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POSSIBILITIES AND LIMITATIONS OF TERRESTRIAL LASER SCANNING FOR CRACK DETECTION IN BUILDING WALLS

Paulina STAŁOWSKA*

Doctoral School of the Koszalin University of Technology, Śniadeckich 2, 75-453 Koszalin, Poland

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Abstract. The inspection of the technical condition of buildings is a highly significant part of the construction field. In particular, symptoms such as cracks are indicators of poor technical conditions of buildings. Currently, technologies that enable remote and non-destructive detection of defects are in great demand. One of these technologies is the Terrestrial laser scanning (TLS) – method very popular in recent years and widely applied in civil engineering. Therefore, surveys have been carried out that have identified the possibilities and limitations of TLS technology for detecting cracks in the walls of buildings. All analyses and discussions were carried out using geometric and radiometric point cloud information.

Keywords: terrestrial laser scanning, diagnostic measurements, crack detection, intensity parameter, measurement conditions.

Introduction

Terrestrial laser scanning is a remote sensing technology that generates precise 2D or 3D digital models of scanned objects (Pesci et al., 2011). The product of TLS measurement is a set of data (referred to as a point cloud), involving the geometric information for each scanned point (X, Y, Z coordinates) and radiometric information on the laser beam reflected from the scanned surface (so-called intensity parameter). TLS technology is a method that has become very popular in recent years and widely applied in civil engineering, especially used as an alternative to photogrammetry techniques (Remondino, 2011). High accuracy, rapidity, and large datasets are the major strengths of that technology.

The deteriorating condition of building walls is an extremely important issue in the construction field. In parallel, unfortunately, it is a fairly common problem. One of the most relevant indicators of a building's poor condition is a crack in the surface of its walls. In some cases, cracks are just a visual matter. However, in other cases, wall cracks can cause serious consequences for the construction. Frequently (e.g., for historic buildings), a periodic survey of the condition of the building is required. Such surveys are intended to detect newly formed cracks or to control cracks already existing because it is crucial to determine whether cracks widen over time and to what extent.

In diagnostic measurements of buildings and structures (the assessment of the technical condition), various measurement techniques can be used. However, it is oftentimes that the researcher faces some obstacles, such as the lack of direct access to the examined object (crack). Then, applying well known methods, such as the ultrasonic pulse velocity test and rebound hammer test, is hugely complicated or even completely impossible. In such cases, remote measurement techniques have to be used. At present, non-destructive technologies are in high demand.

Many studies have established the possibility of crack detection using various remote measurement techniques, including TLS technology. The photogrammetric method of crack detection in concrete structures was presented by Sohn et al. (2005) and Nishiyama et al. (2015). Zhang et al. (2020) used infrared images to detect cracks in a building after an earthquake. Another researcher, Sirca & Adeli (2018) applied infrared thermography for detecting defects in concrete structures. In many studies (Valença et al., 2017; Turkan et al., 2016; Turkan et al., 2018; Truong-Hong et al., 2016), the researchers surveyed the application of TLS technology in the assessment of the technical condition of bridges, especially in crack detection. Other studies (Cho et al., 2018; Laefer et al., 2014; Zhou & Song, 2020; Suchocki et al., 2018; Suchocki, 2020) indicated

* Corresponding author. E-mail: *paulina.stalowska@s.tu.koszalin.pl*

that TLS technology may be effectively used to detect cracks in building walls, especially with the support of other methods. For example, Suchocki et al. (2018) proved that information on intensity values can effectively assist the MSE method in detecting damages, such as cracks and cavities, in building walls.

Nevertheless, TLS technology like any other method has its advantages, and limitations. Taking into account that the shortcomings and limitations of the TLS method in the context of detecting cracks in building walls have not been adequately addressed, and considering the prevalence of wall cracks and acuteness as their consequence, the authors decided to expand the knowledge on this subject matter.

