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COMPARISON OF EFFECTIVENESS OF MEASURING CONCRETE WATER DAM WITH TERRESTRIAL LASER SCANNERS: RIEGL VZ-400, Z+F IMAGER 5010

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Summary

In the span of the last ten years a major spur of evolution has occurred in the area of obtaining object spatial data. The range and form of spatial data are subject to constant technical evolution, and what comes with that – the possibilities and effectiveness of their computation rise. Terrestrial laser scanning, which is the basis for obtaining 3D data, is also a subject of constant innovation. Currently, manufacturers of terrestrial laser scanners offer a wide range of advanced measurement devices; their precision and efficiency fulfill the need of geodesic monitoring. The scientific research in this article is a comparative analysis of the application of two terrestrial laser scanners used in the measurement of a water dam in Rożnowo. The results of the comparison present the ability to compare the influence of the type of measurement device used on the results of a periodical measurement of water dams.

Key words: terrestrial laser scanner, geodesic monitoring of water dams, study of the condition of the concrete

INTRODUCTION

Legal regulations of the monitoring of engineering objects including hydro-technical structures, have been set in the following acts: Construction Act and Water Act. Monitoring is an organized and long-term method of observation, which delivers data about an engineering object's technical condition. It aims to record parameters characterizing the object's condition, including: settlement, horizontal movement, relative deviation in movement joint, leak intensity, level of degradation of the concrete (Kledyński 2011).

According to Witakowski (2007), the monitoring of large engineering structures requires the use of remote measurement methods (*Remote Monitoring)*. From all the available remote monitoring systems, the author, in particular, points to Remote Video Monitoring systems, the observations of which are recorded by visual devices, such as cameras or video cameras. Currently, in literature, the subject of monitoring engineering structures is discussed more and more often, including monitoring water dams with use of terrestrial laser scanning (Schäfer *et al*. 2004, Alba *et al*. 2006, Zaczek-Peplinska and Falaciński 2011, Biłka *et al*. 2013, Gumus *et al*. 2013, Zaczek-Peplinska *et al*. 2013, Zygmunt and Biłka 2014). As per Zaczek-Peplińska *et al*. (2013), terrestrial laser scanning is used in recording the condition of an object on different stages of its execution, including the comparison of executed elements with the design, recording the state after execution, creating and updating geometrical data for the purpose of modeling the behavior of hydro-technical objects under different amounts of load, verification of the existences of relations between the changes of the water level in the basin and the changes in geometry of the structure, as well as the evaluation of the technical condition of the object.

Currently, constant development of TLS technologies heightens the potential for improving measurement devices. Producers offer a wide variety of terrestrial laser scanner, the precision and effectiveness of which fulfills the needs of geodesic monitoring. Formerly, the basic determinant for the use of a particular type of laser scanner in engineering applications was the distance measurement system used. Phase scanners were used in short-range measurement, and their time of operation was relatively short. Meanwhile, impulse scanners were used only for long-range measurements. Currently, these limitations are not as important, both phase and impulse scanners can be used for similar measurement applications. The authors of this article have conducted a comparative analysis of a impulse and a phase laser scanner used in measuring a water dam. The results of these studies allowed the influence of the type of measurement device used on the results of a periodical measurement of a water dam to be determined.

MATERIALS AND METHODS

The comparative analysis of the two terrestrial laser scanners was conducted at a water dam in Rożnow (Figure 1a). The dam was built in the middle of the XX century, and because of the aging processes, it requires detailed monitoring. Moreover, it is one of the tallest heavy concrete dams in Poland, and is a structure of the highest class, which pose the biggest threat. The dam is 49 m tall and 550 m long. Its main designer was Prof. Gabriel Narutowicz (1865-1922) – the I President of the II Republic of Poland.

Included in the scope of the research works a terrestrial laser scan of the test field, located on the landside wall of the water dam, was conducted (Figure 1b). The data was obtained with the use of two laser scanners, both set up at the same scan station. The measurement were obtained in September 2013, during a science camp of the Photogrammetry Section of the Surveying Scientific Group of the Agricultural University in Krakow.

