Terrestrial Laser Scanning for Dam Deformation Monitoring - Case Study

Gergana ANTOVA, Bulgaria

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SUMMARY

This paper presents some first results of a project aimed to access the feasibility of monitoring deformations of large concrete dams by terrestrial laser scanning. Case study of Studena Dam in Bulgaria is described. A large number of retro-reflecting targets have been positioned and measured by a total station in the local datum. Moreover, targets are measured also in captured scans. They are placed in the surroundings as ground control point. Two measurement campaigns are accomplished so far: the second one after earthquake in Pernik on 22.05.2012. Reported analyses are focused on two main problems: the first one is the accuracy and the stability of georeferencing, which is fundamental to make comparisons between different multi-temporal scans; the second one is the computation of deformation based on the acquired point-clouds. Moreover, some notes about a method to compute the accuracy of surface points which have been measured by terrestrial laser scanning are reported.

РЕЗЮМЕ

В статията са представени първите резултати по проект изследващ възможността за използване на наземно лазерно сканиране за мониторинг на деформации на големи бетонни язовирни стени. Разглежда се приложението на метода за язовир Студена. Контролни точки са стабилизирани извън деформационната област на обекта и са измерени с тотална станция в локална координатна система. Точките също така са сканирани за трансформиране на измерванията с лазерния скенер в локалната координатна система. Извършени са два цикъла измервания като вторият е след земетресението в гр. Перник на 22.05.2015 г. изложения анализ е фокусиран върху два основни проблема: първият е точността и стабилността на геореферирането, който е основен при сравнението на данни от различни епохи, а вторият е изчислението на деформациите при сравнението на облаци от точки.

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1. INTRODUCTION

While exploring of deformations with conventional geodetic technics gives better accuracy compared with terrestrial laser scanning (TLS), geometric modeling of point clouds could be effective for presenting of changes in shape for the whole structure. Modeling surface gives more accurate representation of the object than raw observations. Some researches are presented to show the potential of application of laser scanners for deformation monitoring and prove that their accuracy could be significantly improved by modeling of 3D point cloud. The aim of these experiments is determining the sensibility of laser scanners for deformation monitoring and exploring their potential for solving deformation tasks.

The extraction of deformations with laser scanning is made not for separate points but with using comparison of modeling surfaces for different epochs. Determination of deformations in discreet points can not be done, because the TLS doesn't allow measuring the same points in scanning in different epochs. The main advantage of this technology is representing of the whole surface of the exploring structure. Different methods for surface comparison are presented below.

The idea to extract information about the structural deformations from laser scanning data is to improve the accuracy of the measurement taking into account the surrounding points, i.e. a group of dots to represent the element of surface. In the most simple case it can be plain. It is also possible to simplify the task of 2D analysis as presented the surface with profile lines.

2. SURFACE COMPARISON

2.1 Deformation monitoring using control points

Direct comparison of control points is presented in (Tsakiri,2005) using reflective marks known for the software and algorithms for accurate determination of center of the mark. Comparison of X,Y,Z vectors gives deformation 0.4 mm. The weakness of this method according to my opinion is loosing the huge amount of laser scanning data. The same results can be achieved by conventional geodetic measurements.

2.2 Direct comparison of single points

Direct comparison of single points without using brands is viewed in (Schäfer, 2004), where the points are located on a regular network created by the method of Delaunay-Triangulation. Then for each point a new value (y ') can be interpolated. The difference between the two corresponding y ' coordinates represent the value of the deformation (Fig. 1)

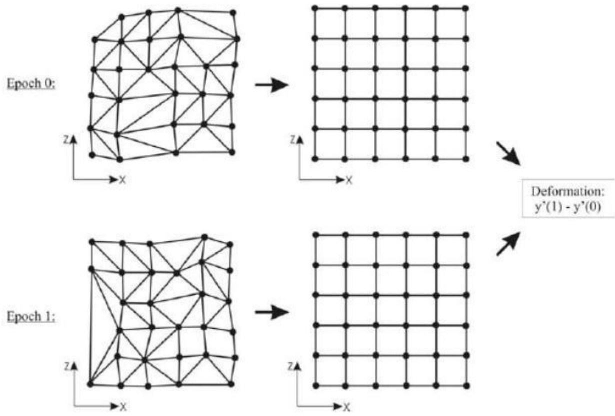


Figure 1: Raw point clouds with an irregular model (left) and the interpolated regular grid (right) identical for every point cloud epoch. The diference in y- direction represents the deformation. Picture taken from Schafer et al, 2004.

2.3 Direct comparison of Digital Elevation Model (DEM)

Some authors as (Bitelli et al.,2004) and (Hesse and Stramm,2004) carry out research through direct comparison of Digital Elevation Models (DEM) of different TLS campaigns. A similar case is described in (Schäfer et al.,2004). Although this approach is easy to accomplish using the proposed software, it has two important limitations. First, it has limited sensitivity for small deformations, which makes it unusable for measuring small deformations. Second, if the digital models are defined as a 2D function i.e. $z = f(x, y)$, then the difference between digital models allows measurement of 1D deformation in the direction z. Considering the 3D nature of the point clouds derived from the laser scanner, this is a major limitation of this approach.