1. Primary research

In the author's opinion, adopting the proper measurement methodology to a particular task is crucial for maximizing measurement efficiency and precision. Hence, in detecting cracks using TLS technology, the knowledge on the potential and limitations of measurement scheme and the scanner model used is key for planning the measurement. In particular, considering the amount of factors that can affect the quality of the obtained point cloud. Primarily, the technical parameters of the scanner, such as the size of the laser spot and the divergence of the laser beam, have a significant impact on the quality of the point cloud and the effective detection of cracks. Moreover, many physicochemical characteristics of the scanned surface affect the absorption and dispersion of laser beams. These are primarily color, roughness, and moisture (Suchocki et al., 2020; Balaguer-Puig et al., 2017; Reshetyuk, 2006; Pesci & Teza, 2008).

In respect of the above, the author along with co-authors, developed a TLS measurement methodology for detecting building wall cracks considering the technical parameters of the scanner and the 'geometric' conditions of the measurement (Stałowska et al., 2022). The researchers examined the dependence of the capability to measure cracks on two basic and most significant measurement 'geometric' parameters: the distance and the angle of incidence. The conducted research is part of the author's dissertation research program and has been published in the "Automation in Construction" journal (Stałowska et al., 2022).

The primary studies consisted of two stages. The first stage – tests under laboratory conditions on a special specimen – was crucial to the entire study. Owing to this stage of the investigation, the authors developed a measurement methodology for testing cracks using TLS technology, and determined what measurement conditions (i.e., maximum distance and maximum angle of incidence of the laser beam) must be met in order to successfully detect a crack of a particular width. Cracks having widths from 1 mm to 10 mm were studied. So far, the intensity parameter has been considered mainly as a parameter for the visualization of the point cloud and has been used for analysis in only a few studies. The authors used both geometric and radiometric point cloud information for all analyses and discussions, which was an innovation in relation to the state-of-the-art.

The second stage – measurements under field conditions – allowed to verify the developed measurement methodology and to confirm its correctness. Several buildings with cracks of different widths were scanned. The measurements were performed under conditions as similar as possible to those tested in the laboratory. Based on the measurement methodology and profiles developed in the first stage (see primary studies Stałowska et al., 2022), the obtained point cloud was analyzed, and the conclusion was drawn as to what width the crack was. Then, the actual width of the crack was verified in the field.

The analyses of many cracks led to the conclusion that the developed measurement methodology is correct. An example is shown below. The obtained point cloud (Figure 1a), profiles created for analysis based on which crack width was defined (Figure 1b), and verification was made of the actual crack width (Figure 1c). Based on the analyses, the crack was identified as 5–7 millimeters in width. Measurement of the actual width of the crack confirmed the analyses.

The conducted investigations have led to many discussions and considerations. A lot of them have been included in (Stałowska, 2022). However, the author deemed it necessary to carry out an additional complementary study.

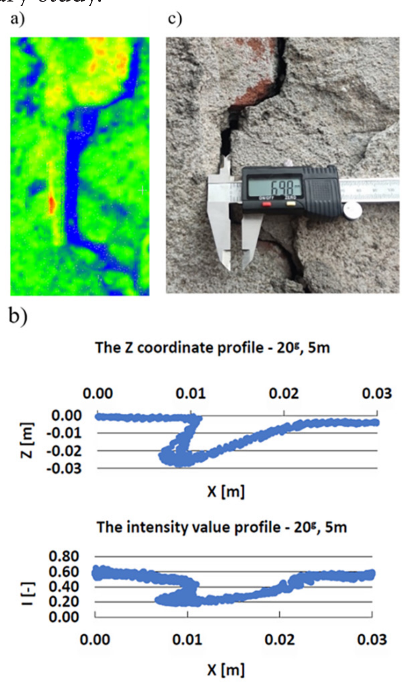

Figure 1. An example of the measurement and postprocessing in the second stage: a) obtained point cloud; b) profiles created for analysis; c) verification of the actual crack width

2. Complementary surveys and considerations

The results that were obtained in the primary studies, led the author to expand the research. In the primary studies, it turned out that on the basis of the radiometric information of the point cloud (intensity parameter), a crack with a width of even one millimeter can be detected effectively. The limitations are a relatively small distance from the scanned object (i.e., a maximum of about 10 m), and the smallest possible angle of incidence of the laser beam (i.e., a maximum of about 20 g). Since the results were satisfactory, the question arises: will it be possible to detect a scratch based on the intensity parameter under similarly favorable measurement conditions? By a scratch, the researcher means a crack the width of less than 1 mm.

