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Research paper

Selected aspects of data harmonization from terrestrial laser scanning

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Abstract: Periodic inventory and check surveys of the surfaces in engineering structures using terrestrial laser scanning require performing scans from many locations. The survey should be planned so as to obtain full coverage of the measured surface with a point cloud of appropriate density. Due to a variety of terrain obstacles in the close vicinity of the surveyed structure, structural and technical elements, as well as machinery and construction equipment (whose removal is impossible e.g. because of their role in the building and protection of the structure), it is often necessary to combine scans acquired from locations having different measurement geometry of the scene and performed in different lighting conditions. This makes it necessary to fill in blank spots with data of different spectral and geometric quality. This paper presents selected aspects of data harmonization in terrestrial laser scanning. The laser beam incidence angle and the scanning distance are assumed as parameters affecting the quality of the data. Based on the assumed minimum parameters for spectral data, an example of a harmonizing function for the concrete surface of a slurry wall was determined, and the methodology for determining its parameters was described. The presented solution for spectral data harmonization is based on the selection of reference fields representative of a given surface, and their classification with respect to selected geometric parameters of the registered point cloud. For geometric data, possible solutions to the harmonization problem have been analyzed, and criteria for point cloud reduction have been defined in order to obtain qualitatively consistent data. The presented results show that harmonization of point clouds obtained from different stations is necessary before their registration, in order to increase the reliability of analyses performed on the basis of check survey results in the assessment of the technical condition of a surface, its deformation, cracks and scratches.

Keywords: data harmonization, intensity, terrestrial laser scanning

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1. Introduction

Periodic surveying of engineering structures, particularly with regard to displacement monitoring, can be carried out in varying degrees of detail, frequency and accuracy using a range of measuring instruments. One such is the terrestrial laser scanner, increasingly often used in comprehensive monitoring conducted at a construction site. They are usually used to survey selected elements of the structure, or just in certain phases of construction, to monitor for changes occurring in certain specific conditions [1, 2].

Terrestrial laser scanning (TLS), just like any other measurement technology, is associated with a variety of measurement errors. Many publications detail the significance of appropriate calibration of terrestrial laser scanners [3–5] while the equipment manufacturers are using increasingly advanced technical solutions and algorithms to improve the accuracy of the acquired data. However, the problem of external errors still remains, with an influence that is difficult to model and which greatly affects the accuracy of geometric data and recorded spectral values. Wang [6] introduced mathematical modeling of external errors and how it can be applied in real TLS measurements. Their results showed an up to 50% increase in point cloud accuracy; however, the authors emphasize that this remains difficult and is still an unsolved issue.

It should be emphasized that the periodic measurements performed using TLS should be planned so as to obtain data with the appropriate accuracy for the task, and full coverage of the measured surface by a point cloud. Due to terrain obstacles located in the close vicinity of the surveyed structure as well as the structural and technical elements used in the construction and protection of the structure, it is often necessary to combine scans acquired from positions with different measurement geometry of the scene. The resulting blank spots need to be filled in with data of different spectral and geometric quality – an issue that can be addressed by data harmonization as presented in this paper.

In research and work with the use of laser scanning technology, usually directly obtained data is used without a basic analysis of their quality, and thus suitability for the task being performed. The authors of the article point to the necessity of selecting and preparing TLS data due to the influence of many factors on the geometric and spectral accuracy of the obtained data The paper presents an innovative approach for the harmonization of spectral data based of the selection od reference fields representative for a given surface and their classification in terms of selected geometric parameters of the registered point cloud. In article, authors also propose the definition of criteria for the reduction of the point cloud in order to obtain qualitatively consistent data.

1.1. Harmonization of point clouds from terrestrial laser scanning

In terrestrial laser scanners based on phase or pulse distance measurement, the X,Y and Z coordinates of individual points in the point cloud are determined mathematically, based on the value of the vertical and horizontal deflection of the mirror together with the measured distance between the point on the surface and the center of the scanning system coinciding with the beginning of the local coordinate system. The acquired geometric data are accompanied by the intensity of the laser beam reflection registered for each point to provide information about the power of the backscattered laser signal for further analyses.

