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Concrete surface evaluation based on the reflected TLS laser beam's intensity image classification

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Abstract: Dynamically developing terrestrial laser scanning technology (TLS) provides modern surveying tools, that is, scanning total stations and laser scanners. Owing to these instruments, periodic control surveys of concrete dams were performed as a part of geodetic monitoring yield point models characterised by quasi-continuity. Using the results of such measurements as a base, one can carry out a number of geometric analyses as well as acquire information for detailed analytical and calculative considerations.

The scanner, similar to total station, by determining distances and angles, identifies spatial coordinates (X, Y, Z) of the surveyed points. Registration of the reflected laser beam's intensity value (Intensity) emitted by the scanner provides additional information on the surveyed object. Owing to high working speed and the large amount of the collected data, the scanners became an indispensable tool for geodesists.

The article assesses the possibility of application of terrestrial laser scanning in surveying changes in the surface of a concrete dam based on the experimental measurements. The condition of the dam's downstream concrete wall was evaluated. The evaluation included changes in the surface's roughness, cracks, seepage points, erosion caused by plant overgrowth and the degressive durability parameter of the used material (concrete).

The article presents an example of the application of the results of a laser scan in the assessment of the condition of a water dam's external concrete surfaces. The results of experimental measurements were analysed – the results of a scan of the downstream concrete wall of a dam in Ecker (Germany) using two laser scanners characterised by different technical parameters, that is, laser wavelength (laser's colour), range, definable point density, method of distance measurement – Leica C10, Z+F Imager 5006h. The measurement was carried out in the same weather conditions from the same sites of the test base.

The results of the measurements were analysed using, inter alia, statistical methods by defining template fields and supervised and unsupervised classification methods in reference to the selected fragments of the surface characterised by known concrete surface properties. Various classification algorithms were used. The obtained results make it possible to assess the suitability of the proposed methodology of evaluating the concrete surface's condition and establish tool selection principles to match the practical application requirements.

Keywords: engineering geodesy; Automatic Image Analysis; control of dams; assesment of concrete surface.

1 Introduction

Periodical measurements of concrete structures, performed within geodetic monitoring, may be implemented using laser scanners. Similar to a tacheometer, laser scanner determines spatial coordinates (X, Y, Z) of surveyed points, specifying the distance and angles. Besides the speed of operations, the parameter that mostly differentiates the scanner from the tacheometer is the registration of the fourth coordinate – an intensity of reflectance of the returning light signal, emitted by the scanner. The analysis of recorded values of that additional fourth coordinate may be applied in diagnosing the conditions of structures. Literature most often presents the utilisation of terrestrial laser scanning techniques for monitoring various types of building structure dislocation and deformations [1,7]. Authors present a completely different approach to this measurement technique – intensity instead of geometry analysis.

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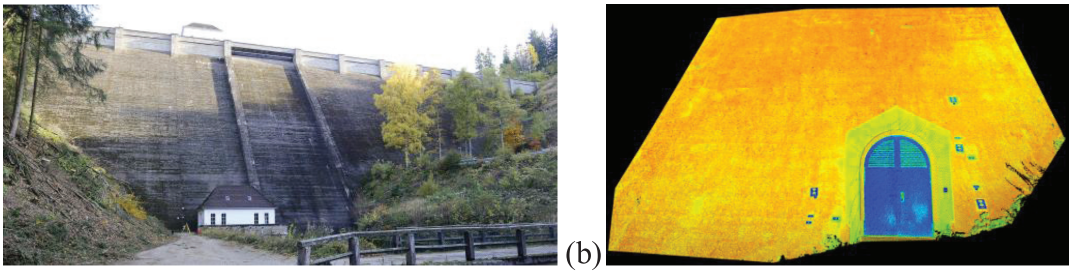
(a) (b)


Figure 1: Ecker Dam. (a) Photograph of the structure and (b) results of laser scanning with Leica C10 of downstream surface – station 501 (image of intensity).