Taking into account the appropriate measurement conditions, the author examined two defects. A scratch and a filled scratch. In the case of the filled scratch, it was barely visible at a distance of about 5 m with the naked eye. The obtained results are presented below (scratch – Figure 2, repaired scratch – Figure 3).

The obtained results were very satisfactory. Particularly astounding were the results obtained of a filled scratch. It turned out that the radiometric point cloud information can be useful for the detection of scratches. However, it is necessary to keep in mind the limitations regarding the measurement conditions. Based on the intensity parameter it is possible to determine whether a scratch occurred or not, but reliable determination of such small width is very complicated.

Another supplementary test verified the effect of the angle of incidence of the laser beam in the vertical axis on the efficiency of crack detection. This is directly related to the distance between the scanner and the scanned object. As the distance decreases, the angle of incidence of the laser beam increases, thereby causing greater blurring of the laser spot and degradation of the quality of the obtained point cloud. These tests take particular significance in situations where the measurement (due to area conditions) must be carried out at a short distance, and the crack is at a great height (e.g., interior measurements of small spaces, walls in close proximity).

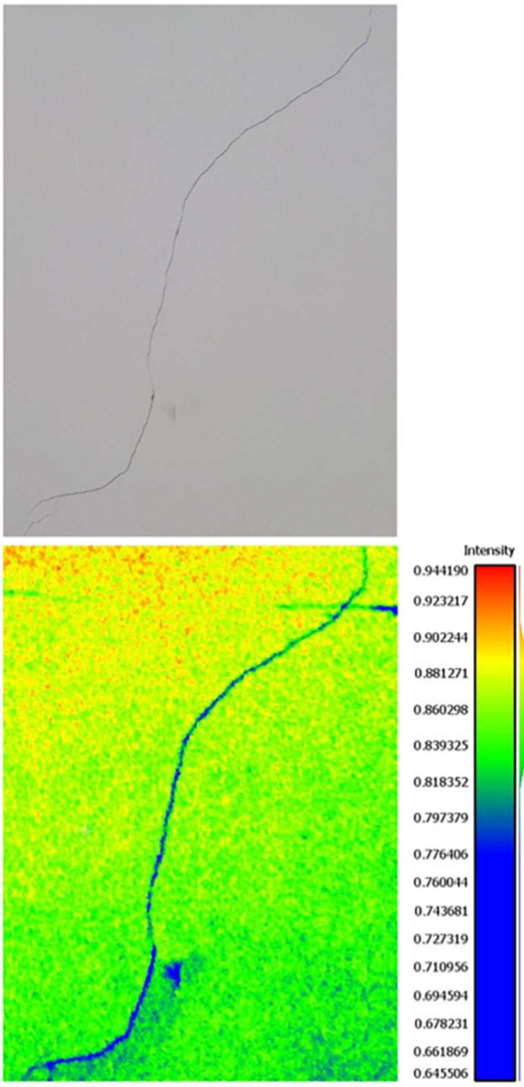

Figure 2. Analyzed scratch: photograph and obtained point cloud

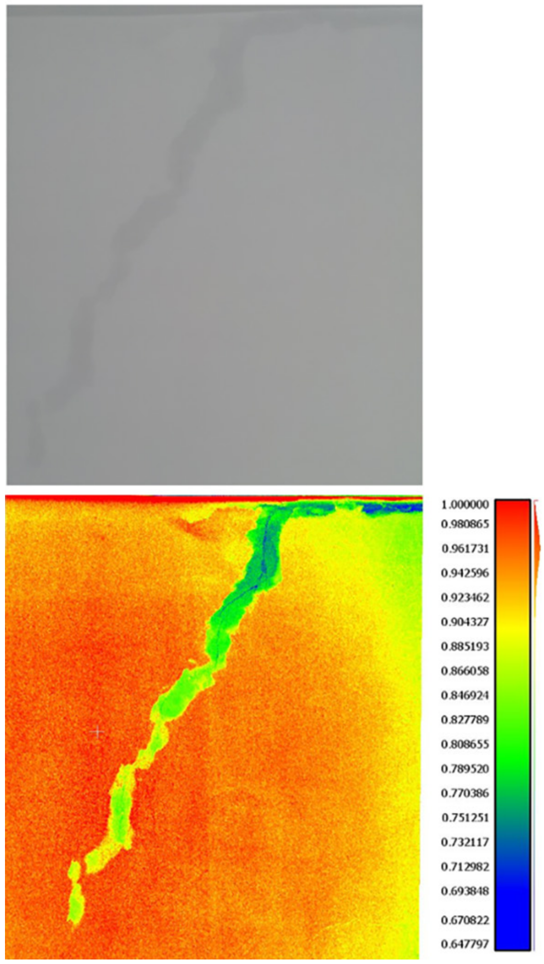

Figure 3. Analyzed filled scratch: photograph and obtained point cloud

The same crack was scanned under two different measurement conditions, with the same angle of incidence of the laser beam in the horizontal axis. Thus, the measurement conditions were as follows: measurement No. 1 – a distance of about 5 m and a large angle of incidence of the laser beam in the vertical axis; measurement No. 2 – a distance of about 15 m and a much smaller angle of incidence of the laser beam in the vertical axis.

