

TLS DEFORMATION MEASUREMENT USING LS3D SURFACE AND CURVE MATCHING

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ABSTRACT:

During last few years the use of Terrestrial Laser Scanner has increased notably in different application fields, like architecture, geology and geodesy. The paper focuses in the use of TLS data for deformation measurement and monitoring purposes which concerns both engineering geology and geodesy. The paper presents a new approach for deformation measurement which fully takes advantage of the TLS data characteristics. The procedure is based on the point cloud matching algorithm Least Square 3D Surface Matching proposed by Gruen and Akca (ISPRS Journal, 2005, 59, 151-174). The proposed approach takes advantage of both surface and curve matching to improve the co-registration quality and it exploits the high density of TLS point clouds, which counterbalances the relatively poor precision of the single TLS points. The work describes the proposed deformation measurement procedure, and discusses in particular some results of the research made at the Institute of Geomatics: the preliminary results obtained with curve matching.

1. INTRODUCTION

In the last years, the Terrestrial Laser Scanner (TLS) has been an increasing interest as a method for deformation measuring in different fields such as engineering geodesy (Alba et al., 2006 and Schneider, 2006) and several applications of geology and geotechnics like landslide monitoring (Bitelli et al., 2004) and rock falls (Alba et al., 2005). At the same time the availability of different typologies of TLS instruments has increased. A classification of available TLS can be found in Fröhlich and Mettenleiter (2004). This increasing interest is due to the key advantages of the TLS with respect to classical techniques, e.g., the high sampling density, the portability and the automatic 3D point measurement. The first one is a key point to counterbalance the relatively poor quality of the single TLS points and, as a consequence, to measure deformations.

The paper presents a new methodology for land deformation measurement from TLS data. This procedure takes advantage of the high redundancy of the point clouds for estimating the deformation parameters. The core of the procedure is the point cloud co-registration based on the least squares 3D surface and curve matching proposed by Gruen and Akca in 2005.

The work is organized in three main parts. Firstly is described the proposed deformation measurement procedure which includes three main steps, the acquisition of the data, the global processing of the entire scene and the estimation of the local deformation. In the second part the first results obtained with the proposed procedure are presented, and finally the preliminary results obtained with curve matching are discussed. Some conclusions follow.

2. PROPOSED APPROACH

The proposed approach takes full advantage of the geometric information contained in the point clouds acquired during different epochs, in order to maximise the sensitivity to terrain changes. The core of the procedure is the least squares 3D surface matching described in Akca and Gruen (2005) and

Gruen and Akca (2005), which has been implemented by the Institute of Geomatics. The procedure is flexible and can be used in a wide range of applications. Figure 1 shows the data flow of the whole procedure, whose main steps are described below.

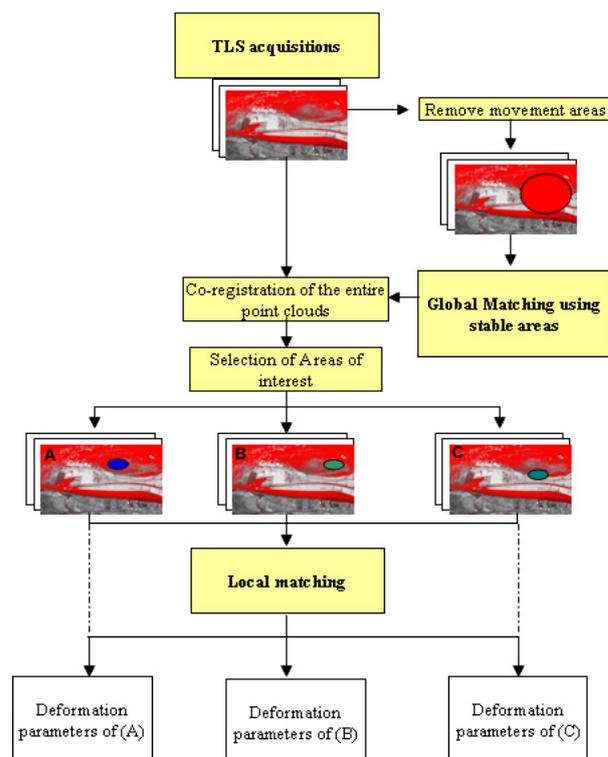


Figure 1: Data flow of the proposed procedure. Its key points are highlighted in bold.

