2609	2543	3	1793	0,25

a. Global matching" considering the stable areas and those with possible movements.

To improve the reliability of the results obtained have been made more cycles of local "matching" and validating the results obtained through statistical tests.

The value of the Student's t test is calculated as the ratio of the observed mean difference and its standard error

$$t = \bar{d} / \sqrt{(S_d^2 / n)} \quad (3)$$

where:

$\bar{d} = \sum d_i / n$ with d_i difference between the pairs of results obtained

$$S_d^2 = \sum (d_i - d)^2 / (n - 1) \quad (4)$$

The last stage of the method consists in the estimation of relative movement to some portions of the hill using the same method but using LS3D local matches in a "local matching". Selected portions for analysis, for each "patch" on the cloud at the time t_1 is automatically detected by the subset corresponding LS3D the cloud at the time t_2, thus obtaining the seven transformation parameters that describe the deformation and, in particular, the three translations and the three rotations.

TABLE V.

Deformation parameters	Unit	Cockpit	Rock
t_x	cm	0,11	0,32
t_y	cm	0,32	0,29
t_z	cm	-0,26	-0,52
ω	gon	0,2	0,1
φ	gon	0,1	0,05
κ	gon	0,09	0,07
m	Pure number	1	1

b. Results of monitoring of deformations of the two regions examined with LS3D (shifts measured in centimeters and rotations in gons (1 circle 400gons)

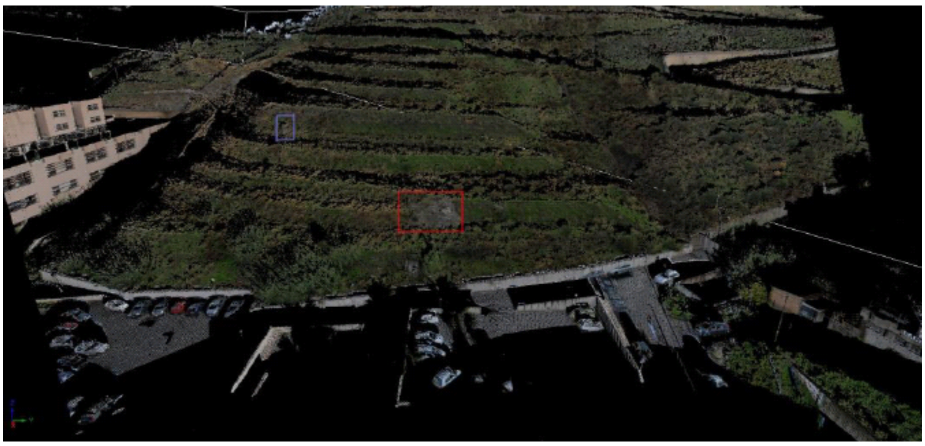

Fig. 8. The areas chosen for the control of the deformations.

IV. CONCLUSION

The experience carried out has highlighted the benefits of LS3D than other methods. The first is to exploit all the information provided by the geometry of the 3D cloud of points to be able to measure strain with a magnitude less than the accuracy of the instrument. The second is to implement a flexible procedure that can be applied with any type of scenes including a wide range of applications of deformation. The third is to measure movement in three dimensions, not only along a preferred direction.

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