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SUPERVISED CLASSIFICATION OF LASER SCANNING DATA IN THE ASSESSMENT OF TECHNICAL CONDITIONS OF MASONRY CONSTRUCTIONS

KLASYFIKACJA NADZOROWANA DANYCH SKANINGOWYCH W OCENIE STANU TECHNICZNEGO KONSTRUKCJI MUROWYCH

A b s t r a c t

In the paper is presented the application of supervised classification to determine the technical conditions of masonry structures. The supervised classification of the registered intensity of laser beam reflection and images from a digital camera are tested to detect dampness, salt stamps and vegetation cover on the surface of the retaining wall of levees. The analyses are referred to two clouds of points obtained with the use of two types of laser scanners which are using different wavelengths. In both cases, the intensity of reflections improved the results of supervised classification.

Keywords: monitoring of structure, laser scanning, laser reflection intensity, image processing, supervised classification

S t r e s z c z e n i e

W artykule przetestowano możliwości wykorzystania klasyfikacji nadzorowanej w ocenie stanu technicznego konstrukcji murowej. Przeprowadzono analizy wykorzystujące zdjęcia wykonywane przez skaner oraz rejestrowaną intensywność odbicia promienia laserowego do wykrywania zawilgoceń, wykwitów solnych oraz pokrycia roślinnego fragmentu muru oporowego wałów przeciwpowodziowych. Opracowywane chmury punktów pochodziły z dwóch typów skanerów laserowych pracujących na różnych długościach fali. W obydwu przypadkach wykorzystanie intensywności odbicia promienia laserowego w klasyfikacji nadzorowanej obrazów spowodowało nieznaczne polepszenie wykrywania ww. zjawisk na powierzchni muru.

Słowa kluczowe: monitoring konstrukcji, skaning laserowy, intensywność odbicia promienia laserowego, klasyfikacja nadzorowana obrazów

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1. Introduction

The evaluation of the technical condition of the constructions includes the recognition of damage in wastages as well as the changes of the constructional element's geometry. Moreover, unfavourable phenomena on the surface of the object such as dampness and the occurrence of vegetation cover and salt stains, which are evidence of lack of the construction's resistance to water, are being inventoried [1, 2].

The usefulness of laser scanning in terms of examining the geometry of building constructions is unquestionable and has been described thoroughly in literature [3, 4]. The evaluation of the remaining factors which influence the technical condition if building construction requires the individual approach. The traditional way of inventorying these phenomena is based on the visual and organoleptic evaluation of the surface's condition, supported by expert experience. The visual evaluation can be conducted on the basis of the pictures of the object taken with the use of the scanning device. The disadvantage of this solution lies in the influence of the disturbing factors like surface illumination or an unclean surface. In connection with this, the question emerges: if taking into consideration the additional information carried by the measured laser beam intensity of reflection would improve the quality of classifying these phenomena. In this paper, these data have been analyzed by means of using the supervised classification method. Researches embraced the fragment of the stone retaining wall of the Vistula boulevards in Krakow. The object of the analysis included clouds of points obtained with the use of two laser scanners, i.e. phase based FARO FOCUS^{3D} as well as pulse based TOPCON GTS 1500.

2. The application of the recorded intensity of laser beam reflection in the detection of unfavourable phenomena

The inventory of dampness, salt stains and vegetation cover on the surface of masonry structure is conducted in situ or on the basis of visual analysis of pictures of the object. This analysis can be automated by using the procedures of supervised classification applied in remote sensing.

The purpose of the research embraced comparing the results of classification of the fragment of the stone retaining wall of the Vistula boulevards in two cases. The analysis of the first case was based merely on three spectral bands (red, green and blue) derived from the photo taken with the scanner's in-built camera. In the second case, the set of bands was supplemented with the band of intensity of reflection.

