CO-REGISTRATION OF TLS POINT CLOUDS FOR DEFORMATION MEASUREMENT

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ABSTRACT

In the last years the use of Terrestrial Laser Scanning (TLS) data for deformation measurement has gained increasing interest. This work presents a new approach to land deformation monitoring, which makes use of an advanced procedure to co-register TLS 3D point clouds. The core of the proposed procedure is the least squares 3D surface matching proposed by Gruen and Akca in 2005 (*Least squares 3D surface and curve matching, ISPRS Journal*). The proposed approach takes advantage of both surface and curve matching to improve the co-registration quality. This approach exploits the high density of TLS point clouds, which counter-balances 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, and the automatic search of optimal areas for surface matching.

1. INTRODUCTION

During last years the use of TLS for applications such as engineering geodesy [1,8], geology, geotechnics, landslide monitoring [4] and rock falls [2] has increased notably. A classification of available TLS can be found in [5]. 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 point, which is fundamental to counter balance the poor quality of the single TLS points, is a key aspect for deformation measurement. This work describes a new procedure 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 [6].

The paper is divided in three main parts: firstly the proposed approach for deformation measurement is described, then the first results obtained with curve matching are discussed, and finally the automatic search for optimal areas for TLS point cloud surface matching is presented. 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 [3] and [6], 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.

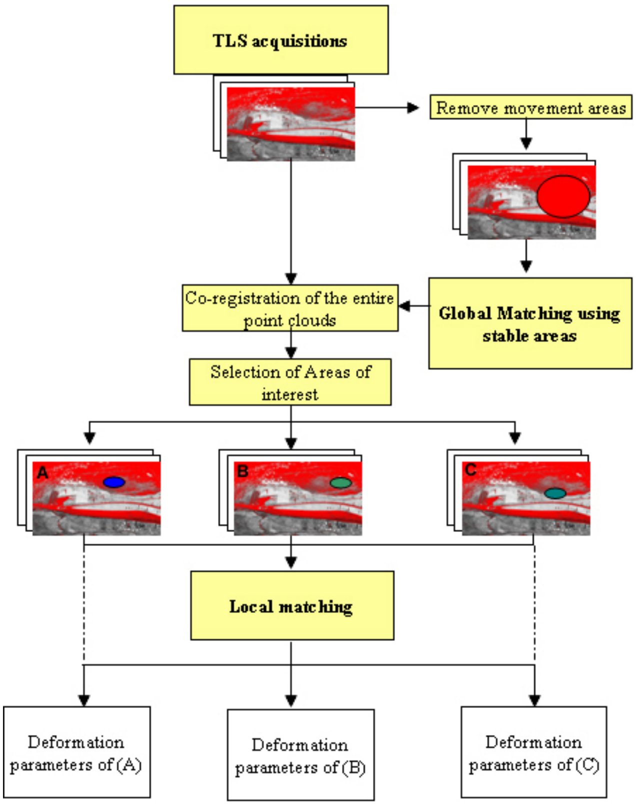

Figure 1: Data flow of the proposed procedure. Its key points are highlighted in bold.

1 Acquisitions of the TLS data. Let's assume that we have to monitor a moving area which is surrounded by stable areas. The acquisition of the data involves at least two steps:

- Getting the first scan covering both the stable and moving areas.
- Re-visit the place at least once, getting a second acquisition of the same place. For the second acquisition the use of exactly the same viewpoint is not required. This operation can be repeated several times.

In this step some key points have to be considered in order to help the subsequent analysis of the data:

- The viewpoint has to be approximately the same in all acquisitions in order to minimise the geometric differences between the analysed TLS data.
- In order to optimize the final results, the number of scans to acquire the area of interest should be minimum. Ideally the area of interest should be covered by just one scan.
- The resolution should be set taking into account the dimension of the object of interest. The better the resolution the higher the available redundancy, and, as a consequence, the higher the sensitivity to deformation.

2 Global processing of the entire scene. Once the acquisitions are done all the point clouds have to be put on the same geometry. For this purpose the stable areas should be discriminated from the movement area and the transformations parameters between the point clouds should be estimated using only the stable areas. The deformation areas are typically known; if this is not the case, extra processing can be performed in order to detect them. This step is one of the most critical due to the effects that it can produce over the deformation areas. The main characteristics of the studied area have to be studied a priori, assessing the feasibility of the global matching. The global matching can be checked by means of the standard LS based tools, e.g., residuals, outlier rejections, etc.