The article presents an evaluation of possibilities to use laser scanning results for the determination of outer surface conditions of water dam construction.

Experimental measurements described in this article aim at the comparison of analysis results of laser scanning measurements – the intensity of reflection of laser radiation (I) and results of analyses performed with the use of other, non-destructive methods – visual evaluation and sclerometric measurements (using the Schmidt sclerometer) – not only with respect to the results obtained but also considering economic aspects, such as time, costs and involvement of the measuring team. Measurements of water dams in Poland performed by authors of this paper indicate a high potential of practical use of laser scanning technology not only for surveying and building geometrical models of those objects [10] but also for the technical condition assessment and digital modelling of performance of those objects concluded, for example, by finite elements method (FEM) as proposed by [8].

Analysis of recorded values of the fourth coordinate may be applied in diagnosis of the conditions of the structure. Some cases are known, when – basing on initial analysis – it could be stated that elements of the structure are produced from different materials or that they were influenced by high temperatures in the past [4]. Attempts to diagnose the structure conditions made from the same material, which is influenced by age and changing pressures, based on the registered values Intensity I, have not been made.

Between 2009 and 2012, grouping algorithms (used for image classification) were used for the first time at Besko Dam (Poland) for downstream face concrete conditioning assessment by authors of this paper [11,12]. Quoted article proposed sequence of analysis starting with unsupervised classification with ISODATA algorithm for single image of Intensity for the assessment of using measurement data for such kind of analysis, selection and description of reference sample areas defining various conditions of concrete surface; statistical analysis (analysis of the distribution of intensity values for selected reference samples) aimed at defining the degree of reference fields similarity. The final stage involved analysis using a maximum likelihood supervised classification method integrating data such as the results of concrete surface measurements performed by scanners of various technical parameters (Leica C10 – 532 nm (green) laser, pulsing, Z+F 5006h – infrared laser, phasing and thermal images of the object).

Proposed methodology of survey data handling was used for Ecker Dam concrete surface condition assessment in 2013–2014. That article presents the results of surveys and analysis performed for Ecker Dam during the first control period. The part of the recommendation had been implemented in 2015–2016.

2 Object

The test object is concrete-gravity water dam Ecker Dam (figure 1), located in the Harz Mountains (Germany). The concrete dam on the Ecker River went into service in 1942. The dam consists of 13 contraction joints 15.7-m wide and one spillway that is 31-m wide. The maximum height of the section is 65 m, and the maximum height of the reservoir in the area of overflow sections is 57 m. Experimental measurements of Ecker Dam were performed in the autumn of 2013 using Z+F Imager 5006h scanner as well as a Leica ScanStation C10 instrument.

3 Survey

Development of Automatic Multisource Images Analysis method used the following data:

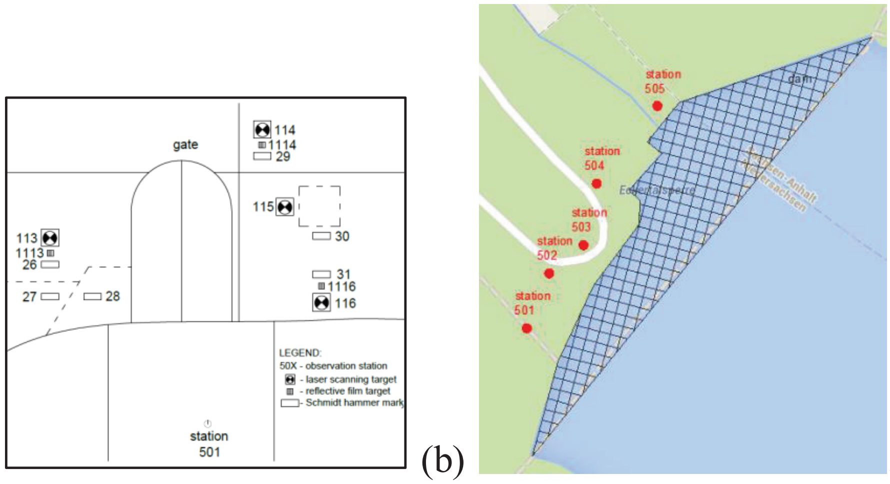


Figure 2: Ecker Dam: (a) example of survey markers/planar targets/signs distribution (station 501) and (b) survey position locations.