The laser beam, which is incident on the surface of the object, undergoes scatter and absorption, which results in the fact that only part of the signal is recorded. The impact of various factors on the intensity of reflection have been examined by many authors [5–8]. What is essential in the proper classification of dampness, salt stains and vegetation cover is color, humidity and the structure of the object's surface. Disturbing factors include: distance, incidence angle of the beam on the surface and less significantly, surface illumination. In the conducted research, the impact of the latter was reduced by means of choosing the test field in a shaded place (homogeneous illumination) (Fig. 1) as well as applying the so-called normalized intensity in the calculation. This value is recorded in 8 bits [0–255] for each point of the cloud and it takes into account the influence of the distance on the object [5]. The influence of the incidence angle of the laser beam on the surface of the object can be eliminated only under laboratory conditions.

Fig. 1. Object of research

The separate issue is the wavelength of the scanners. The usage of the scanner with visible wavelengths (380–780 nm) seems to be ineffective in the classification when photos from the digital camera are used as well. Therefore, the information which carries the intensity of reflection is strongly correlated with the proper band from photo. In connection with that, the application of near infrared or mid infrared lasers (780–5000 nm) appears to be more beneficial. The important factor is the principle of operation of the scanner – phase based or pulse based. By taking this information into consideration, two scanners, FARO FOCUS^{3D} which uses the wavelength 785 nm and GTS 1500 TOPCON with laser working on the wavelength 1535 nm, were applied (Fig. 2).

Fig. 2. Scanner FARO FOCUS 3D and TOPCON GTS 1500

A wide spectrum of methods of classification could have been applied in the research, nevertheless, the pixel-based classification was used. This was due to the fact that it is impossible to define the shape of texture and the proximity of those phenomena initially, which information is taken into consideration in the object-oriented classification. The methods which apply hard classifiers were chosen from among the supervised classification methods due to the simplicity of the result's interpretation. From among three of them (*Pieped*, *Mindist, Maxlike*) the Maximum likelihood classification method (*Maxlike*) based on the Bayesian classifier produces the best results.

3. The results of the classification of images from the FARO scanner

The colors were put on the cloud of points obtained from the FARO scanner by means of using photos taken with the device's in-built camera. The obtained image was separated to create 3 byte binary images representing the bands: red, green, blue (R,G,B). Furthermore, the image of the intensity of the laser beam reflection was prepared (INT). The laser in FARO scanner works with the wavelength 785 nm, i.e. just beyond the red light border. Nevertheless, it transpires that the image of the intensity of reflection (INT) is considerably less correlated with the red band (R) than the green (G) and blue (B) bands. Coefficients of determination R^2 are as follows: 0.84, 0.97 and 0.93 (Fig. 3).

The coefficient of determination for multiple regression which describes the level of a linear relationship between the dependent value from the intensity (INT) band and the independent variables from the R,G,B bands is 0.93.

a)

b)

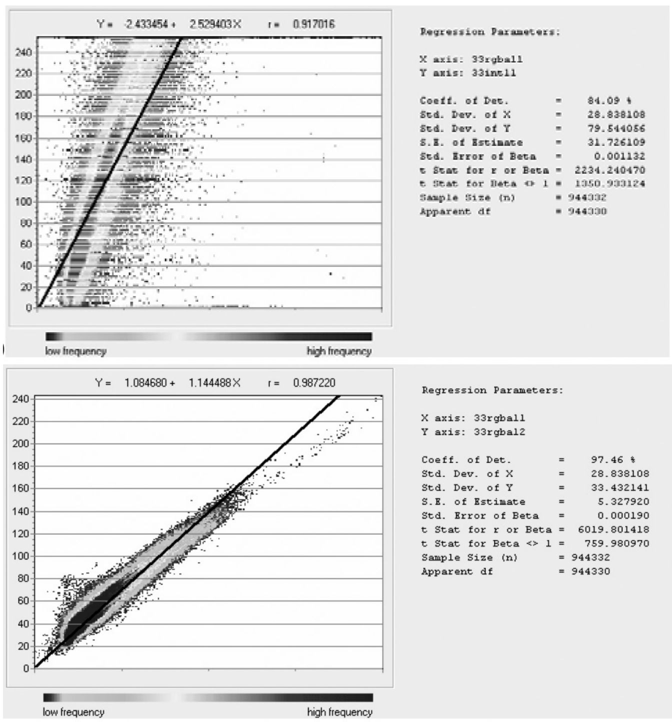

Fig. 3. The results of regression analysis between bands: a) red-intensity, b) red-green for FARO scanner

Three classes were defined for the purpose of the analysis:
- salt,
- dampness,
- vegetation cover.