1. Acquisitions of the TLS data: Let's assume to have a deformation area to be monitored, which is surrounded by a stable area. The data acquisition involves at least two steps:

- Perform a first TLS acquisition that covers both the moving and stable areas. In this stage it is important to consider that the key parameters of the acquisition, like the sensor-to-object distance and the sampling density, have a direct impact on the deformation analysis results. Another key factor is given by the distribution of the stable areas in the observed scene. The best scenarios are given by the deformation area completely surrounded by stable areas. This aspect can strongly impact the quality of the global matching, which in turn can generate systematic errors in the derived deformation results. This can be relaxed by using co-registration procedures based on a set of ground control points (GCPs) or tie points distributed in the scene, e.g. see Giussani and Scaioni (2004).
- After a given time period, which depends on the characteristics of the deformation at hand, perform a second TLS acquisition over the same area. Note that this operation can be repeated several times, getting a complete temporal deformation monitoring. We restrict the discussion to the simplest case, based on two acquisitions. It is worth noting that the geometry of the second acquisition can be slightly different from the previous one. In fact, the procedure does not assume to perform the data acquisition from the same viewpoint.

2. **Global Matching:** We name hereafter master the first point cloud, and slave the second one. Since each point cloud has its own reference system, we need to co-register them. This is achieved by applying a global LS3D matching over the areas of the scene that remain stable between the two acquisitions. For this purpose the parts of the scene that are subjected to deformation have to be properly removed before performing the co-registration. The deformation areas are often known from external information on the observed scene. Otherwise some extra processing is required to identify stable and deformation areas. As already mentioned above, the global matching represents a critical step of the procedure, which can directly affect the estimation of the deformation parameters. For this reason, the key characteristics of the studied area have to be a priori properly considered, and the feasibility of the global matching have to be assessed. In case of weak configurations one should consider the option of performing a co-registration based on GCPs or tie points. If the configuration is feasible and the global matching is performed, its quality has to be checked by taking advantages of the standard LS based tools, e.g. analysis of the residuals, outlier rejection, etc.

3. **Local matching:** Once the two point clouds are co-registered, the deformation analysis involves two key steps:

- Identification of the specific areas to be analysed. This can be done by selecting on the master point cloud specific objects or areas of interest, and can be properly performed working on the TLS intensity data. Alternatively, if no specific areas of interest have to be studied, the study area can be divided in subsets that contain a specified number of TLS samples. Note that this operation can be performed through an automatic procedure.
- For each subset, using the LS3D matching, the corresponding subset on the slave is automatically searched, obtaining the transformation parameters (local matching). These parameters, which in the experiments described in this work are six, three translations and three rotations, describe the deformation that each subset has undergone between the two acquisitions.

The presented procedure has been validated using both a simulated deformation scenario, which is described in the following section, and a real landslide monitoring scenario; see for in depth description Monserrat and Crosetto (2008).

3. DESCRIPTION OF THE VALIDATION EXPERIMENT

In order to verify the effectiveness and evaluate the precision of the proposed deformation measurement approach an experiment was realized. In the experiment a deformation measurement scenario was simulated. On this basis a comparison was done between results estimated with use of two independent techniques: the proposed TLS approach and a topographic survey with total station. The experiment took place in the Mediterranean Technology Park of Castelldefels (Barcelona), where the Institute of Geomatics is placed.

Figure 2 shows the scene where the measurements took place and the artificial targets in its bottom part. It is an intensity image of the entire measured area. The scene includes some buildings and structures in the back that were used as stable areas. The numbered objects located on the bottom part of the image are the 10 artificial targets that were displaced during the experiment in order to simulate a deformation phenomenon. The targets have an approximate dimension of 60 by 120 cm and they differ one from the other for their geometry and the type of material (wood, concrete, aluminium, foam, cartoon, etc.). Figure 3 show the area selected as stable area for the Global Matching.