- results of laser scanning,
- optical images,
- thermal images (thermography),
- results of Schmidt hammer tests for the assessment of designated reference samples conditions from the downstream surface of the dam,
- tacheometric measurements.

The presented analysis use traditional tacheometric techniques in order to combine different types of measurements into one corresponding coordinate system. Three groups of signs were applied for marking points on the edge of the dam section: reflective foil, black and white planar targets for coordination of various scanning sessions and charts marking designated reference fields, the material characteristics of which were assessed using Schmidt hammer (Fig. 2a).

Black and white cards with a cross sign allow for conclusive and repetitive aiming. Observations were performed using Leica 1202+ instrument from five associatedor related points located along the face of the dam in 20 m distances (Fig. 2b). At each station, tacheometric measurements and laser scanning were performed, as well as the photographs and thermal images of the dam surface were taken. Observation points and markers on the object were measured with a local resolution (point spacing) of 1 mm.

The survey of the dam has been conducted by two laser scanners: a Leica ScanStation C10 as well as a Z+F Imager 5006h. Owing to unclear scenery caused by many trees and altitude changes, no direct sight onto the surface was possible. In order to overcome this issue, seven scans have been conducted by the C10 scanner at first, as the instrument is capable of measuring distances up to 300 m. Subsequently, detailed scans of the dam's surface were conducted at very high local resolution. Subsequently, four areas of interest on the dam have been scanned by the Z+F instrument whose reach is restricted to 78 m. After data acquisition, all scans have been transformed into a common coordinate system by using the Iterative Closest Point (ICP) algorithm as proposed by [2] and [3] where the seven registered C10 scans served as a framework for the remaining Imager 5006h scans. By using artificial targets that were distributed within the scene, all registered scans have been georeferenced into the coordinate system as defined targets.

All digital processing of the acquired images and data was conducted using ERDAS Imagine software, designed especially for satellite image processing.

4 Study For Ecker Dam

Digital images (e.g. optical, multispectral and thermal) and raster representation of the intensity captured by TLS based on Ground Control Points (GCPs) (terrain/dam details) were geometrically transformed, so that they received a consistent orientation.

Assuming that the measuring of laser beam reflection intensity allows for diagnosis of concrete construction conditions, [13] performed an analytical experiment exploring possibilities of using automated image recognition methods such as ISODATA (Iterative Self- Organizing Data Analysis Technique), [9]) used for

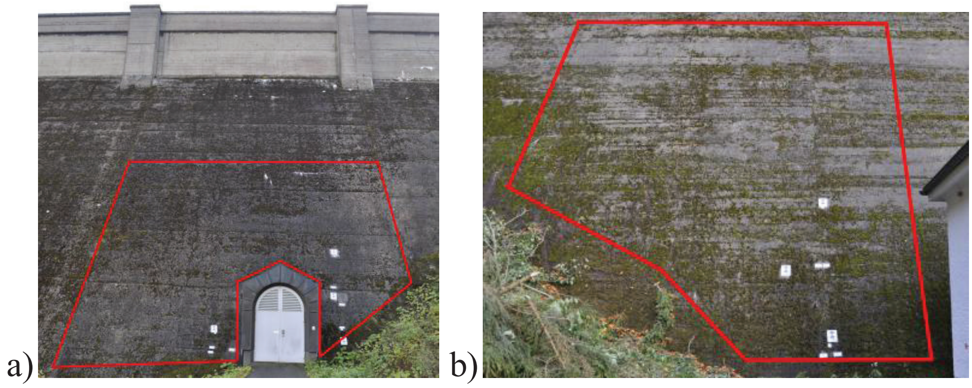


Figure 3: Selected fragments of Ecker Dam surface: (a) east section (station 501) and (b) west section (station 505).

unsupervised classification of multispectral satellite images [5,6]. This technique allows for obtaining classes (groups) of pixels with similar radiometric properties.