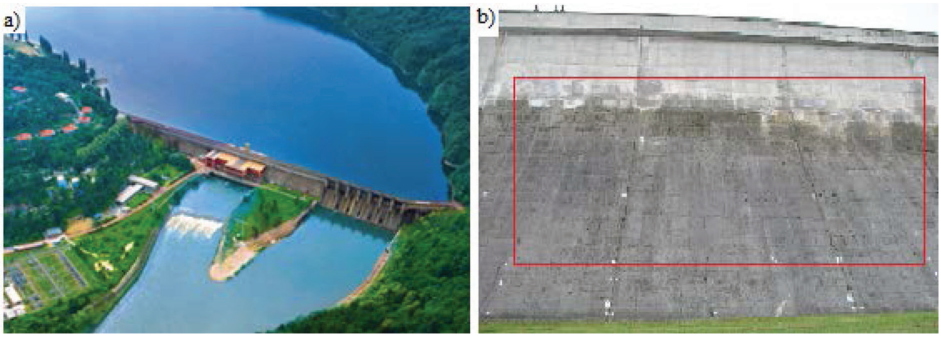

Figure 1. Water dam in Rożnów a) Bird's eye view (*Source:www.tauron-ekoenergia.pl*); b)Test field

The studies were conducted on point clouds originating from two terrestrial laser scanners: impulse Riegl VZ-400 and phase – based Z+F Imager 5010 (Table 1). The utilized measurement devices are widely used in engineering applications, and the level of their reliability and precision allows them to be categorized in the same class of measurement devices. As per Ostrowski *et al*. (2012), a large advantage of the Z+F Imager 5010 is its high precision and quick measurement. The device has the ability to record over a million point per second, and its range is over 180m. Li *et al*. (2012) however, point out the higher quality of data obtained with the Riegl VZ-400 and its large range, which allows for a precise measurement of the geometry of hard to reach objects. Thanks to the appropriate parameters of the device, it has been used for the monitoring of the metro tunnels in Tianjin.

The terrestrial laser scanning technology allows acquisition of three dimensional data needed for mapping objects quickly. A laser scans ensures surface coverage of the studied object with measurement data, capturing the coordinates of millions of point, contrary to the few points of measured object obtained in the course of a traditional measurement. However, when using the laser scanning method, important elements of the object, such as the corners and edges, are not measured precisely, but are designated by way of post processing. That's why, the appropriate density of the point cloud, guaranteeing a proper rendering of the object's geometry is so important. The density of the point cloud of the test field obtained from the scanners has been presented in table 2, as the number of point and the distance between neighboring points, in accordance with point cloud density definition set by Lichti (2004).

Table 1. Characteristic of terrestrial laser scanners used for the comparative analysis

	Riegl VZ-400	**Z+F Imager 5010**
Year of introduction onto the market	2009	2010
Work mode	Impulse	Phase
Measurement precision : **Distance (mm/m)** **Angle (°)**	 5/100 0,0005	 1,2/50 0,007
Scanning speed (point/s)	122 000	1 016 000
Scanning range: **minimum (m)** **maximum (m)**	 1,5 600	 0,3 187,3
Field of view: **vertical (°)** **horizontal (°)**	 100 360	 320 360

Source: Magazyn Geoinformacyjny Geodeta 11/2011 (Appendix: Skanery laserowe)

Table 2. The density of obtained point clouds for the test field

	Number of points	**Average distance between neighboring points**
Riegl VZ-400	235 211	0.04 m
Z+F Imager 5010	2 092 452	0.02 m

Source: Prepared by the authors

In the framework of comparing effectiveness of the measurement of the concrete water dam with the Riegl VZ-400 and Z+F IMAGER 5010 scanners, the obtained point clouds have been processed, generating reports which present detailed information about the scanned object. Widely used for the purposes of controlling and evaluating the technical condition of the hydro-technical control are the TIN (Triangulated Irregular Network) models, generated on the basis of network of triangle mesh (3D RiskMapping 2008, Zygmunt and Biłka 2014, Alba *et al*. 2006). The triangle mesh method is an automatic method for creating a surface model on the basis of a given point cloud, for which the corners of the obtained triangles are single points of the cloud (Tokarczyk *et al*. 2012). By using complex algorithms for creating a TIN mesh, neighboring points are connected, constructing surfaces corresponding to a representation of the actual shape of the water dam (3D RiskMapping 2008). Different algorithms exist for creating sieves of the mesh from TLS data, the most popular being based on the Delaunay criterion (3D Risk Mapping 2008, Jurczyk 2000). In the framework of the comparative analysis, the test field was converted into precise surfaces, based on TIN meshes, using the Lecia Cyclon 8.1.1 software. The two most important parameters of each TIN mesh were matched: the number of vertex and the total number of sieves. The TIN models of the test field (Figure 2) were compared against one another, creating a differential model. Also conducted was descriptive statistic of the differences obtained between models.