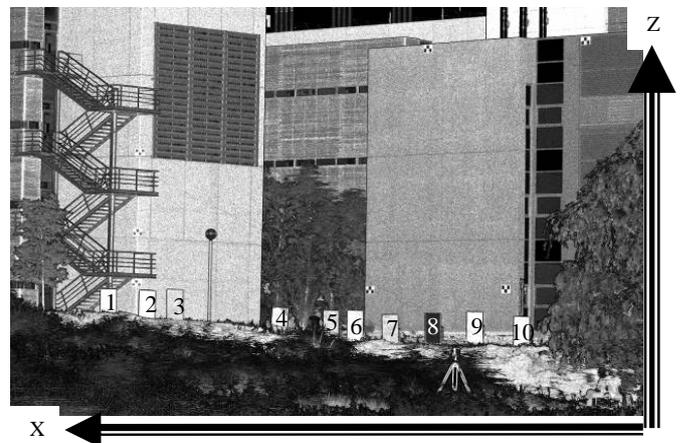


Figure 2: TLS intensity image acquired during the experiment, at an average distance of 134 m. Over the same image are indicated the approximate directions of two of the three axes of the reference system used for the data analysis. The Y direction is approximately parallel to the TLS range direction

The measurements have been performed with use of the laser scanner ILRIS 3D of Optech and Trimble 3601 DR total station. The experiment was realized in the following main steps:

- Measurement of the scene with the TLS, acquiring the data from two different positions:
 - the first one, with an average distance sensor-object of 134 m, is called hereafter the 100 m dataset.
 - the second one, with an average distance sensor-object of 225 m, is called hereafter the 200 m dataset.

- Measurement of the coordinates of 15-20 marked points per each target. The points were measured manually with a precise reflective prism and Trimble 3601 DR total station. In addition, other targets located on the buildings and visible in Figure 1 were measured in order to guarantee a set of tie points that link the TLS with the topographic data.
- Movement of the 10 targets, imposing displacements with different magnitudes (approximately between 19 and 60 cm) and directions.
- Repetition of the steps 1 and 2.
- Estimation of the 6 parameters of deformation for each target by using the proposed TLS approach: Global matching over the stable areas (the scene shown in Figure 1, with the exception of the 10 targets) and Local matching over each target.
- Independent estimation of the 6 deformation parameters of for each target by using the topographic data.
- Comparison per each target of the two independently estimated sets of 6 parameters of deformation.
- Analysis of the results. The outcomes of the analysis are discussed below.

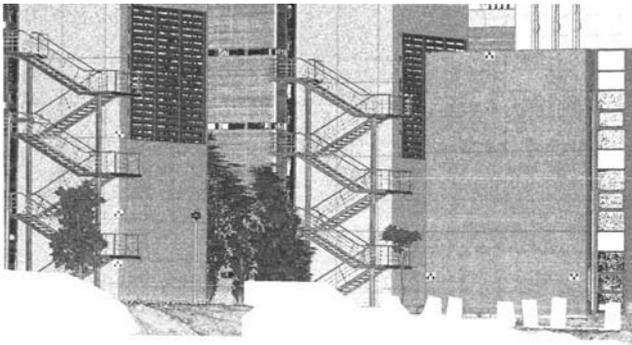


Figure 3: Data used in the global matching of the point clouds.

3.1 Validation results

Once the experiment was done the comparison between the results coming from the proposed TLS approach and the results coming from topographic survey was performed. The topographic results are treated here as the real values here since their precision is assumed to be one magnitude better than the precision of the results coming from TLS. The differences between the TLS estimations and the estimations coming from topography represent the TLS errors.

Results are compared for both 100m and 200m datasets. For this analysis it have been used only the translations. More detailed analysis can be seen in Monserrat and Crosetto (2008). The TLS errors for the three estimated movement components (X, Y and Z) are shown in Table 1. Note that due to some occlusions that had place in the area in the dataset acquired from 200m only 8 targets were measured.