The class which is defined as the fourth (norm) concerned the area in which any of the above mentioned phenomena occurred. Despite the fact that many attempts have been made to define the training polygons (Fig. 4), not all signatures of classes proved to be fully separable. Jeffreys-Matusita distance for pairwise of signatures oscillated between 0.56 and 1.95 (tab. 1, 2). The optimal value of J.M.-distance is 1.8–2.0 [9, 10]. This results from the poor quality of photos taken with the use of this scanner. Poor separability of signatures has a considerable impact on the final results of the classification.

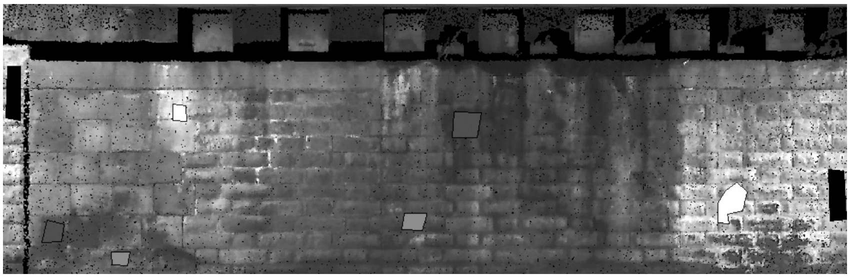

Fig. 4. Training polygons (white – salt, light grey – vegetation cover, dark grey – dampness, black-norm)

Table 1

J.M. distance for pairwise of signatures for 3 bands: R, G, B – scanner FARO

Classes	vegetation cover	salt	norm
Dampness	1.12	1.22	1.28
Vegetation cover		1.74	1.80
Salt			0.56
The average distance for pairwise of signatures 1.29			

Table 2

J.M distance for pairwise of signatures for 4 bands: R. G. B. INT – scanner FARO

Classes	vegetation cover	salt	norm
Dampness	1.23	1.81	1.53
Vegetation cover		1.92	1.95
Salt			0.58
The average distance for pairwise of signatures 1.51			

However, it should be emphasized that there was a considerable improvement in the signatures of separability for all pairs of classes after the band of the intensity of reflection was incorporated into the analysis. Therefore, making use of this band makes sense due to the fact that it carries additional information about the object.

The classification was conducted twice, by applying the Maximum likelihood classification method (maxlike) with the use of 3 bands R, G, B (Fig. 6) as well as, independently, the use of 4 bands R, G, B, INT (Fig. 7). In both cases, the occurrence of 5% of the unclassified pixels was allowed. In order to verify the obtained results, the unfavorable phenomena were inventoried manually, based on the high resolution photo from the digital camera – Nikon D5100 (Fig. 5). The impact of the incorporation of the band of intensity into the analysis is visible through the change in Cramer's V coefficient which illustrates the strong correlation between results of supervised classification and manual inventory, as well as the Kappa index of agreement, KIA, which determines the comparability of pictures [11, 12] (tab. 3).