2.4 Using appropriate approximating surface

Another type of method uses the appropriate surface models that fit of TLS point clouds. The key idea is to move beyond the limited accuracy of single TLS points using the advantage of the great density of measurements i.e. 3D points and geometrical characteristics of the surveyed area. In (Van Gosliga et al., 2006) they use a cylindrical approximating surface to remodeled tunnel, while in (Alba et al. 2006) this approach is followed to the study of large dam as adjusted polynomial surface on measured 3D point clouds.

Another example of this type of method is described in (Schneider, 2006) for deformation analysis of the television tower. To define the curves, the point cloud is divided into N thin layers and is designed as a plain, and thus transforms the task of 3D in 2D corresponding tasks. For each layer circle is approximated using the adjustment on the MNMK. The line of the bending of the TV Tower is given by connecting the centers of the N circles.

The main advantage of these methods is the high quality of strain parameters in terms of the quality of the original TLS data. The limitation of these methods is related to the need to rely on a model of the surface, which requires analysis, dependent on the specific task, applicable only to objects with certain geometric characteristics. In addition, if the deformation is calculated of the differences between models of surfaces defined for different epochs (Alba et al. 2006), the deformation field is 1D. This is the same restriction mentioned for the previous method. However, it is important to note that the impact of this restriction depends on the type of application. In fact, in some cases, the 3D information is not necessary.

2.5 Using plane approximation

Finally, it is worth mentioning another study suggested by Lindenbergh and Pfeifer (2005), which is based on the statistical deformation analysis for determination of deformation. This study includes segmentation of the object of the planar pieces, least square adjustment for each piece, least square calculation of deformations from age to age for each piece, and a statistical analysis of the received deformation parameters. The key advantage of this study is the ability to retrieve deformations under the nominal accuracy of separate point. The main disadvantage of this technology is the need for a clearly defined model of the parts of the surface, which cannot be applied to a variety of tasks, such as those which include many natural sites.

3. CASE STUDY FOR STUDENA DAM

3.1 Description of the object

Studena dam is situated in west part of Bulgaria 40 km west from capital city Sofia. The dam, built in the period 1950-1953 is a concrete buttress with 26 concrete blocks- 55 m maximum high and 259 m in length in the crest. In blocks 6, 9, 11 and 16 are mounted four straight cliffs with numbers respectively 1, 2, 3 and 4.

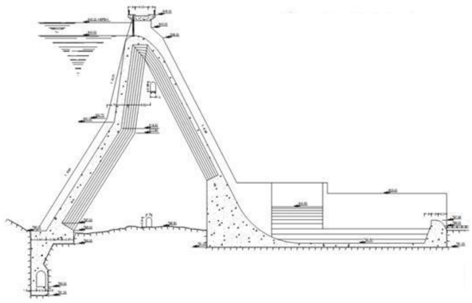


Figure 2: On the left a typical cross section of the Studena dam, on the right a frontal view of the dam the site.

3.2 Geodetic frame

A local coordinate system is defined with the x-axis coinciding with the crest line, the Y axis perpendicular to it in the direction of the air swath and the z-axis in the zenith. New ground control points (GCPs) with the number 100, 101, 102, 103, 104 and 105 are located outside the deformable zone and stabilized near the air-swath of the wall and were measured with total station Leica TCA 1800 with angular accuracy 1 (0.3 mgon) and accuracy of measurement of lengths 1 + 2 ppm. The least squares network adjustment has resulted in the determination of 3D points with estimated standard deviations of ±2 mm in X-Y and ±3 mm in Z.

3.3 Laser scanning measurements

In December 2011 geodetic measurement was carried out in the framework of the research project on the theme "Use of terrestrial laser scanners for deformation applications" financed by the subsidy for scientific research in 2011. The measurement is carried out under the water level elevation 832,81 m and air temperature 6^{o}C. The measurements were performed with scanner Leica Scan Station C10 with a range up to 300 m and accuracy 6 mm and speed of scanning 50000 points per second. The scan was performed by two stations at a distance of 100 m from the wall and a density of scanning of 2 cm. 80 million points were measured. The orientation of the measurements was made using special signals from Leica, which the software recognizes automatically. Local transformation of the measurements from both stations is made with an accuracy of 3 mm using 5 GCPs 100, 101, 102, 103, 104. The standard deviation of the results of the registration is 3.1 mm, which is 2 times more accurate than the accuracy of the unit point. This value is actually the limit for registering the absolute deformations (Schneider, 2006). The processing is done with Cyclone software (Fig. 3).