The validation results of the 100 m dataset are summarized below:

100m	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
X	0.6	0.2	0.8	0.6	0.3	1.1	2.0	0.5	0.1	-0.6
Y	0.5	0.5	0.1	0.8	1.0	0.9	1.1	1.6	0.2	-1.3
Z	0.3	0.5	0.8	0.4	1.2	0.3	0.6	2.4	1.9	-0.3
200m										
X	0.8	-	-	2.4	0.3	5.7	2.7	2.2	1.0	1.1
Y	2.3	-	-	1.3	2.6	1.0	1.0	1.4	1.8	-1.8
Z	0.4	-	-	0.5	1.3	4.4	1.4	2.8	2.9	-2.4

Table 1: TLS errors in the estimated deformation displacements (X, Y and Z) for the 100 m and 200 m datasets. The errors are given in centimetres.

- in X, 8 of 10 targets have errors with magnitude below 1 cm; the mean absolute error over the 10 targets is 0.7 cm, and the maximum absolute error is 2 cm,
- in Y, 6 of 10 targets have errors with magnitude below 1 cm; the mean absolute error is 0.8 cm, and the maximum absolute error is 1.6 cm,
- in Z, 7 of 10 targets have errors with magnitude below 1 cm; the mean absolute error is 0.9 cm, and the maximum absolute error is 2.4 cm.

The 200 m dataset has the following characteristics:

- in X, 2 of 8 targets have errors with magnitude below 1 cm; the mean absolute error over the 8 panels is 2 cm, and the maximum absolute error is 5.7 cm,
- in Y none of the 8 targets has an error with magnitude below 1 cm; the mean absolute error is 1.7 cm, and the maximum absolute error is 2.6 cm,
- in Z, 2 of 8 targets have errors with magnitude below 1 cm; the mean absolute error is 2 cm, and the maximum absolute error is 4.4 cm.

Results presented above indicate significantly better performances of 100 m dataset in respect to the 200 m one. Secondly it can be also observed that there are no remarkable differences between the errors associated with the three displacement vector in X, Y and Z. In the following section a detailed analysis of the above data is done.

4. CURVE MATCHING

The first results of the deformation measurement procedure described above were achieved only using the surface matching. The procedure has been recently extended to include the curve matching procedure proposed in Gruen and Akca (2005). The proposed approach involves the extraction of contours from objects in the given point clouds and the matching of these contours. Below the main steps are described:

- Identification of the same objects in the different point clouds.
- Extraction of the contour of each object and for each point cloud. In this way we get the curves to be matched. This step, which is currently performed manually, needs to be improved. For this purpose different kinds of edge detectors could be used. However, there are limitations to get a fully

automatic procedure because some areas should be removed manually, e.g. the vegetated areas where the TLS point clouds, from the viewpoint of deformation measurement, are particularly noisy.

- c. Matching of the extracted curves. We apply the least squares curve matching in order to estimate the transformation (i.e. deformation) parameters.

The above presented approach can be used in two different ways. The first one is to check and refine the global matching based on surface matching. The second one is to provide good initial parameters to the surface matching. In the other side, it is worth to underline one of the critical points of the procedure which is the extraction of the contours in an automatic way.

Here below are presented the preliminary test results obtained over simulated data in order to check the capability of the method and to improve it. Future works will involve the validation of the proposed approach using real data. The first test was done using a simulated curve, which is shown in Figure 4. This curve provides good geometric information in all directions, i.e. it provides the geometric information needed for solving all the transformation parameters. For the test two different point clouds, of about 600 points, of the same curve have been simulated. Then a Gaussian noise with standard deviation of 1 cm has been added to each point cloud. The tests consisted in applying a known 6-parameter transformation to one of the two curves, and then to estimate the transformation parameters by using the curve matching.

Table 2 shows the results obtained in three different tests. Each table represents the mean and the standard deviation of the differences between simulated and estimated parameters, which were obtained using 30 different simulations. For the first table, T1, the rotation angles have been fixed to zero, i.e. the estimated rotations are expected to be zero. The translations in X, Y and Z direction ranged randomly between -10 and 10 cm. The results of this test show that for the translations there is a mean difference up to 3 mm, with a standard deviation of the differences of about 1 mm. For the rotations the standard deviation of the differences is up to 0.2 gons.