Table 3

Coefficients: Cramer's V and Kappa index of agreement (KIA) between results of supervised classification and the manual inventory

Coefficient	Classification R, G, B,	Classification R, G, B, INT
Cramer's V	0.5098	0.5120
Overall Kappa	0.5130	0.5137
Kappa for Norm	0.6037	0.5349
Kappa for Salt	0.5729	0.5941
Kappa for Vegetation cover	0.2082	0.2415
Kappa for Dampness	0.6184	0.6995

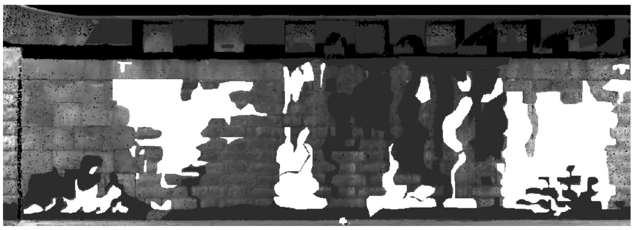

Fig. 5. Manual inventory (white – salt, light grey-vegetation cover, dark grey – dampness)

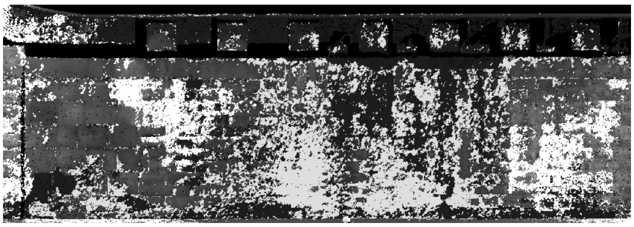

Fig. 6. The results of the supervised classification with the use of bands: R, G, B

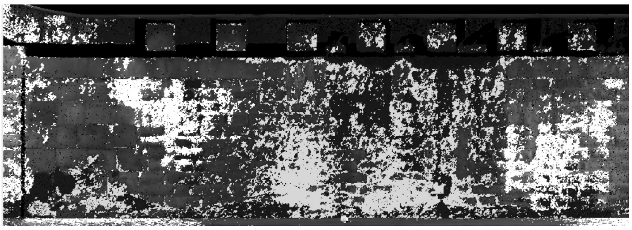

Fig. 7. The results of the supervised classification with the use of bands: R, G, B and INT

These coefficients indicate the moderate correlation and comparability of the results of the analyses with the manual inventory. The introduction of the band of intensity resulted in a slight increase of both coefficients. Moreover, there was an improvement in the coefficients of agreement for classes which related to the occurrence of unfavourable phenomena.

4. The results of the classification of images from the Topcon scanner

The algorithm of proceedings which was presented in the previous chapter was repeated for the cloud of points obtained with the use of the scanner TOPCON GLS 1500. According to the expectations, the coefficient of correlation of the band of intensity (INT) with relation to the red (R) band is lower than it was in the case of FARO scanner and is 0.73 (Fig. 8a). The

a)

a)

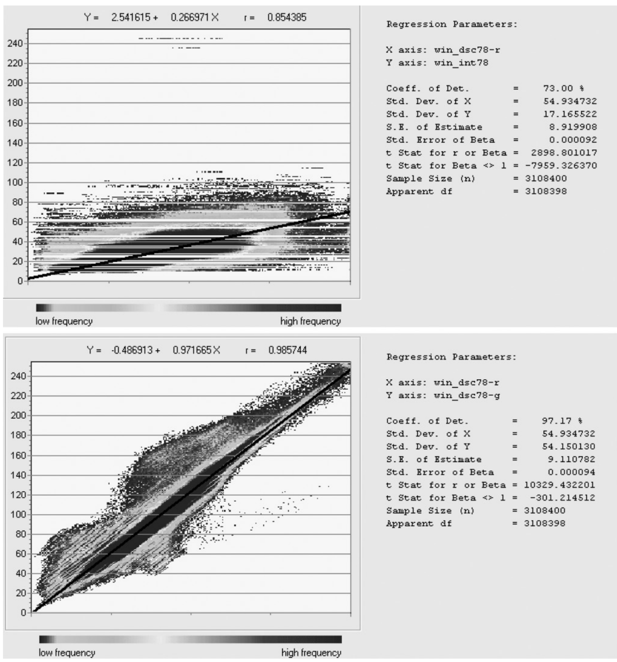

Fig. 8. The results of regression analysis between bands: a) red-intensity b) red – green for TOPCON scanner

relationship between the green and blue bands and the red band remains on the same level, which is as follows: 0.97 (Fig. 8b) and 0.93. Nevertheless, it has to be emphasized that those measurements were taken at a different time and in different weather conditions.