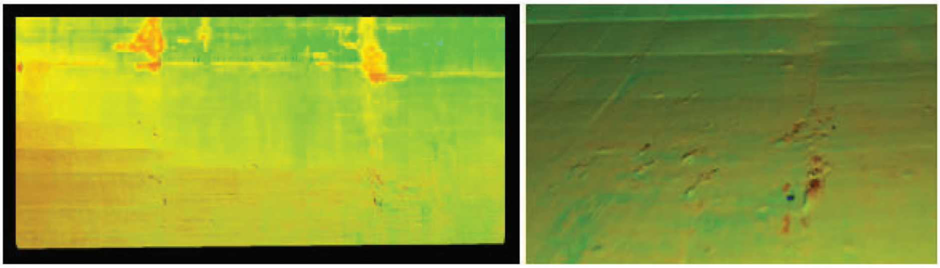

Figure 2. TIN models of the test field

The point cloud allow for a visual evaluation of the condition of the hydro-technical building's surface, enabling the detection of scratches, fracturing and dampness. To diagnose the level of damages and dampness of the object, most often used is the value of intensity of the laser beam's reflection. The ratio of the intensity of the beam's reflection to the characteristic of the reflective surface, its color, roughness and amount of humidity, allows detailed analysis of its condition to be conducted. To compare the condition of the surface set at each test site, techniques for automatic recognition of image have been used, allowing classes of pixels with similar reflective properties to be obtained. The raster representations of the results of reflection intensity measurements have been exported as .tiff images. The intensity images in grayscale have been loaded into GEOMATIC 2013, in which an unsupervised classification has been conducted. With the help of the Fuzzy k-means algorithm (Armesto-Gonzalez *et al*. 2010), 16 classes of pixels have been identified, with similar reflective properties.

The correlation between analysis results, conducted by each test field, has been determined on the basis of comparing classified images against each other.

RESULTS AND DISCUSSION

Basic diagnostic actions, conducted with the aim of controlling and evaluating the technical state of the hydro-technical buildings include the measurement of deformations of the object's surfaces. TIN models created on the basis of point clouds present detailed information about the geometry of water dams. They show deformations and differences between the constructed building and the project, as well as small defects, damages or cracks (Zygmunt and Biłka 2014). The comparison of model obtained during consecutive measurement cycles allows a evaluation of the compliance of the geometric processes of the individual elements of the structure to be conducted, and small deformations to be detected. The parameters of the TIN meshes created on the basis of the test point clouds, obtained with Riegl VZ-400 and Z+F Imager 5010 scanners, have been presented in Table 3.

Table 3. TIN mesh parameters

	Number of vertexes	**Number of triangles**
Riegl VZ-400	164 723	329 261
Z+F Imager 5010	260 849	521 488

Source: Prepared by the authors

Despite the differences in the mesh parameters, the TIN models generated on their bases did not differ significantly. The differential model created on their bases and its statistical parameters shown in table 4, show a correlation between both the TIN models in the precision limits of both scanners. Model created on the basis of results cyclical measurements of water dams, even when created with different types of laser scanners, will be therefore fully comparable and will allow for a surface (not point) analysis of the changes in the building's shape and created damages. Utilizing differential models in studies of the technical condition and the safety of hydro-technical buildings, will allow quantitative and qualitative analyses of the process of their deformation and degradation. The potential of the terrestrial laser scanning technologies in surface analyses of deformations and dislocations of the water dams, and the possibility of their evaluation, has been confirmed by multiple studies conducted in this field (Alba *et al*. 2006, Schäfer *et al*. 2004, Gumus *et al*. 2013).

Table 4. Statistical parameter of the differential model for Riegl VZ-400 – Z+F Imager 5010

Scanner type/ comparison criteria	**Differential model Riegl VZ-400 – Z+F Imager 5010**
For all observations	
Average	-0,0104
Min	0,0000
Max	0,0880
standard distribution	0,0014
number of observations	27 624
Rejected observations, over 3 times the value of standard deviation	
the limit for rejecting observations (cm)	1
number of rejects	18 533
Average	-0,004
Min	0,000
Max	0,006
standard deviation	0,0018

Source: Prepared by the authors

Visual observations of the objects' surfaces are an important element of evaluating the technical condition and safety of hydro-technical buildings. Concrete water dams should checked for changes in the condition of the surfaces meaning scratches, cracks, excess dampness or leaks. Moreover, any irregularities discovered during the inspection should be documented in a way which allows their evaluation during following inspections (Jankowski 2008). The data obtained from a laser scanner, allow a diagnosis of the surfaces' condition to be conducted. Cartometric precision of the data guarantees the correct location of damages and determining their dimensions, and their proper documentation. Used in diagnoses of the buildings' condition is the value of the fourth coordinate – the intensity of a laser beam's reflection (I). A flat, undamaged surface of the dam is characterized by a higher intensity (brighter color – value close to 1) than a rough, crack or damp surface (darker color – value close to 0). However, the range of intensity values recorded by the laser scanner differs for each model of the measurement device (Figure 3a, Figure 3b).