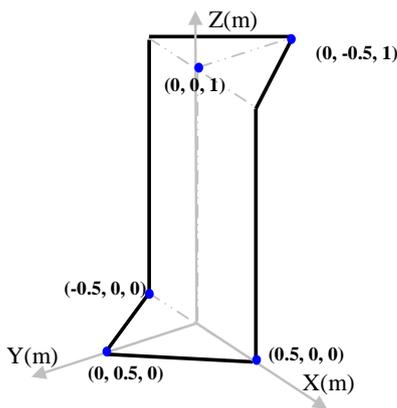


Figure 4: Simulated curve for testing and improving the implemented curve matching.

For the second test, whose results are shown in table T2, the simulated translations in X, Y and Z ranged between -10 and 10 cm, and the rotations angles between -10 and 10 gons in each direction. The results show again small biases for the translations. In X and Z the differences have the same magnitude than in the previous. In the Y direction the mean

difference equals 7 mm. The standard deviation of the differences has a noticeable increase, up to 8 mm. A similar behaviour can be observed for the rotations.

Finally the last test, whose results are shown in table T3, has the worst results. In this case the simulated translations in X, Y and Z ranged between -20 and 20 cm, and the rotations angles between -20 and 20 gons in each direction. One may notice that the standard deviations of the differences are up to few centimetres for the translations, and up to 2.3 gons for rotations. These larger values, compared with the previous tables, are probably due to the relatively large translation and rotation to be estimated. In fact, in all simulations the approximate values for the matching were set to zero.

T1	Trans. of 10 cm					
	Simulated - Estimated Param.					
	(cm)			(gons)		
	Tx	Ty	Tz	Rotx	Roty	Rotz
Mean	0.2	0.3	0.3	-0.1	0.0	-0.2
Stdv	0.1	0.1	0.2	0.2	0.1	0.0

T2	Trans. of 10 cm and Rot. 10 gons					
	Simulated - Estimated Param.					
	(cm)			(gons)		
	Tx	Ty	Tz	Rotx	Roty	Rotz
Mean	0.2	0.7	0.3	-0.3	0.5	0.4
Stdv	0.8	0.6	0.8	0.4	0.8	0.7

T3	Trans. of 20 cm and Rot. 20 gons					
	Simulated - Estimated Param.					
	(cm)			(gons)		
	Tx	Ty	Tz	Rotx	Roty	Rotz
Mean	0.9	0.1	0.2	-0.8	1.2	0.6
Stdv	3.2	4.0	3.0	1.2	2.3	1.7

Table 2: Main statistics of the three tests done in order to analyse the capabilities of the curve matching. T1 is related to a test where no rotations were simulated. In T2 we added rotations between -10 and 10 gons. In T3 the translations vary between -10 cm and 10 cm, and the rotations between -20 and 20 gons.

5. CONCLUSIONS

A procedure for deformation measurement using TLS data has been presented. The procedure is based on point cloud surface matching algorithm described in Gruen and Akca, (2005). In addition, the first results obtained with the proposed procedure have been presented and a research topic concerning to the preliminary results obtained with curve matching have been discussed.

From the results of the validation experiment the following aspects have been highlighted:

- In the 100 m dataset the majority of the targets have errors below 1 cm in the three components of the deformation vectors. Considering the non optimal characteristics of the targets, these represent promising results.

- The results achieved with the 100 m dataset are sensibly better than those of the 200 m dataset. The mean of the absolute errors of the 200 m dataset is approximately two times bigger than that of the 100 m dataset.
- Considering the displacement errors, there are not remarkable differences between the three main components.

To conclude, the first results obtained with the least squares curve matching have been presented. They concern simulated data, and were mainly used to test the matching capabilities and improve different aspects of the matching algorithm, like the outlier rejection. The achieved results using synthetic data are encouraging. Future work will involve the test of the proposed approach using real data. The usefulness of curve matching for deformation studies, say the added value with respect to surface matching, has to be proved.

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