Application of TLS Intensity Data for Detection of Brick Walls Defects

Czeslaw Suchocki 1, Jacek Katzer 2, Carles Serrat 3, Marcin Jagoda4
1,2,4 Koszalin University of Technology, Faculty of Civil Engineering Environmental and Geodetic Sciences, Śniadeckich 2, 75-453 Koszalin, Poland
3 Universitat Politècnica de Catalunya-Barcelona TECH, Department of Mathematics, IEMAE-EPSEB, Barcelona 08028, Spain
czeslaw.suchocki@tu.koszalin.pl

Abstract. Terrestrial Laser Scanning (TLS) is a well-established technique for remote acquisition of geometrical data of a tested object. For the past two decades it has been commonly used in geodesy, surveying and related areas for acquiring data about spacing of civil engineering structures and buildings. An average TLS apparatus, apart from 3D coordinates registers radiometric information of laser beam reflectance. This radiometric information of the laser beam reflectance is usually called intensity and has no meaning for solely geometric measurements. Nevertheless, the value of intensity depends mainly on physicochemical properties of scanned material such as roughness, colour and saturation. Keeping these facts in mind, authors suggest using changes in value of intensity to locate various imperfections on a brick wall. So far, authors have conducted a thorough and successful research programme dedicated to detection of saturation and saturation movement in brick walls. Based on this experience a new research programme was conducted focused on various aspects of detection of brick wall defects. The main aim of the paper is to present the possibility of using the intensity value in for the diagnostics of the technical condition of a brick walls. Advantages and limitations of harnessing TLS for detection of surface defects of brick walls are presented and discussed in the paper.

1. Introduction
In order to evaluate the building or structure safety, the Terrestrial Laser Scanning diagnostic measurement is one of the most important and modern methods. The TLS surveys of building and structures enable remote and rapid acquisition of large dataset, simultaneously reduce the costs and the risks associated with field work. The TLS technology were used in various field of civil and structural engineering such as: structure deformations [1][2], landslides monitoring [3][4], deformation measurement of tunnels [5][6], diagnostic measurements of bridges [7][8] etc.

TLS, apparatus, apart from spatial coordinates (x,y,z), also provides information about the intensity of a laser beam reflected from an observed object. One of the factors that mainly affects the value of the intensity is the physicochemical characteristic of the scanned material. Such properties as roughness, colour and saturation are the most interesting. Currently, in the diagnostic tests of buildings conducted with TLS, the value of intensity is increasingly used as a key measurement result. This study presents an approach based on using the intensity as an additional element of information in diagnostics of technical state of structures and buildings.
2. Radiometric information of laser beam provided by TLS

*Intensity* is defined as amount of energy of a laser beam reflected by an object and recorded as a value of reflectance by a TLS receiver [9]. The mathematical relationship between the transmitted ($P_T$) and received ($P_R$) signal power in TLS is represented by a simplified version of laser equation [10].

$$P_R = \frac{\pi P_T \rho \cos \alpha}{4R^2} \eta_{Atm} \eta_{Sys}$$

(1)

The power of a received signal depends on multiple factors (see eq. 1). The power of backscattered light from the scanned objects mainly depends on the transmitted signal power, the system transmission factor ($\eta_{Sys}$), the atmospheric transmission factor ($\eta_{Atm}$), the distance ($R$), the incident angle effect ($\alpha$) and the reflectance of a material ($\rho$). The parameters $P_T$ and $\eta_{Sys}$ can be considered constant. They depend on the scanner technical specifications e.g.: type and power of a rangefinder (phase-shift based or time-of-flight technology), wavelength of a laser, aperture diameter of TLS, sensitivity of a detector etc. The atmospheric effect is negligible. It can be ignored because it does not change during the short measurement time [11][12]. Distance and incident angle influence on the TLS intensity dataset can be eliminated as well. The reduction of the distance and incident angle effects on the intensity values is well described by several researchers [13][14][15]. The last factor which affects the received signal power is reflectance of a material scanned surface. The reflectance of a material depends on physical characteristics of scanned objects. The most important are roughness, colour, and humidity of the scanned surface [16][17][18]. Thus, Equation (1) can be simplified further [19]:

$$Intensity = \rho_1 \cdot C_1 \cdot C_2$$

(2)

where:

- $\rho_1$ – reflectance of a material
- $C_1 = \pi P_T \eta_{Atm} \eta_{Sys}$ – unknown but constant parameter for a specific scanner
- $C_2 = \frac{\cos \alpha}{4R^2}$ – changeable parameter which can be eliminated

Any change of the above-mentioned factors can cause variations of the intensity value during TLS measurement. In the case of disturbance of the homogeneous surface of buildings or structures, which are caused by cavities and cracks, the power of the laser beam reflectance should be significantly changed due to the changes in roughness and colour of the surface. The change of reflectance of a laser beam in wall cavities can also be caused by the change of the incidence angle of laser beam in relation to the undamaged area [20][21]. It should be noted that in cracks of the wall the decrease in the intensity value can be caused by the so-called edge effects [22][23]. Thus, cavities, cracks and moisture of a building wall can be detected by an appropriate interpretation of the intensity value.

3. Materials and conducted studies

3.1. Used equipment and research objects

The research programme was carried out in both laboratory and field conditions. In the laboratory, the measurements were carried out on two specially prepared specimens. The first specimen was made of traditional red ceramic bricks and cement mortar. The second specimen was made of silicate white bricks and cement mortar (see Fig. 1). Before the tests, the specimens were intentionally damaged in multiple places to simulate real old brick walls. The specimens were remotely scanned by a TLS Leica ScanStation C10 from the distance of 10m. The Leica ScanStation C10 scanner uses time-of-flight principles of distance measurement. This scanner is characterized by high scan speed of approximately 50,000 pts/sec and the maximum range of 300m @ 90%. Laser wavelength is equal to 532 nm (visible green).
In the field conditions, the measurements were carried out on a 19th century brickwork (citadel located on the Kościuszko Mountain in Cracow, Poland). The brick wall in question was chosen for tests due to its poor technical condition (see Fig. 2). The brickwork was renovated multiple times in the past and currently consists of different types of ceramic bricks in varied technical state. For the second phase of the research a time-of-flight TLS Riegl VZ-400i was used. A narrow infrared laser was used in the Riegl VZ-400i scanner. The maximum measurement range and maximum measurement rate of this TLS depends on used laser pulse repetition e.g. 100 KHz (800 m, 42,000 pts/sec), 1200 KHz (250 m, 500,000 pts/sec) respectively.
3.2. Post-processing of data
The CloudCompare software was used for the processing of the datasets. Two AA profiles were made for the ceramic brick wall specimen in order to carefully analyse the cavities in the context of changing the intensity value. The profiles present a strip of 0.01m width. The first profile shows the distribution of points in the OXZ coordinate system (see Fig. 3c). The second profile shows the distribution of points in the OXI coordinate system (where I - intensity value of each points), see Fig. 3d.

![Profiles of the ceramic brick wall specimen](image)

**Figure 3. Profiles of the ceramic brick wall specimen**

The analysis of a profile the ceramic brick wall specimen is graphically represented in Figure 3c. One can locate defects in the wall in relation to the assumed reference plane. The analysis of Figure 3d profile allows to track changes in the intensity value in the research area. One can easily notice that there is a change in the intensity value of the laser beam reflectance at the places of defects and in areas of material change (cement mortar in comparison to the brick). In areas of defects, the intensity value slightly decreases in comparison to the areas without defects. The intensity value increases on the cement mortar surface in relation to the ceramic brick surface. Thus the proper analysis of intensity value of point clouds may be useful information for detecting cavities in the ceramic brick wall. In addition, the intensity value can be used for segmentation of dataset e.g. separation of points on a cement mortar.

The analyses of datasets from the TLS measurement of the silicate white brick wall specimen were carried out in the same way as for the ceramic brick wall specimen. Fig. 4 presents profiles made on the basis of the silicate brick wall specimen.

