USE OF A POINT CLOUD CO-REGISTRATION ALGORITHM FOR DEFORMATION MEASURING

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Abstract: During last few years the use of Terrestrial Laser Scanner is increasing notably in different application fields as can be architecture, geology and geodesy. This paper is focused in the use of TLS data for deformation measurement and monitoring purposes which concerns both engineering geology and geodesy. The authors propose 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). In addition, the results of two validation experiments, one over a simulated deformation scenario and a second one over a real landslide case, are commented.

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 [1,7] and several applications of geology and geotechnics like landslide monitoring [3] and rock falls [2]. A summary of the scanner specifications can be found in [6] and a technical classification of the available TLS in [4].

The paper presents a new methodology for deformation monitoring by using TLS data. This work is organized in three main parts. In the first one 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.

The second part consists on the description of two validation experiments which was done in order to asses the effectiveness of the proposed procedure. The first experiment was done at the Institute of Geomatics in June 2006. For this experiment a deformation scenario was simulated, and the obtained results from TLS data were compared with the results obtained by using a total station instrument. The second one was performed on a real landslide case scenario located in the Spanish Pyrenees. In the last section the results of the validation experiments are presented.

2. PROPOSED APPROACH

This section presents a new approach for deformation monitoring based on repeated TLS scans of the same area. The approach takes fully advantage of the high density of the TLS point clouds counter balancing the relatively poor precision of its single points. The key tool for this proposed procedure is the Least Squares Surface Matching proposed by Gruen and Akca in 2005, see [5]. The results presented in this paper were achieved using the Least Squares 3D surface Matching software implemented at the Chair of Photogrammetry and Remote Sensing of the Swiss Federal Institute of Technology Zurich.

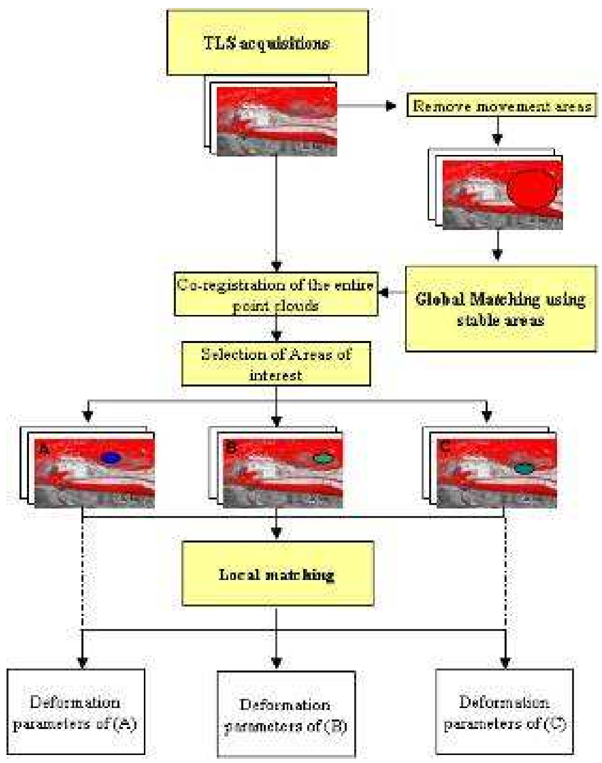

Figure 1 - Scheme of the proposed procedure. The main steps of the procedure are in bold.

The approach involves three main steps, see Figure 1, which are described below: acquisitions of the TLS data, Global matching and Local matching.

1. - <u>Acquisition of the data</u>: Let's assume that we have a moving area which is surrounded by a stable area. The data acquisition involves at least two steps:
   - Get a first scan that covers both the moving and the stable areas.
   - After a certain time, depending on the movement characteristics, repeat the scan acquisition. This operation has to be performed at least once. Note that the geometry of the second acquisition can be slightly different from the previous one.