Therefore, the question arises: deterioration of which measurement condition- distance or angle of incidence – will more adversely affect the quality of the data obtained and the possibility of detecting a crack? In this study, the crack about 4 mm wide was analyzed, and the analyses covered both geometric and radiometric point cloud information.

On the basis of the obtained point clouds, the profiles were prepared for both measurement conditions, as shown below in Figure 4.

As can be observed on the profiles in Figure 4, the detection of the crack at close distance was possible using both the geometric point cloud information and the intensity parameter, despite the great angle of incidence in the vertical axis. In contrast, for the measurements at a greater distance, despite a much smaller angle of incidence in the vertical axis, none of the information was sufficiently accurate. Consequently, based on the conducted surveys and the created profiles, it can be concluded that increasing the distance has a more negative impact on the ability to detect a crack than increasing the angle of incidence in the vertical axis.

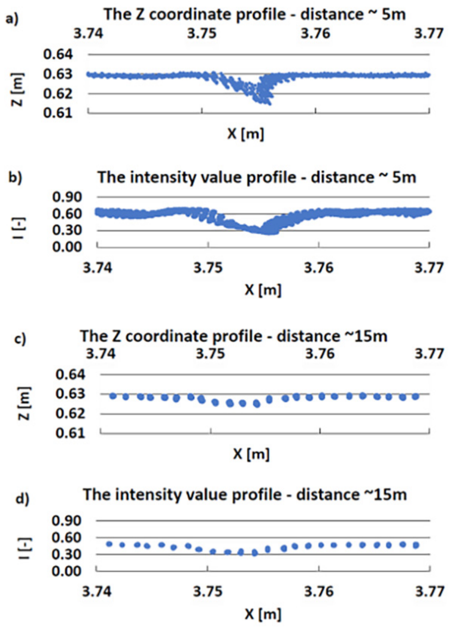

Figure 4. Profiles for angle of incidence close to 0 gon and: the distance of about 5 m (a, b); the distance of about 15 m (c, d)

Conclusions

The conducted supplementary investigations are an expansion of the primary research and provided additional knowledge about the possibilities and limitations of TLS technology for crack detection in building walls. These tests indicate another requirements and rules that the researcher must follow in performing the measurement, so that the resulting point cloud is useful and allows the identification of cracks.

Two significant conclusions were drawn:

- the intensity parameter can provide the information about the deteriorating condition of the wall even at a very early stage due to the possibility of detecting scratches under appropriate measurement conditions; intensity may indicate if the scanned wall requires control measurements shortly.
- determining the measurement conditions, in order to obtain the valuable point clouds, the researcher should set the TLS position as close as possible to the tested object, even at the expense of a very large angle of incidence in the vertical axis and blurring of the laser spot.

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