3 Estimation of the local deformation: once the point clouds have been co-registered we proceed to the estimation of the deformation parameters. This involves the selection of the areas to be studied. Typically they are subsets of the movement area. The deformation parameters are calculated over each selected area. The selection of the local areas can be performed by a selection of specific objects located on the movement area. Alternatively, the movement areas can be automatically divided into subsets containing specific number of TLS points. Once the selection of the subsets has been performed, for each subset of the reference point cloud, the corresponding subset on the second point cloud is automatically searched using the LS3D matching algorithm, thus obtaining the transformation (deformation) parameters. Typically these parameters are three translations and three rotations.

The presented procedure has been validated using both a simulated deformation scenario and a real landslide monitoring scenario, see for details [9].

3. CURVE MATCHING

The first results of the deformation measurement procedure described above were achieved only using the surface matching, see [9]. The procedure has been recently extended to include the curve matching procedure proposed in [6]. The proposed approach involves the extraction of contours from objects in the given point clouds, and then matching these contours. It involves the following steps:

1. Identification of the same objects in the different point clouds.
2. 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.
3. 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.

Here below are presented the preliminary test results obtained 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 2. 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 curves have been simulated, adding a Gaussian noise with standard deviation of 1 cm. Each curve has around 600 points. 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 1 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.

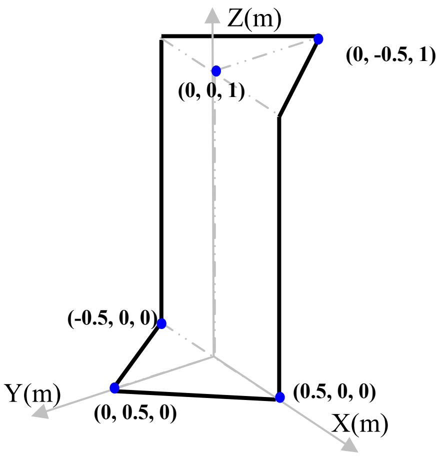

Figure 2: Simulated curve for testing and improving the implemented curve matching.

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 1: 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. The translations vary between -10 cm and 10 cm for each direction. 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.

4. QUALITY OF MATCHING

One of the key aspects of the procedure here presented is the quality assessment of the results. Although the least squares estimation provides different tools to analyse this quality, e.g. the residues and the number of iterations, these are sometimes not enough to get a good quality check. This fact can be illustrated by considering a plane surface. With such a surface we can obtain very small residues from the matching, but, due to the geometric characteristics of the surface, getting at the same time completely erroneous transformation parameters. To overcome this limitation, it is necessary to develop tools which allow evaluating a priory the quality that the surface matching can achieve. This section briefly describes this work.

The matching algorithm takes advantage of the geometry of the matched surfaces. The geometric content of the surfaces is a key point for a good behaviour of the matching. For instance, the residues provide good information on the quality of the matching only if there is enough geometric information in the matched surfaces. This fact suggests the idea of using tools which give information about the geometry of the areas to be matched. We used for this purpose the Förstner operator [10], which is based on the variations of gradients of the surface.

Our approach is to firstly apply the interest operator to one of the two point clouds to be matched, removing the areas with poor geometric information. The deformation measurement procedure is then applied only for the remaining areas. Even though sometimes TLS provides noisy observations, in general the interest operator allows separating the areas with high geometric content from the other ones. However, there are problems related with the vegetation, e.g. grass or trees, which are usually associated with big changes of the surface gradient without having any relation with the changes due to deformation phenomena. For this reason the vegetated areas are not good for matching, and have to be removed. This can be done manually by using the intensity image, or other optical images of the measured area. Furthermore, is must be noted that the results of the above tool is rather case dependent. In fact, it depends on the signal-to-noise of the TLS acquisitions, which varies depending on the sensor to target distance, the type of measured surface, the weather conditions, etc. For this reason the outputs of the above tool provide qualitative information to choose the good candidate areas to be matched.

The above procedure has been applied over two test areas. First one includes the building of the Institute of Geomatics. The TLS data were taken from a distance of about 200 meters, with a resolution of about 1 cm. This area is interesting because includes objects with high geometric information, like the upstairs, and several flat structures like the building walls. Figure 3 shows the results obtained over this area. The upper image is a TLS intensity image of the scene. The bottom image represents the geometric information map derived from the above described operator. The bluish colours correspond to areas which have strong gradient variations. The darker the blue, the stronger is the geometric information. One may observe that the areas with vegetation have stronger blue. These areas should be removed manually before performing the matching. Other interesting areas are the edges of the buildings which have weak blues. The rest of the scene consists basically on the big walls of the buildings. These areas, with poor geometries are represented by green, yellow, red and white colours on the map.