For this study, two fragments of surface were selected: west section – surfaces around the entrance door into the inspection gallery (station 501; Fig. 4a) and surface of full east section – in proximity of power plant, with no visible concrete infill observed on surface of this section (station 505; Fig. 3b). Owing to article length restriction, only the analyses for the west section are presented in this paper (Fig. 3a).

The results obtained with ISODATA algorithm indicate possibilities of distinguishing classes of concrete structure surface with different characteristics. High compliance of results achieved based on this method with results of test samples analysis allows for drawing such conclusions.

Following these findings, the next test method was supervised classification, in which concrete samples of known characteristics as training samples were used. In further analysis, several classes of concrete were distinguished on the dam surfaces – 10 classes on Ecker Dam.

Different classifying algorithms, including minimum distance and maximum likelihood, allowing for the delimitation of classes of concrete different properties, were tested.

In order to obtain reference information for automated image analysis, a series of sclerometric measurements were performed. Schmidt sclerometer measurements were taken immediately after scanning and cleaning the reference sample area. Detailed statistical analysis of reference (training) fields was performed under different scenarios of image intensity calculations (including creating average intensity value for 5 cm × 5 cm and 10 cm × 10 cm windows). Analysis show that average intensity value and standard intensity deviation within samples depend on concrete characteristics.

Consecutively, the following image processing methods of the registered Intensity images were performed:

Step 1. Unsupervised classification with ISODATA algorithm – 10 classes for each kind of data (obtained with different types of scanner) separately for 5 mm × 5 mm image of Intensity,

Step 2. Unsupervised classification with ISODATA algorithm for integrated data – 10 classes.

In consideration of the expected changes in values – from 5 cm, which is significant from hydrotechnical object condition assessment point of view – it was decided to perform digital processing for the data degraded (average) to pixel size of 5 cm × 5 cm and 10 cm × 10 cm. The 10 cm × 10 cm pixel size allows for optimum indication of changes within the object. The results of unsupervised classification for station 501 are presented in Figure 4.

Step 3. Supervised classification based on reference samples – after analysis of the obtained results, reference samples for surface of different properties were defined and analysis of intensity value distribution (histograms) on selected fields was performed.

Reference fields for surveyed surfaces were selected (Fig. 5; Table 1). They were indicated during concrete strength measurements using Schmidt hammer, performed directly after laser scanner surveys.

On the basis of the statistical characteristics of intensity value distribution and histogram similarity for the reference areas (Fig. 6) – method described in [13] – similar areas were defined and grouped accordingly in matching classes. For each class, an exemplar area was determined for supervised classification purpose (Table 2). This article presents scanning results for data obtained with Leica C10. The same analysis was