As in the previous example, the intensity value also changes in the places of defects and in areas of material change (cement mortar in comparison to the brick).

The next phase of the research was a visual analysis of the intensity value distribution on the real object: 19th century brickwork. Cavities in the wall were presented in Fig. 5. These cavities were numbered (1-3) in RGB photo and intensity image created by TLS. In Fig. 6 the reconstructed part of brick wall was presented.
Figure 4. Profile of the silicate brick wall specimen

Figure 5. Presentation of cavities in the RGB picture and on the point cloud

Figure 6. Presentation of reconstructed part of brick wall
Such analysis is very useful for localization of areas of walls in need of urgent repair and areas renovated using different type of bricks. In Fig. 5 areas with missing bricks and missing mortar were clearly located. In case of the wall presented in Fig. 6 old ceramic brickwork was repaired using modern bricks. The area covered by modern bricks was clearly located. Using modern bricks for restoration of old brickwork is a very serious technical mistake. Both types of bricks are characterized by a very different mechanical properties [24][25]. Modern bricks are characterized by significantly higher compressive strength and modulus of elasticity than the old bricks. Modern bricks are basically “incompatible” with old brickwork and will cause its quick degradation.

4. Results and discussions
The carried out tests reveal that wherever there are cavities in bricks the intensity value of the laser beam changes. The decrease or increase of the power of laser beam reflectance in the area where the brick is damaged is mainly caused by a change in roughness and colour. Ceramic bricks are usually characterized by significant local discoloration, causing difficulties in the interpretation of cavities. In silicate bricks it is not the case.

5. Conclusions
The performed research shows that the analysis of intensity value of point clouds may be successfully used as additional information for detecting brick wall cavities. Moreover, the proper intensity analysis allows the localization of a part of a brick wall with different physicochemical properties e.g. a wall after reconstruction.

Funding: The measurement with the Riegl VZ-400i scanner was funded by Miniatura 1, grant number DEC-2017/01/X/ST10/01910.

References
[1] G. Vosselman, B.G.H. Gorte, G. Sithole, and T. Rabbani, “Recognising structure in laser scanner point clouds,” In: ISPRS 2004 : proceedings of the ISPRS working group VIII/2 : laser scanning for forest and landscape assessment, Freiburg. pp. 33–38 (2004).
[2] C. Suchocki, M. Damięcka, and M. Jagoda, “Determination of the building wall deviations from the vertical plane,” In: 7th International Conference on Environmental Engineering, ICEE 2008 - Conference Proceedings. pp. 1488–1492 (2008).
[3] J. Kasperski, C. Delacourt, P. Allemand, P. Potherat, M. Jaud, and E. Varrel, “Application of a Terrestrial Laser Scanner (TLS) to the study of the Séchilienne landslide (Isère, France),” Remote Sensing. vol. 2, no. 12, pp. 2785–2802, 2010.
[4] C. Suchocki, “Application of terrestrial laser scanner in cliff shores monitoring,” Rocznik Ochrona Srodowiska. vol. 11, pp. 715–725, 2009.
[5] R. Argüelles-Fraga, C. Ordóñez, S. García-Cortés, and J. Rocas-Pardiñas, “Measurement planning for circular cross-section tunnels using terrestrial laser scanning,” Automation in Construction. vol. 31, pp. 1–9, 2013.
[6] Z. Kang, L. Tuo, and S. Zlatanova, “Continuously deformation monitoring of subway tunnel based on terrestrial point clouds,” In: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. pp. 199–203 (2012).
[7] D. Qiu and Y. Ding, “Deformation Monitoring of Bridge Approach Using Terrestrial Laser Scanning.” In: FIG Congress 2010. pp. 1–7 (2010).
[8] B. Riveiro, H. González-Jorge, M. Varela, and D. V. Jauregui, “Validation of terrestrial laser scanning and photogrammetry techniques for the measurement of vertical underclearance and beam geometry in structural inspection of bridges,” Measurement: Journal of the International Measurement Confederation. vol. 46, no. 1, pp. 784–794, 2013.
[9] M. Balaguer-Puig, A. Molada-Tebar, A. Marqués-Mateu, and J.L. Lerma, “Characterisation of intensity values on terrestrial laser scanning for recording enhancement,” ISPRS -
International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. vol. XLII-2/W5, pp. 49–55, 2017.