The second selected area concerns Castellfollit de la Roca, a small village located in northern Catalonia (Spain), see Figure 4. Compared with the previous example, this one has measurements with lower resolution. The measuring distance was around 200 m, and the resolution about 6 cm (this makes difficult the identification of vegetation areas). Looking at the intensity image, one may observe that the blue and black areas (strong gradient variations) are related to vegetation areas like grass and trees. These areas have to be cleaned manually before performing the deformation analysis.

5. CONCLUSIONS

A procedure for deformation measurement using TLS data has been presented. The procedure is based on point cloud surface and curve matching algorithms described in [6]. In this paper, two research topics addressed at the Institute of Geomatics have been discussed. The first one concerns the preliminary results obtained with curve matching, and the second one the search of optimal areas for surface matching.

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.

In the second part of the paper, a procedure to identify the goods candidate surfaces to be matched has been described. The procedure, which looks for areas characterized by high geometric information, is based on the Förstner operator. The preliminary results based on this procedure have been presented. The discrimination between good and weak areas, say areas with high geometric variations vs. flat areas, seems to work well, even though it is based on rather qualitative information. There are however limitations related with vegetation, which usually presents high geometric variations but has to be discharged before running the matching. Future research work will be focused on the comparison of matching performances of good vs. bad areas.

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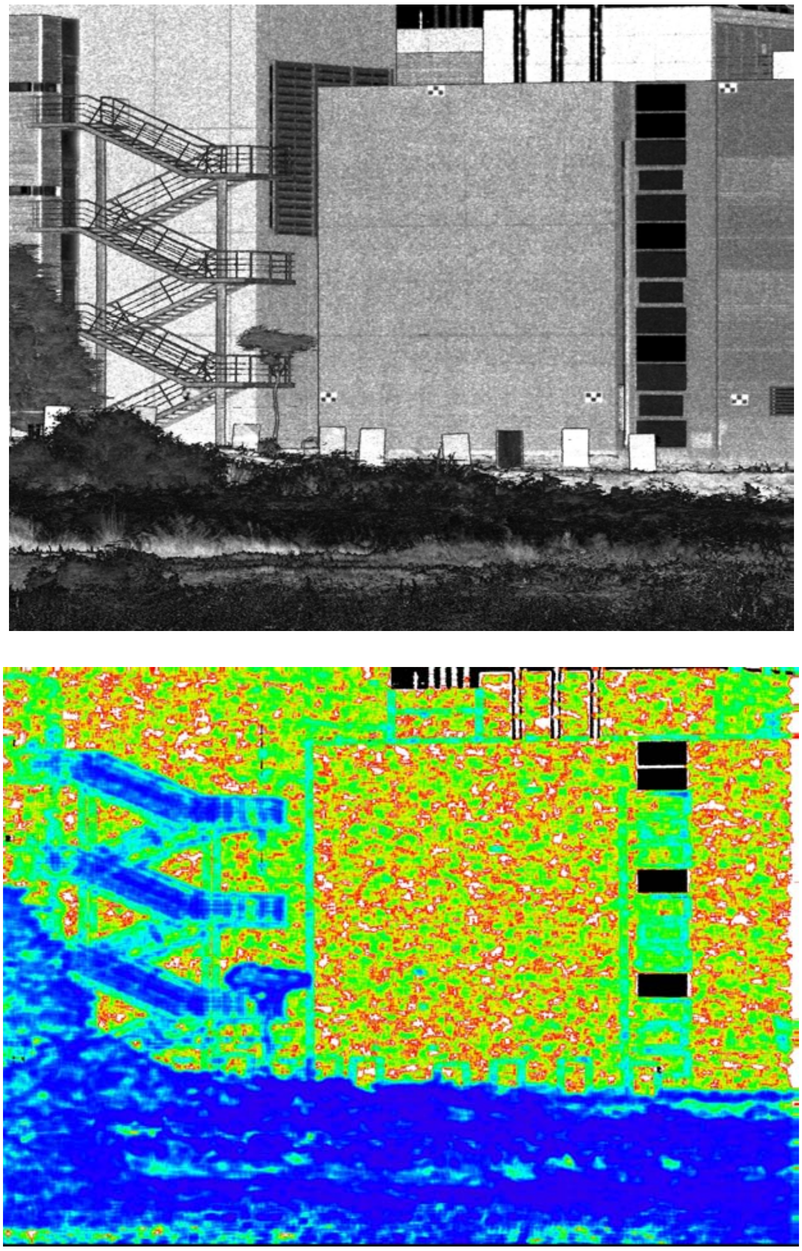

Figure 3: The upper image represents the TLS intensity of an acquisition taken in the Campus of the Institute of Geomatics. The main part of the scene is composed surfaces with poor geometric information. The bottom image shows the geometric information map derived from Förstner operator. The areas with good geometric information are represented by blue. Green, yellow, red and white colours indicate areas with poor geometry.