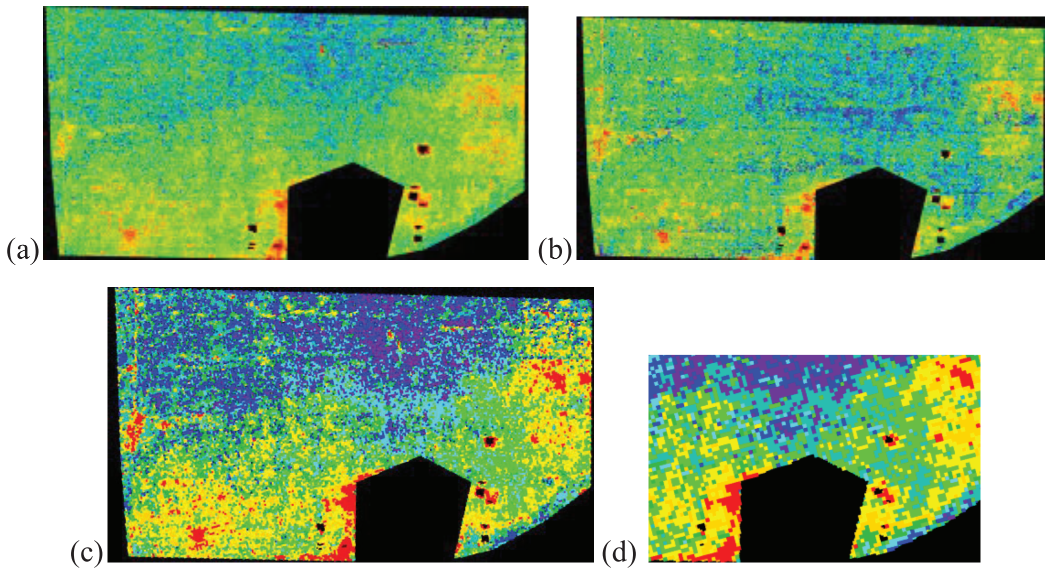


Figure 4: Results of unsupervised classification of intensity value using ISODATA algorithm, Ecker Dam, station 501: (a) Scanner Leica C10, pixel 5 mm × 5 mm; (b) scanner Z+F 5006 h, pixel 5 mm × 5 mm; (c) integrated data, pixel 5 cm × 5 cm; (d) integrated data, pixel 10 cm × 10 cm (fragment) clearly visible/legible separate surface areas of concrete surface filled with different material (red colour) and clear concrete (yellow and orange colours).

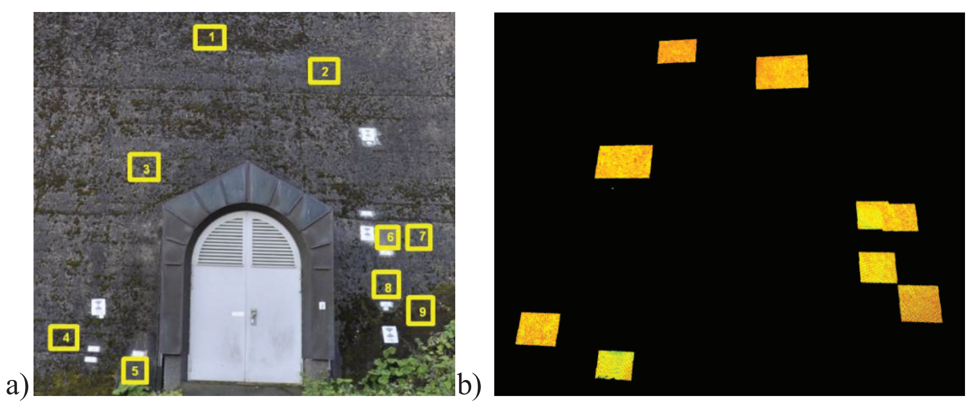


Figure 5: Reference fields Intensity images (with Leica C10, station 501): (a) reference fields marked on the concrete dam's wall and (b) image of intensity of the reference fields.

performed for Z+F 5006h scanning results. The results of the analysis were similar for both instruments, as guiding results measurements obtained with Leica C10 scanner were adopted. Decision was made following technical performance of the laser, especially its lower sensitivity for surface humidity. Differences in class identification are given in Table 3.

In the next step, the reference fields used for maximum likelihood supervised classification method were identified.

Step 4. Supervised classification of images of intensity using maximum likelihood method.

Table 1: Selected reference fields for stations 501 and 505.