In June 2012 second measurement of the dam is made after the earthquake in 22 May. The scan was performed by the same two stations and same density of points and configuration as the first scan. 80 million points were measured in water level elevation 841,25 m and the air temperature 22 ° C. As a result of the scan 3D model of object is obtained with 1 cm density in point cloud.

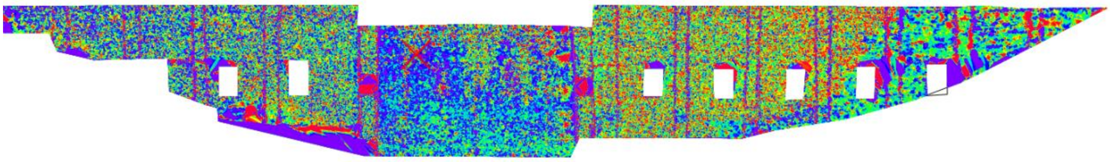
3.4 Surface comparison for deformation extraction

On the basis of the analysis made above two methods for retrieving information about the deformation state of the dam are selected and used:

1) direct comparison of Digital Elevation Model (DEM) obtained by two cycles of measurements;

2) profile lines across blocks 11 and 16 at the dam were made, in which straight verticals are located. Compare both profiles with one another and with the data from the reports on straight verticals.

The comparison of the two surfaces obtained from measurements in December 2011 and June 2012 is done by these 2 methods and on the premise that the ground control points were stable. First irregular models of the surface of air swath of the dam is created with AutoDesk Civil 3D for both measurement eras. Comparative area describing the differences between the two measurements (fig. 4).



Legend

-15 to -5 mm
-5 to +5 mm
+5 to +15 mm
+15 to +20 mm
+20 to +25 mm

Figure 4: Surface comparison of TIN models with AutoDesk Civil 3D

The measured differences are in the range from 18 mm to + 15 mm, which corresponds to the accuracy of the measurements (6 mm double point and 3 mm for the constructed surface area) and expected for this period of year to the wall. Taken into account and that the air surface of the dam collapsing, and the surface is not smooth.

Second surface comparison was made with PolyWorks. Differences from 5 to 10 mm are detected. The results are shown in Fig. 5.

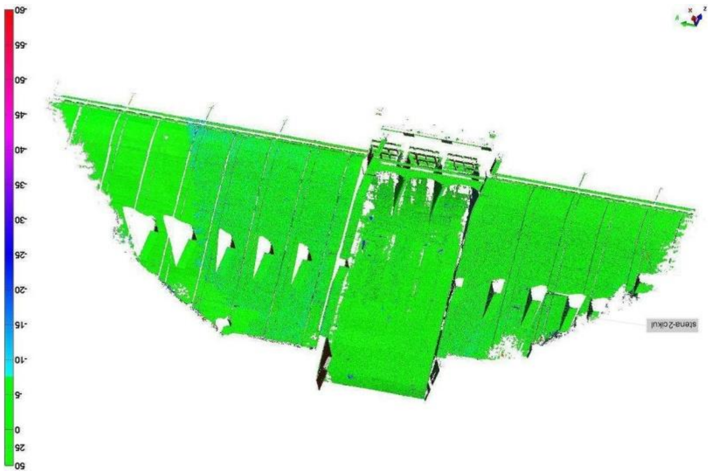


Figure 5: Surface comparison with PolyWorks with triangulated models

4. CONCLUSION

Taking into account the above and based on the results of the scanning measurements before and after the earthquake of 22.05.12 may make the following conclusion:

The resulting values of the movements correspond to the measurements of the technical operation of the dam. Not observed extreme values of the deformation of the surfaces in both measurements. Straight verticals report and geodetic survey confirmed the elastic nature of these movements, which are in direct relation to the dynamics of water level in the dam and from temperature fluctuations.

The reported differences are within the limits of the accuracy of the tool and of course within the limits of the values measured during the prolonged period of operation of the wall. For this time of year they are affected to a greater extent than the temperature of the air, which heats air swath of the wall than the water level in the dam. In this situation, check the usual returns to higher blocks toward the water.

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BIOGRAPHICAL NOTES

Gergana Antova is a chief assistant professor at the Department of Surveying and Geoinformatics, Faculty of Geodesy, University of Architecture, Civil Engineering and Geodesy, Sofia, Bulgaria since 2001, where she lectures in basic and advanced courses in surveying, mathematical post processing of geodetic measurements, CAD systems and Geoinformatics.
She studied Geodesy and achieved her MSc. degree in 2000 in the same university. Now she is writing her PhD thesis. Her research interests and fields of publication are based on "Terrestrial laser scanning for dam deformation monitoring".

CONTACTS

Gergana Antova
University of Architecture, Civil Engineering and Geodesy
Hr. Smirnenski 1 blv.
Sofia
BULGARIA
Tel. +359887747138
Fax +35928662201
Email: antova_fgs@uacg.bg
Web site: www.uacg.bg