One of the key points of this step is the choice of the scene to be scanned. This selection affects in the deformation estimation. Ideally this area should be a moving area completely surrounded by stable areas.

2. - Global matching: let's assume that we have two point clouds acquired at different times. Each point cloud has its own local coordinate systems. For measuring the movement occurred between the two acquisitions it is required to put the point clouds in the same coordinate system. Let's call the first acquisition master point cloud and the second one slave point cloud. In order to put master and slave in the same geometry we estimate a 6 parameter transformation, 3 angles and 3 translations. Optionally a scale factor can be considered. The estimation of these 6 parameters is achieved through an iterative least squares method, which is named Least Squares 3D Surface Matching (LS3D matching) and has been proposed by Gruen and Akca in 2005, see [5]. For this global alignment of the point clouds we use only the areas without movement between the acquisitions. All moving areas should be removed from the point clouds before performing the estimation.

   Global matching is one of the critical steps of the procedure. A wrong alignment of the point clouds can produce systematic errors which can make, in the worst case, impossible estimating the movement. For this reason, it must be performed different quality controls to check the quality of the estimated parameters.

3. – Local matching: this is the last step of the procedure. Once the two point clouds are in the same geometry we focus on the movement area. This area is identified in the master point cloud and then we divided it in several subsets. For each one of these subsets is searched the corresponding one on the slave point cloud and then the transformation parameter between both are estimated. These operations, searching and estimating are done in an automatic way by the LS3D matching. Assuming that each subset represents a part of a rigid body, the transformation parameters describe the deformation suffered by the subset between two acquisitions.

3. VALIDATION EXPERIMENTS

This section describes two validation experiments performed in order to validate the presented methodology. The first one, Campus experiment, was performed over a simulated scenario located in the Park Mediterrani de la Tecnologia where the Institute of Geomatics is located. The second experiment was done over a real landslide case of Formigal, in the Spanish Pyrenees.

3.1. Campus experiment

In order to evaluate the capabilities of the proposed procedure a validation experiment has been performed at the Institute of Geomatics in June 2006. The experiment involved the simulation of a deformation scenario and the comparison of the results estimated by the proposed TLS approach and the results coming from a topographic survey with a total station.

The simulated scenario consisted on a stable area where several artificial targets were distributed along the scene and moved during the experiment. Figure 1 shows the scene of the experiment. The scene includes some buildings and structures. In the bottom part of the main

Figure 2 - Image of the experiment. The buildings and structures visible in the photo have been used as stable areas. In the bottom part of the image are located the 10 rectangular artificial targets used to simulate the deformation.

Figure 3 - Image of the targets used to simulate the deformation scenario.

building are the artificial targets used as movement areas. They were 10 rectangular panels made with different type of materials (wood, foam, concrete, etc) and different surface shapes. The dimensions of the panels were approximately of 60 by 120 cm.

All TLS measurements have been done using the laser scanner ILRIS 3D of Optech. The used instrument belongs to the RISKNAT group, the research group of natural hazards of the University of Barcelona. The main steps of the experiment are described below:

1. Distribution of the panels along the scene. Figure 3 shows the panels.
2. Get the first TLS acquisitions. The data were acquired from approximately 130 meters.
3. Measurement of the coordinates of several points, about 20 for each panel, with the topographic instrument. The points were measured using a Trimble 3601 DR total station and a precise reflective prism.
4. Moving the artificial target. The targets were moved using different magnitudes (between 19 and 60 cm) and directions.
5. Repetition of the steps 2 and 3.
6. Applying Global matching to put all the TLS acquisitions in the same coordinate system. The used stable area is the entire scene with exception of the panels.
7. Applying local matching over each panel. This step gives us the 6 parameters transformation which contains the movement information.
8. Estimation of the 6 deformation parameters for each target by using the topographic data.
9. Comparison per each target of the two independently estimated sets of 6 parameters of deformation.
10. Analysis of the results. The outcomes of the analysis are described in the next section.