Class	Description	Reference fields
		Station 501
1	Clean concrete	1, 2
2	Concrete covered with mosses to a lower extent	3, 4, 7
3	Concrete covered with mosses to a higher extent	-
4	Concrete covered with mosses	9
5	Infill areas with material of different properties (such as. cement)	5, 6, 8

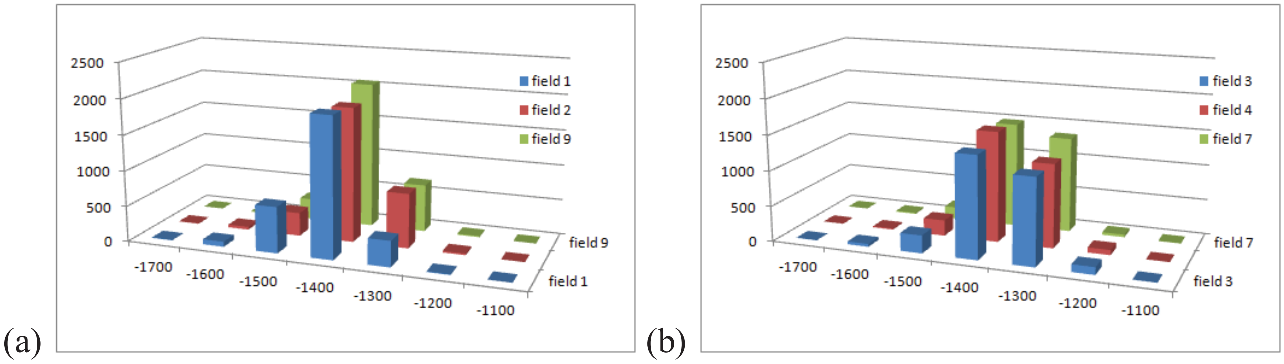


Figure 6: Classes 1 and 2 histograms (station 501, scanner Leica C10): X-axis – registered values range; Y-axis – occurrence number for sample area. (a) Class 1 – clean concrete; and (b) Class 2 – concrete covered with mosses to a small extent.

Table 2: Comparison of statistical parameters, characterising reference samples – Ecker Dam.

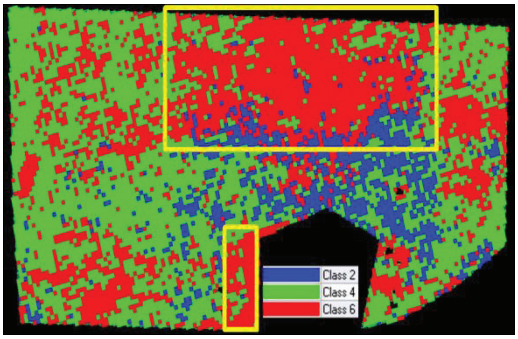
Class	Sample fields/ reference	Description	I	Minimum	Maximum	Mean	Standard deviation	Dominant (range of values)
Ecker Dam – Leica C10 – Station 501								
1	2	Clean concrete	I*	−1,630	−1,274	−1,427.42	36.05	−1,455 to −1,397
			Iavg5**	−1,456	−1,396	−1,425.60	14.38	−1,440 to −1,409
			Iavg10***	−1,455	−1,403	−1,427.00	11.68	−1,435 to −1,418
2	4	Concrete covered with mosses to a small extent	I*	−1,643	−1,207	−1,415.91	45.10	−1,461 to −1,378
			Iavg5**	−1,452	−1,351	−1,415.34	19.75	−1,429 to −1,392
			Iavg10***	−1,441	−1,389	−1,412.77	12.83	−1,423 to −1,403
3	-	Concrete covered with mosses to a high extent	Not designated					
4	-	Concrete covered with mosses	Identification error caused by significant surface dampness					
5	6	Infill areas with material of different properties (such as cement)	I*	−1,403	−1,311	−1,357.21	18.69	−1,380 to −1,332
			Iavg5**	−1,442	−1,299	−1,358.26	30.58	−1,366 to −1,340
			Iavg10***	−1,380	−1,322	−1,350.20	18.26	−1,357 to −1,353

*Registered Intensity value in standardised sample
** Average Intensity for 5 cm × 5 cm,
*** Average Intensity for 10 cm × 10 cm,

For this classification, images of intensity obtained from two scanners measured at the same time were used.

