IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: Czesaw Suchocki *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **603** 022100

IOP Conf. Series: Materials Science and Engineering **603** (2019) 022100 doi:10.1088/1757-899X/603/2/022100

Application of TLS Intensity Data for Detection of Brick Walls Defects

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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].

$$P_R = \frac{\pi P_T \rho \cos \boldsymbol{\alpha}}{4R^2} \eta_{Atm} \eta_{Sys} \tag{1}$$

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 (η_{Sys}), the atmospheric transmission factor (η_{Atm}), the distance (R), the incident angle effect (α) and the reflectance of a material (ρ). The parameters P_T and η_{Sys} can be considered constant. They depend on the a 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]:

$$Intensity = \rho_1 \cdot C_1 \cdot C_2, \tag{2}$$

where:

ρ_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).

IOP Conf. Series: Materials Science and Engineering **603** (2019) 022100 doi:10.1088/1757-899X/603/2/022100

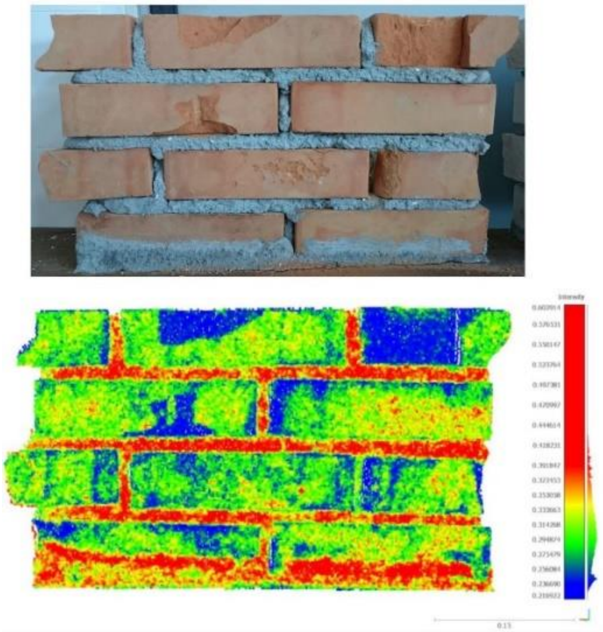

Figure 1. Real photo and point clouds of the tested specimens

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.

Figure 2. Tested historic brickwork (left) and point clouds of this wall

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.

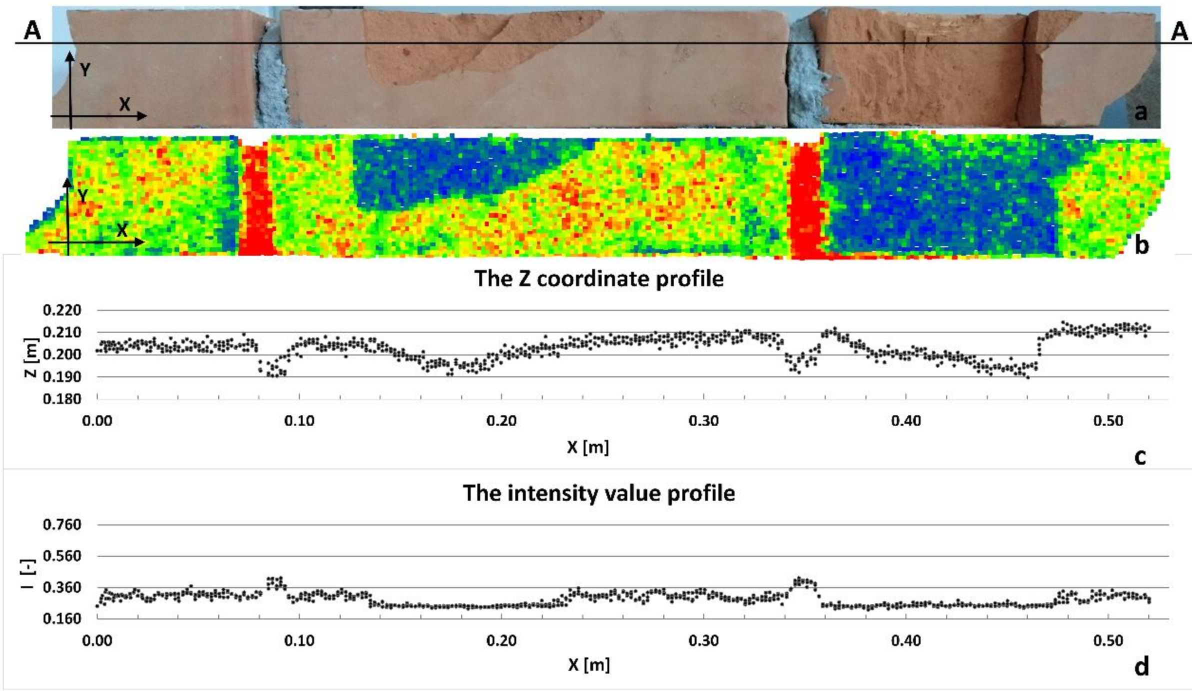

Figure 3. Profiles of the ceramic brick wall specimen

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: 19^{th} 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.

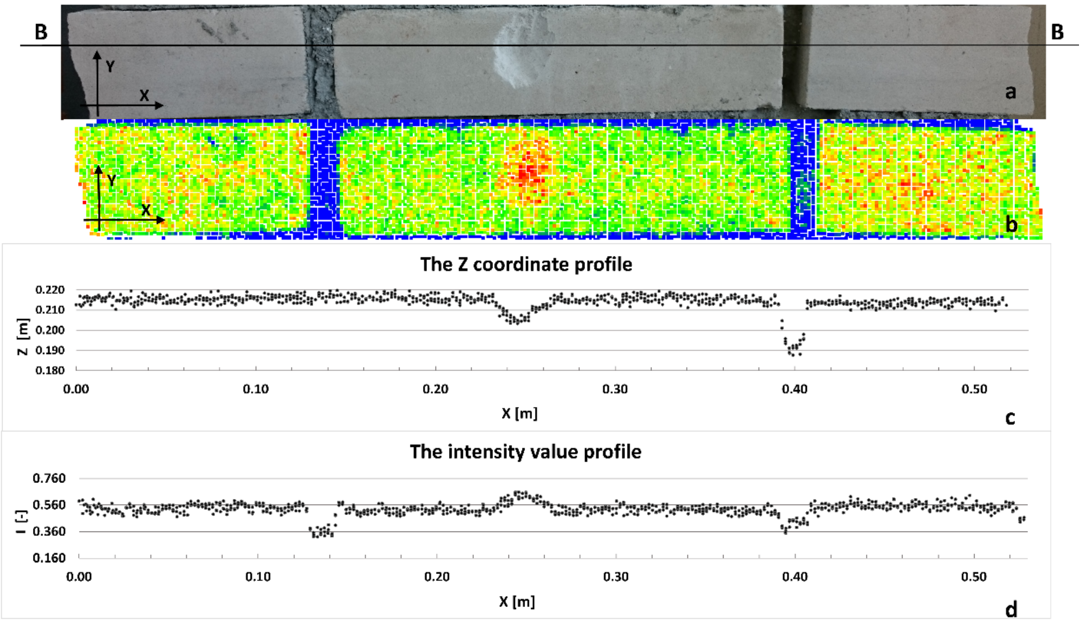

Figure 4. Profile of the silicate brick wall specimen

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.

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