3.2. Formigal experiment.

This experiment was performed over a landslide case located in the Central Spanish Pyrenees. The experiment was done in the framework of the project Galahad, “Advanced Remote Monitoring Techniques for Glaciers, Avalanches and Landslides Hazard Mitigation” of the EU 6FP.

This experiment gave us an example of the importance of the acquisition geometry for the global matching. Figure 4 shows the TLS intensity images corresponding to TLS acquisition on t0 (July 2006) and t1 (October 2006). In red the non data value points. As it can be seen on the images, there is an important lack of data between the two acquisitions. The second one has a 24 per cent less data than the first one. The weather conditions during the October acquisition (just after intense rains) are the main cause of it. This fact joint with a poor geometry, the high amount of noisy areas (vegetation areas) and the magnitude of the studied movement converges in a poor quality of the global matching and as a consequence makes the deformation estimation with the proposed procedure not possible. However, it is worth mentioning that in the same area there are other parts of the landslide which fulfils the conditions to apply the proposed procedure, see Figure 5. The area has a lot of relatively big rocks where the matching works without problems. Unfortunately there was no movement on this area between two acquisitions. The results obtained in this area, in fact, over the three rocks marked by blue circles in Figure 5 are briefly commented in the next section. More in depth analysis can be found in [10].

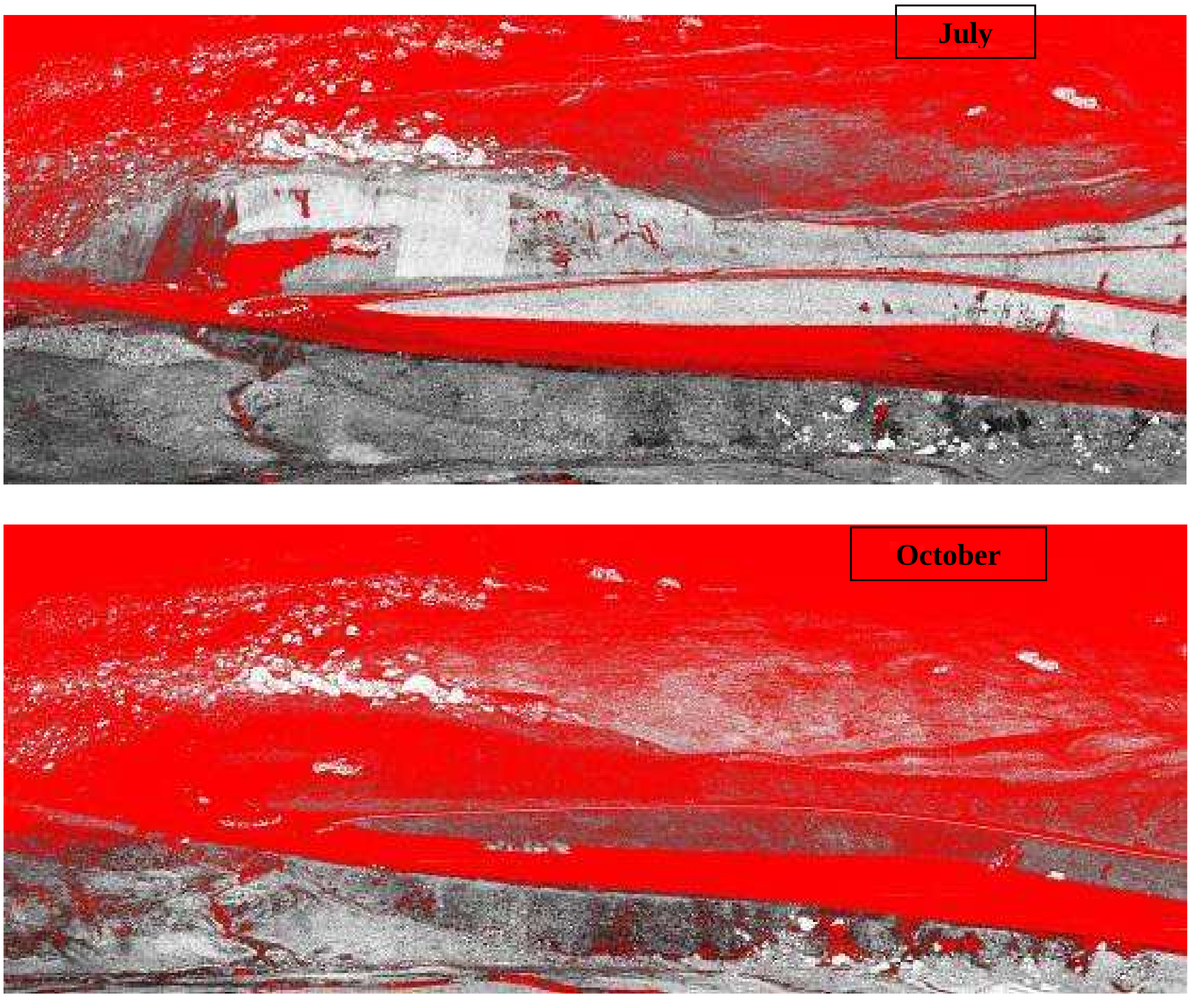

Figure 4 - Intensity images of TLS acquisitions on t0, July 2006, and t1, October 2006. The red points correspond to no data, i.e. points with no response. In July 40% of the points of the scene are no data points, whereas in October acquisition most of the points, 64% are no data. There is a severe loss of data in both acquisitions.

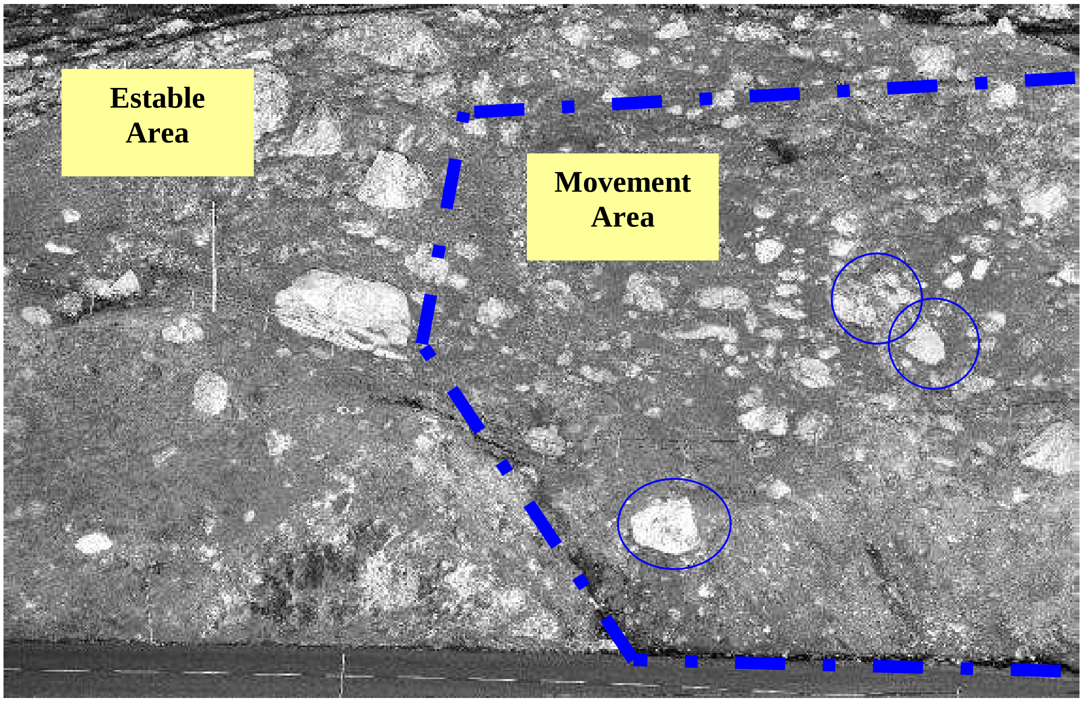

Figure 5 - Intensity image of a good area to apply the procedure. The movement area is bounded by the discontinuous blue lines.