Owing to variances in technical performance of lasers working in different range of spectrum, each scanner registers different intensity level of the reflected beam. Using both images allows for surface classification reflecting the actual condition of the surface. Taking into account the difference in lasers' wavelength allows for higher diversity of surface properties.

The results obtained using maximum likelihood algorithm indicate the possibility of using image analysis techniques to separate classes of concrete surfaces with

(a) 

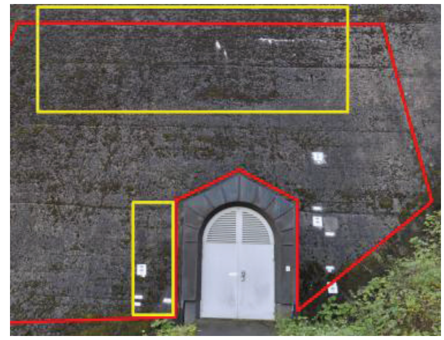
(b) 

Figure 7: The areas indicated for preservation in station 505: (a) area highlighted with yellow colour was defined using supervised classification results, classes defined as follows: 2 – Class I (clean concrete), 4 – Class II (concrete covered with mosses to small extent), 6 – Class V (infill areas or significant surface erosion); and (b) area designated for preservation marked on the visible spectrum image.

Table 3: Differences in class identification.

Fields	Station 501	
	Leica C10	Z+F 5006h
1	Class I	Class I
2	Class I	-
3	Class II	Class II
4	Class II	Class II
5	Class V	-
6	Class V	-
7	Class II	Class I
8	Class V	-
9	Class I	-

different properties. Quite a large compliance of the results of the classification using this method with the reference samples allows one to form such conclusion. The preliminary study results were included in [12].

Main goal of this classification was to indicate areas of concrete structure belonging to predefined classes. Intensity images of different pixel size were analysed: 5 mm × 5 mm, 5 cm × 5 cm and 10 cm × 10 cm.

5 Practical Applications

Practical result of this research was to determine the areas of concrete within the surveyed surface that need to be repaired by infill, cleaned or preserved in order to avoid or stop erosion of the structure. Figure 7 presents areas of concrete surface designated for preservation – station 501. Figure 8 presents areas of concrete surface designated for cleaning – station 505. The selection was made according to the results of supervised classification using maximum likelihood algorithm in accordance to the intensity images obtained by different scanners.

Owing to various wall preservation techniques of the structure present on site, classification results for window of 10 cm × 10 cm pixel size was used for selection. In addition, optical and thermal images as well as the results of concrete surface resistance (hardness) measurements made using Schmidt Hammer were obtained at the same time as laser scanning.

Station 501 (Fig. 7) indicated areas around the inspection gallery entrance that require preservation, and an area of 42 m^2 (10-m wide by 4.2-m high) 5.2 m above the entrance.

Station 505 (Fig. 8) indicated area suitable for cleaning at the bottom of downstream face measuring around 73 m^2 (16 m × 4.6 m high).

Such preliminary analyses allow for estimating required work in heights and prepare more accurate costing. Reducing workloads to necessary extent helps to achieve economical savings as well as better protection of people working at heights.