The correlation of the 16 pixel classes with similar reflective properties identified in the test point clouds, has been set by comparing classified images (Figure 3). Reports showing the amount of pixel groups with similar spectral properties, indicated a large influence of not only damages and dampness of the surfaces, but also the type of terrestrial laser scanner used, on the results of the classification. Despite differences between classes, the results of the conducted analyses are characterized with a certain analogy. Spectral analyses conducted on data obtained from the Z+F Imager 5010 scanner clearly presented the conditions of the water dam's surface in two aspects: humidity level (filtration to through the dam body) and the level of damage to the surface (Figure 3d). Low intensity values recorded by the Riegl VZ-400 scanner directly influenced the level of detail of the identified concrete surface classes with different properties (Figure 3b).

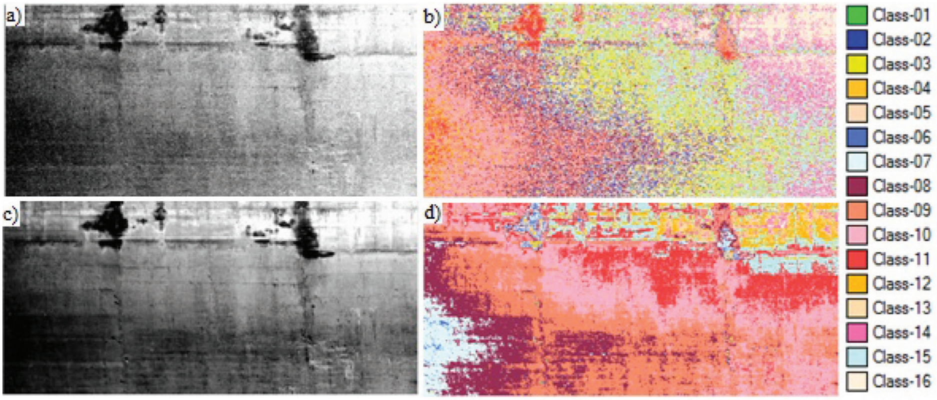

Figure 3. a) Raster representation of reflection intensity in grayscale – Riegl VZ-400 scanner; b) Ratio of operation for the Fuzzy k-means algorithm (8 classes) – Riegl VZ – 400 scanner; c) Raster representation of reflection intensity in grayscale – Z+F Imager 5010 scanner; d) Ratio of operation for the Fuzzy k-means algorithm (8 classes)– Z+F Imager 5010 scanner.

In determining the level of surface erosion processes and filtration events, the intensity value of the laser beam's reflection allows for an advanced analysis. The evaluation of the current condition of the object can be based on the percentage determination of the damaged or dampened surfaces. The development of degradation of the surfaces of the water dam, meanwhile, can be evaluated by comparing percentage values obtained during consecutive measurements. In Zaczek-Peplińska's and Falaciński's (2011) paper, on the basis of detailed studies, showed the usability of intensity values and visual analysis techniques in diagnosing a hydro-technical object's condition. It should, however, be noted, that in the course of periodical monitoring of the level of degradation of a water dam's surfaces, the influence of the used scanning device on the results of conducted analyses cannot be overlooked.

CONCLUSIONS

The specificity of hydro-technical objects points to the fact, that these structures should be subject to careful examinations, and the data obtained in the framework of evaluation measurements and observations should be used in preparing an evaluation the object's safety. The terrestrial laser scanning technology, which ensures comprehensive coverage of the object with data, is reliable addition to basic diagnostic actions, carried out with the aim of controlling and evaluating the technical condition of the water dams. Using the intensity value of a laser beam's reflection to determine the condition of the dam's surface, enables an evaluation of the level of humidity and the level of damage to the surface to be carried out. Meanwhile, the TIN models created on the basis of a point cloud provide detailed information about the water dams' geometry, essential for studying the objects' deformation. Analyzed in this article was the influence of the scanning device mode on the evaluation of the deformation of the water dams' surfaces' deformation and the description of the objects' surfaces' condition. Small irregularities between the created TIN models ruled out the need to use the same measurement device during the periodical monitoring of the water dams' deformation. Meanwhile the influence of the type of the scanning device used, on the obtained reflection value for the laser beam and the analyses conducted on its basis, turned out to be significant.

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