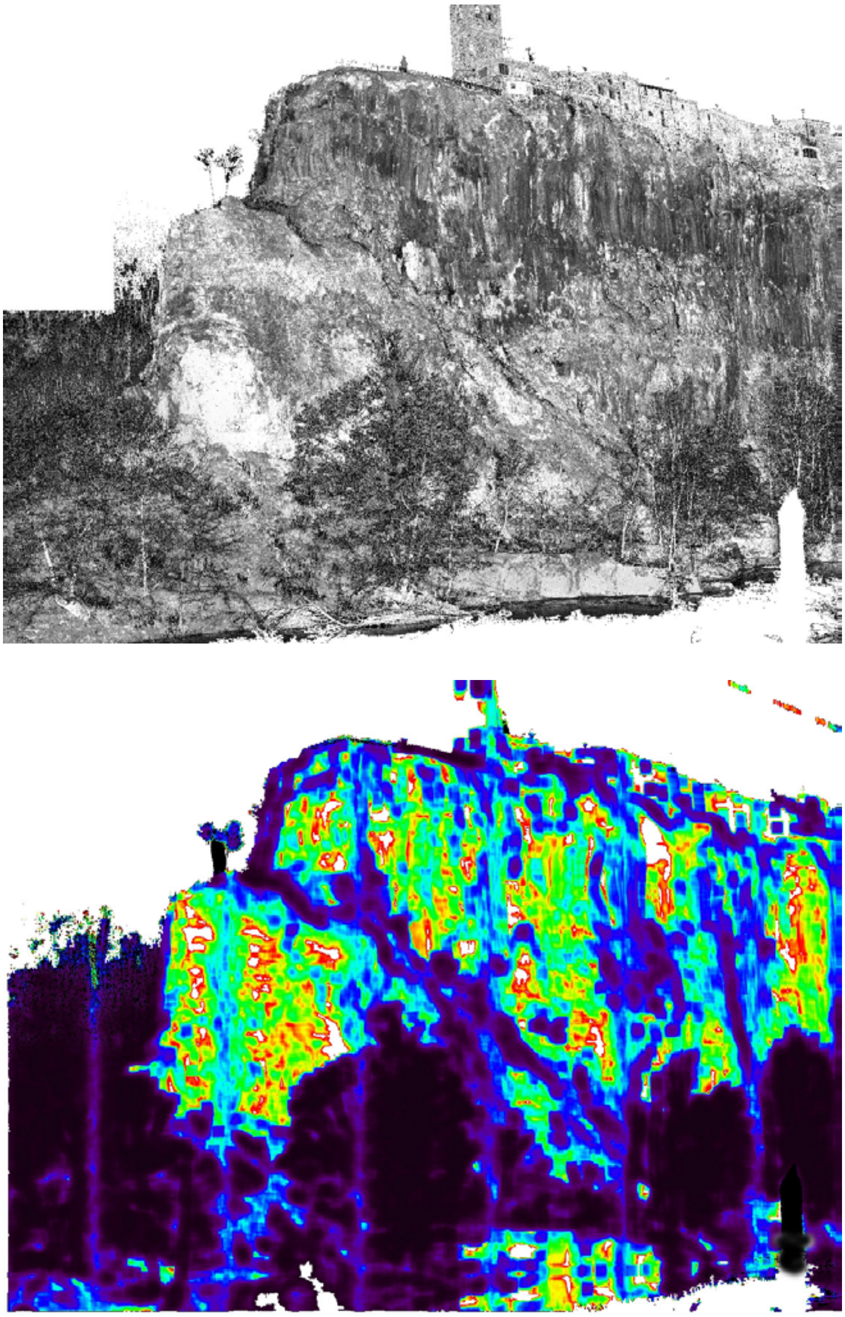

Figure 4: The upper image is a TLS intensity image. The images area includes a lot of vegetation. The geometric information map, which is represented on the same way than the previous one, shows large blue and black areas, which mainly correspond to vegetation areas.