[10] A. Jelalian, Laser Radar Systems. Artech Print on Demand, 1992.

[11] T. Xu, L. Xu, B. Yang, X. Li, and J. Yao, “Terrestrial laser scanning intensity correction by piecewise fitting and overlap-driven adjustment,” Remote Sensing. vol. 9, no. 11, pp. 1–16, 2017.

[12] T. Xu, L. Xu, X. Li, and J. Yao, “Detection of Water Leakage in Underground Tunnels Using Corrected Intensity Data and 3D Point Cloud of Terrestrial Laser Scanning,” IEEE Access. vol. XX, pp. 1–9, 2018.

[13] K. Tan and X. Cheng, “Correction of incidence angle and distance effects on TLS intensity data based on reference targets,” Remote Sensing. vol. 8, no. 3, pp. 1–20, 2016.

[14] S. Kaasalainen, A. Jaakkola, M. Kaasalainen, A. Krooks, and A. Kukko, “Analysis of incidence angle and distance effects on terrestrial laser scanner intensity: Search for correction methods,” Remote Sensing. vol. 3, no. 10, pp. 2207–2221, 2011.

[15] W. Fang, X. Huang, F. Zhang, and D. Li, “Intensity correction of terrestrial laser scanning data by estimating laser transmission function,” IEEE Transactions on Geoscience and Remote Sensing. vol. 53, no. 2, pp. 942–951, 2015.

[16] M. Oren and S.K. Nayar, “Generalization of Lambert’s reflectance model.” In: Proceedings of the 21st annual conference on Computer graphics and interactive techniques - SIGGRAPH ’94. pp. 239–246 (1994).

[17] T. Voegtle, I. Schwab, and T. Landes, “Influences of different materials on the measurements of a terrestrial laser scanner (TLS),” In: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. pp. 1061–1066 (2008).

[18] C. Suchocki and J. Katzer, “Terrestrial laser scanning harnessed for moisture detection in building materials – Problems and limitations,” Automation in Construction. vol. 94, pp. 127–134, 2018.

[19] C. Suchocki, J. Katzer, and A. Panuš, “Remote Sensing to Estimate Saturation Differences of Chosen Building Materials Using Terrestrial Laser Scanner,” Reports on Geodesy and Geoinformatics. vol. 103, no. 1, pp. 94–105, 2017.

[20] J. Armesto-González, B. Riveiro-Rodríguez, D. González-Aguilera, and M.T. Rivas-Brea, “Terrestrial laser scanning intensity data applied to damage detection for historical buildings,” Journal of Archaeological Science. vol. 37, no. 12, pp. 3037–3047, 2010.

[21] C. Suchocki, M. Jagoda, R. Obuchovski, D. Sliškas, and J. Sužiedelytė-Visockienė, “The properties of terrestrial laser system intensity in measurements of technical conditions of architectural structures,” Metrology and Measurement Systems. vol. 25 (2018), no. 4, pp. 779–792, 2018.

[22] C. Suchocki and J. Katzer, “TLS technology in brick walls inspection,” In: 2018 Baltic Geodetic Congress (BGC Geomatics). pp. 359–363. IEEE, Olsztyn (2018).

[23] W. Boehler and A. Marbs, “Investigating Laser Scanner Accuracy,” The International Archives of Photogrammetry Remote Sensing and Spatial Information Sciences. vol. 34, pp. 696–701, 2003.

[24] J. Katzer and J. Kobaka, “Assessing the Strength of Gothic Brickwork,” Restoration of Buildings and Monuments. vol. 13, no. 4, pp. 256–276, 2007.

[25] K. J and M. G, “Water Induced Corrosion of Silica Lime Brick Masonry,” Restoration of Buildings and Monuments. vol. 13, no. 2, pp. 109–116, 2007.