6 Conclusions

The authors concentrate on the application of the results of a measurement carried out using a laser scanner in order to evaluate the condition of the external surfaces of a dam's construction in two aspects: dampness evaluation and assessment of the surface's condition. It has to be noted that because of the surface character of laser scanning, it is only possible to evaluate a thin external

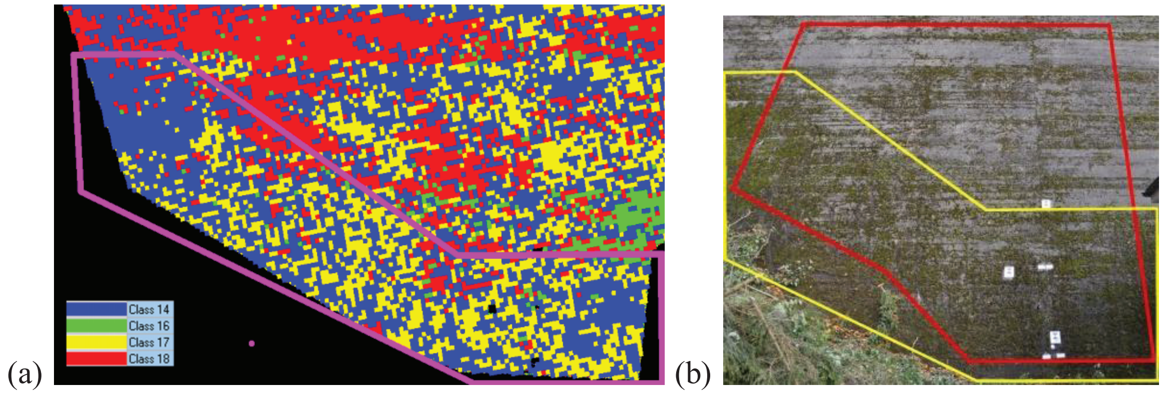


Figure 8: Areas indicated for cleaning in station 505: (a) area highlighted with magenta was defined using supervised classification results, classes indicated analogically to Figure 7, and (b) area designated for preservation marked on the visible spectrum image.

layer of concrete using the analysis of changes in intensity value.

The result of a scan of a single point after appropriate numeric processing – merging, orientation of the scans in the object's local coordinate system and filtration aimed at detection of 'gross errors' (scanning of a random objects, e.g. passing birds, water splashes, elements present in front of the object in the path of the light beam) – corresponds to the X, Y and Z coordinates and I (intensity – reflection's intensity – the amount of the laser beam's energy returning to the registering device). The value of the fourth coordinate 'I' is influenced by the following factors: physical properties and topography of the scanned surface, laser used in the instrument (wavelength) and atmospheric factors (source energy and its fluctuations can be omitted if single scans taken using the same instrument are being analysed). The preliminary results of the research indicate the possibility of using automatic image analysis techniques to identify areas of concrete structures with similar properties.

Works concerning preparation of an appropriate algorithm of technical conditions evaluation of the water dam's downstream face concern: selection of a surveying instrument (scanner, scanning tacheometer), development of a method for control fields selection, methods of measurements, methods of measurements using the sclerometer, development of algorithms for filtration of measurement results (measuring errors detection, selection of points from a cloud of points measured using the scanner for a representative sample corresponding to the evaluated surface) and selection of methods of calculations, numerical analyses and interpretation of results – preparation of preliminary evaluation of the structure, specification of places for detailed inspection (works at heights on water dam's sections performed by contracted workers trained to perform such tasks).

Simultaneous utilisation of tests using damaging and non-damaging methods (including laser scanning) will allow for an increase in the accuracy and reliability of the performed evaluations of the structure conditions. Proposed approach is the first example of such application used for monitoring high-volume concrete structure surfaces.

Using digital algorithms for registering and comparison of point clouds captured using laser scanning in order to assess concrete surface changes allows for more reliable evaluation of dam structure condition.

Studying this kind of data is an interdisciplinary problem and, in addition to intensity images analysis study, should also include geometrical analysis scans for the determination of concrete surface deformation. Such analysis can use accordingly modified algorithms used for surveys performed in different chapters, fields or areas. Development of complex algorithm for concrete structure surface assessment is the subject of research at the Faculty of Geodesy and Cartography of the Warsaw University of Technology.

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