The coefficient of determination for the multiple regression between the dependent value from intensity (INT) band and the independent variables from the R,G,B bands is 0.83.

The JM-distance for the pairwise of signatures was also determined for bands R, G, B and R, G, B, INT (tab. 4, 5).

Table 4

J.M. distance for pairwise of signatures for 3 bands: R, G, B – scanner TOPCON

Classes	Vegetation cover	Salt	Norm
Dampness	1.56	1.98	1.81
Vegetation cover		1.99	1.82
Salt			0.46
The average distance for pairwise of signatures 1.60			

Table 5

J.M. distance for pairwise of signatures for 4 bands: R, G, B, INT – scanner TOPCON

Classes	Vegetation cover	Salt	Norm
Dampness	1.57	1.98	1.83
Vegetation cover		1.99	1.85
Salt			0.7
The average distance for pairwise of signatures 1.65			

It should be noted that as a result of better illumination, a different camera and, simultaneously, better contrast of the photos, the JM-distance for pairwise of signatures for all classes has been improved significantly with regard to the FARO scanner. The fact that the spectral set was supplemented with intensity could not cause any significant improvement in very good coefficients. The exception is the pair of classes *Salt-Norm*, the coefficient of which increased from 0.46 to 0.7.

The results of the supervised classification for bands R, G, B (Fig. 10) and R, G, B, INT (Fig. 11) have been compared with a previously conducted manual inventory (Fig. 9). The introduction of the additional band of intensity to the analysis has not significantly changed the Cramer's V and KIA coefficients for the whole image. Nevertheless, there has been a slight improvement in coefficients KIA for individual classes which concerned the unfavourable phenomena (tab. 6).

Table 6

Coefficients: Cramer's V and Kappa index of agreement (KIA) between results of supervised classification and the manual inventory

Coefficient	Classification R, G, B,	Classification R, G, B, INT
Cramer's V	0.5520	0.5582
Overall Kappa	0.5726	0.5869
Kappa for Norm	0.5937	0.5667
Kappa for Salt	0.3586	0.3773
Kappa for Vegetation cover	0.4170	0.4206
Kappa for Dampness	0.7063	0.7362

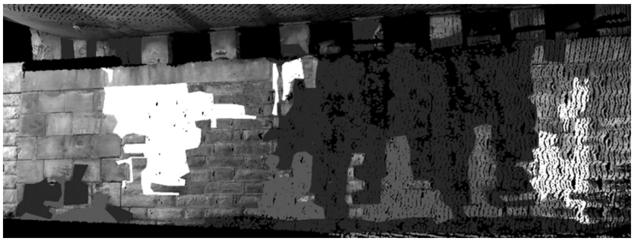

Fig. 9. Manual inventory (white – salt, light grey – vegetation cover, dark grey – dampness)

Fig. 10. The results of the supervised classification with the use of bands: R, G, B.

Fig. 11. The results of the supervised classification with the use of bands: R, G, B and INT

5. Conclusions

On the basis of the previously conducted research, it is possible to formulate the following conclusions:

- All unfavourable phenomena, for instance, salt, vegetation cover as well as dampness, which occur on the surface of the object, can be inventoried by means of using data from the scanner and the supervised classification method. However, in case of masonry structure, its results indicate a moderate correspondence with a reality.
- The results of the classification are highly dependent on the quality of the photos taken with the use of the device's in-built camera.
- The introduction of the intensity of the laser beam reflection as an additional band expands the separability of the pairs of classes in the supervised classification. Nevertheless, it does not improve the results of this classification considerably. This results from the influence of the disturbing factors, like an unclean surface of the object, incidence angle of the beam on the surface and surface illumination. These factors cannot be eliminated in field research.
- The intensity of reflection carries additional information about the object. However, it is not correlated with the bands R, G, B from the photos. It suggests a need for research on algorithms dedicated to this type of data.

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