4. VALIDATION RESULTS.

The validation was based on the comparison of the 6 parameters estimated from the topographic data with those coming from the proposed TLS approach. For the Campus experiment, the points measured by total station have a standard deviation, estimated through repeated measurements, of about 1 mm in the depth direction Y, and of about 3 mm in the horizontal and vertical directions. Using 15-20 points to estimate the 6 transformation parameters of each panel the estimated standard deviation is below 1 mm for the translations, and below 0.1 gons for the rotations. Therefore, for the purpose of this validation experiment, the topographic estimates can be used as the reference values, and the differences between the TLS estimates and those coming from topography directly represent the TLS errors.

The results obtained on the campus experiment are described in the Table 1. Note that in this table we only show the three translations. The columns of the table represent the results related to each one of the targets. The lines represent the TLS results, the topographic results and the differences between them (e.g. X TLS, X Top and X err). As can be observed, the differences between two techniques are in most of the cases below one centimeter. Taking into account the non optimal characteristics of the used targets, from the point of view of the LS3D, these are promising results.

100 m	Units	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
X TLS	cm	-2,5	-19,5	-32,0	23,4	-6,2	8,7	21,3	15,0	-1,4	59,2
X Top.		-3,1	-19,2	-32,8	23,9	-6,4	9,8	23,4	15,5	-1,5	58,6
X Err.		0,6	-0,3	0,8	-0,5	0,2	-1,1	-2,1	-0,5	0,1	0,6
Y TLS		19,8	-32,3	-8,3	-20,8	21,4	-21,3	9,1	-19,6	-47,3	9,6
Y Top.		19,2	-32,8	-8,4	-20,0	20,4	-22,2	10,1	-18,0	-47,1	8,3
Y Err.		0,6	0,5	0,1	-0,8	1,0	0,9	-1,0	-1,6	-0,2	1,3
Z TLS		-0,3	-0,2	-1,9	0,0	1,0	-4,6	-0,3	1,2	-2,8	-0,7
Z Top.		-0,6	-0,7	-1,1	0,5	2,2	-4,3	-1,0	-1,2	-4,7	-1,0
Z Err.		0,3	0,5	-0,8	-0,5	-1,2	-0,3	0,7	2,4	1,9	0,3

Table 1- Differences between the results based on topography and TLS data. The 6-parameter transformation was used. However this table only shows 3 translations.

To conclude, we briefly mention the validation results obtained over the Formigal test site, and in particular in the three rocks indicated in Figure 5. We estimated again the 6 deformation parameters with both TLS and topographic techniques. The estimated errors of the deformation vectors, shown in Table 2, are comparable with those shown in Table 1: all of them are below 1 cm. These results, obtained in a real deformation case study, confirm the results based on the simulated deformation scenario discussed in this paper. It is worth noting that in this case the real deformation is almost zero. This is probable due to that the observed period coincides with the dry season, where the landslide is inactive. However there is no reason for expecting a degradation of the accuracy having bigger deformations

	Units	Rock1	Rock2	Rock3
X TLS	cm	-0.6	-0.1	0.1
X Top.		0.4	0.5	0.6
X Err.		1.0	0.5	0.5
Y TLS		-0.9	0.1	-0.1
Y Top.		0.1	-0.1	-0.3
Y Err.		1.0	-0.2	-0.3
Z TLS		-0.5	-1.2	-0.2
Z Top.		-0.5	-0.5	-0.4
Z Err.		0.1	0.7	-0.2

Table 2- Differences between the results based on topography and TLS data for the Formigal experiment. Again the 6-parameter transformation was used. The table only shows 3 translations.

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