The recorded intensity values are influenced by several factors that can be classified in several ways [7,8]. For example, [9] divide these factors into four main categories: (i) target surface characteristics (reflectivity and roughness), (ii) data acquisition geometry (range and incidence angle), (iii) instrumental effects, and (iv) environmental influence. Many publications emphasize that the recorded intensity is mostly influenced by the reflectivity, surface roughness, and scanning geometry – understood as the laser beam incidence angle and the scanning distance [10–13]. In order to perform reliable analyses of intensity variability in large plots covered by measurements taken from several sites, data harmonization should be performed so that the influence of these factors is homogeneous over the entire plot. Surveying and cartographic law defines harmonization of data sets as legal, technical and organizational measures aimed at making the data sets mutually coherent and suitable for their shared and joint use. In the case of terrestrial laser scanning, data harmonization may concern the geometric data layer or spectral data layer, so that time-varying or geometric factors (those dependent on the external measurement station) have the least possible impact on the results of the analysis, e.g. the determination of surface deformation (geometric analysis), assessment of the degree of contamination (spectral data layer analysis). Depending on the subject being harmonized, it requires an individual approach to the process of data alignment into a harmonious whole.

2. Data harmonization methodology

The methodology and processing of geometric and spectral data presented here uses the example of scanning a concrete slurry wall, part of the deep excavation casing of the Mennica Legacy Tower in Warsaw [1]. The slurry wall is 3 m high and about 70 m long. Along the wall, during check surveys, the analyzed surface is partially obscured with metal building props and supports, as shown in Fig. 1.

Fig. 1. View of the concrete slurry wall with supports and some construction elements that may obstruct surveying

In order to carry out measurements, a design for the scanner stations (designated on Fig. 2 as ST1–ST9) and measuring targets was prepared. The measurement took into account the existing terrain obstacles and changes in measurement conditions: traffic on the construction site, variation in intensity and source of illumination of the construction site (solar and artificial). Planning for the measurement not only allowed optimizing the measurement time, but above all ensured continuous coverage of the wall surface data acquired at a laser beam incidence angle not exceeding 45° (critical angle of incidence marked with red lines in Fig. 2). The choice of the critical incidence angle for the laser beam was based on scientific publications [12–15], which indicate a significant deterioration of data quality when the incidence angle exceeds 45°. The surveying plan also took into account the need to ensure proper mutual coverage between adjacent scans to allow for filling in the blind spots created by the presence of terrain obstacles with the data from neighboring sites. The combination of scans acquired from different sites gives full coverage of data recorded under different geometric conditions (subject to the unsystematic influence of factors such as the laser incidence angle, scanning distance, differences in albedo of the surface due to impurities).

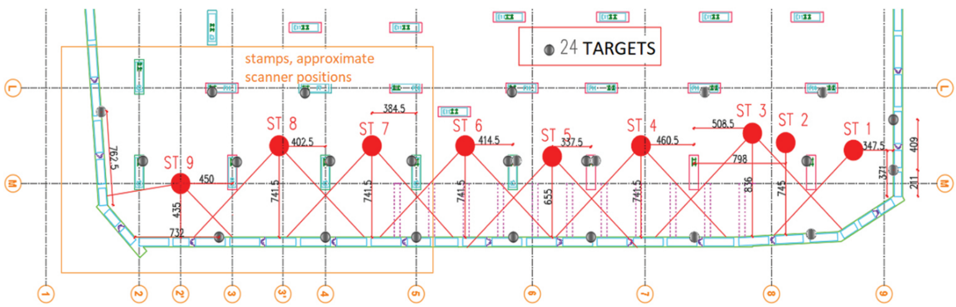


Fig. 2. Layout design of the scanner stations (ST1–ST9) and measurement targets for the selected slurry wall of the test facility

Fig. 3 shows the view of a fragment of point cloud sequentially from (a) station ST7, (b) ST7 with an overlay of points acquired from ST6, ST7 with an overlay of points acquired from ST8, and ST7 with an overlay of points acquired from ST6 and ST8. The figure clearly shows how the data from the neighboring stations complement the blind spots on a single scan.

The aim of the conducted research was to obtain the most complete coverage with qualitatively homogeneous data, both geometrically and spectrally (intensity), of the surface of the straight concrete wall or the refracted surface expanded to the mean plane. The analyzed surface was made entirely of concrete of the same material parameters, characterized by a rough texture and stained fragments. It should be noted that each building material had a different reflectivity; for concretes, it will depend on the admixtures and colorants used. In addition, the surface texture of concrete depends on the pouring technology used, the type of concrete and the surface erosion and rheological phenomena. The variety of physical characteristics of materials is the key to adopting appropriate criteria for data reduction and

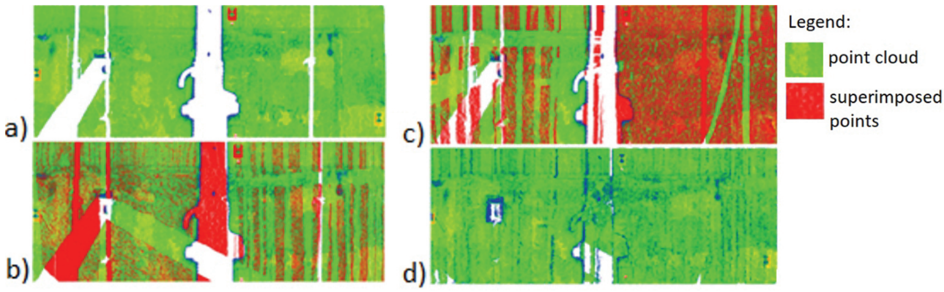


Fig. 3. Fragments of point clouds: a) ST7, b) ST7 with superimposed points from ST6, c) ST7 with superimposed points from ST8, d) ST7 with superimposed points from ST6 and ST8 (own elaboration)

selection of sample areas. Thus, the methods presented below are adopted for geometric and spectral data layers and should be properly adapted to the geometry and properties of the material from which the object was made.

The methods presented in the following subsections discuss the procedure to be followed for properly acquired and preprocessed data, i.e. filtered and oriented data.

2.1. Methodology of harmonizing TLS point cloud geometric data

The harmonization of geometric data in TLS point clouds can be done in two ways – either by making appropriate mathematical corrections or by properly selecting the data so that they are of equal quality.

The introduction of mathematical corrections requires taking into account a number of factors influencing the quality of the acquired data, the modeling of which is often very difficult due to their high unpredictability and thus difficulty in appropriate mathematical approximation. The data selection approach allows distinguishing ranges for which the most influential parameters of data quality have similar values. The parameters with the strongest influence on the quality of geometric data are the incidence angle of the laser beam and the scanning distance.

Based on the study of selected factors affecting the quality of the acquired point cloud by [2] and [15], a number of classes of homogeneous areas defined by the expected accuracy of surface mapping were developed (Table 1). It can be seen how a relatively small change in the location of the scanning site causes a significant change in the laser beam incidence angle and the scanning distance, which confirms the need to separate appropriate classes of data.

The classes presented in Table 1 were developed by expected surface representation accuracy of 5 mm, 10 mm and above 15 mm, respectively. This division corresponds to the typical accuracies of periodic survey work for engineering structures. The adopted limit values are appropriate for concrete surfaces.

Table 1. Classes of homogeneous areas defined by the expected accuracy of surface mapping [2]

Expected surface mapping accuracy		
Class	Incidence angle of the laser beam	Distance
< 5 mm		
Class I	0°–15°	0 m–10 m
Class II	15°–25°	
approx. 10 mm		
Class III	0°–20°	0 m–20 m
Class IV	20°–35°	
approx. 15 mm		
Class V	0°–20°	0 m–40 m
Class VI	20°–30°	
Class VII	30°–45°	

According to the aspects presented above, the TLS point cloud geometric data harmonization proposed in this paper is based on data limits and includes the following steps:

1. Data limitation related to the angle of incidence of the laser beam
2. Data limitation related to the scanning distance.
3. Data filtering.

Harmonization of geometric data is mainly performed for reliable comparative analyses that must be preceded by:

1. Selection of areas of comparable quality for two series of repeated measurement
2. Assessment of determinable differences.
3. Selecting a suitable algorithm for comparing point clouds.

The evaluation of determinable differences includes a secondary analysis whether, after data limitation according to the adopted criteria, we have obtained a coverage of the analyzed surface by the point cloud that is sufficiently continuous for a comparison with the next measurement series. In the last step, depending on the roughness of the analyzed surface, an algorithm is selected for the point cloud comparison. Literature [16, 17] and the available software dedicated to terrestrial laser scanning uses four main methods of distance calculation: DEM of Difference (DoD) – distance between models, Cloud To Cloud Distances (C2C) – direct cloud to cloud distance, Cloud to Mesh Distance (C2M) – point to model distance, Multiscale Model to Model Cloud Comparison (M3C2) – directed distances between two point clouds.

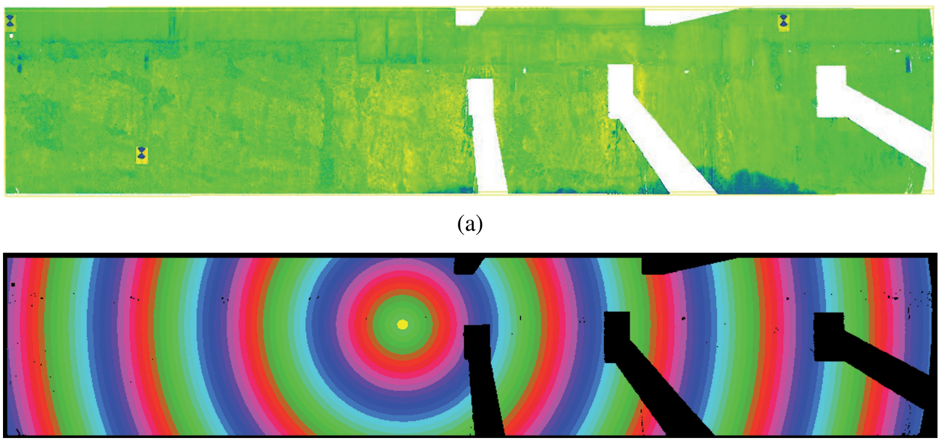
2.2. Methodology of harmonizing the spectral layer of tls point clouds

Although literature includes many publications dealing with spectral data harmonization, numerous authors emphasize that the selected method must be individually adjusted to the analyzed data. Authors in [18] discuss harmonization of data acquired from a long distance and indicate that their improved method can accurately nullify the effects of incidence angle and distance on the intensity data of long-distance TLS. The classification results of the study intertidal zone show that the improved method can effectively eliminate the variations caused by the incidence angle and distance in the original intensity data of the same target to obtain a corrected intensity that merely depends on target characteristics for improving classification accuracy by 49%. Another example can be found in the study by Bolkas [19] for colored, smooth and semi-gloss-sheen surfaces. The authors used two models – Trowbridge–Reitz and GGX – which gave very good results for the correction of spectral data. However, in the case of the object in our study, we are dealing with small distances and a rough concrete surface – hence a customized approach is necessary.

Unlike geometric data harmonization, spectral layer harmonization was proposed based on reference fields [20], selected on the scanned real surface of the object. In our study case, they were fragments of the least contaminated surfaces.

The method is outlined in the points below:

1. Selection of the station with the best imaging geometry and the largest recorded area (without obstructions).
2. Selection of the least impure area (arbitrarily oriented strip of a width selected depending on the surface roughness and expected analysis accuracy). Orientation of the strip in relation to the scanner projection (centre point). Due to the fact that the distribution of the influence of the laser incidence angle and distance is concentric, the strip orientation has no influence on the analysis results (Fig. 4).



(a)

(b)

Fig. 4. Concentric nature of the distribution of the influences of the beam incidence angle and scanning distance on the recorded beam reflection intensity values: a) scan of the slurry wall in intensity colors, b) distribution of influences of geometrical factors (incidence angle, distance), a 10 cm step along the measured wall, centre: projection of the center point of the scan

In Fig. 4, a correlation between the location of the projection of the center scan point (Figure 4b) and the intensity values (color variation) (Fig. 4a) can be observed:

3. Division of the test area into fragments of size $n \times n$ (e.g. 5×5 cm or 10×10 cm).
4. Exclusion of sections with high surface contamination from the test strip – based on site inspection and preliminary visual analysis of the data.
5. Data transformation to the local system of the wall (we assume that the projection point, unequivocal with the projection on the wall of the centre point of the scan, has coordinates 0,0)
6. Determining the average angle of incidence and average distance for each field.
7. Exclusion from the test strip for fragments with an irregular distribution of residual impurities – based on histogram analysis.
8. Determine the average intensity value for a single strip test field.
9. Determination of the dependence of the intensity on the laser beam incidence angle and the distance (two variables), determination of the formula for the harmonizing correction (universal for all scans of the object, for a surface made of the same material as the selected strip).

In the example described in the paper, on the basis of the analysis of the recorded intensity values, with a properly planned measurement, it was found that the influence of distance changes was insignificant. The calculations were limited to determining the dependence of intensity changes on the angle of incidence. In order to find a function describing this dependence, a mean-square approximation was used with the assumption of weighting by the size of the average error for the fields of the chosen strip and reference fields.

The mean-square approximation was chosen because in the computational process it does not destroy the variation in the observed signal caused by factors not included in the approximation model.

10. Implementing a fix/correction on all scans.
11. Combining scans and demonstrating how the algorithm works.

It has been assumed that performing spectral layer harmonization according to the presented approach will result in a correction that harmonizes the data but will still show areas of a different character (e.g., soggy, significantly soiled or with different surface properties (e.g., contaminated to a different degree, with a different substance or covered with a layer of vegetation made of a different material)) than the previously selected reference strip. Moreover, the harmonized data will show cracks and fissures as well as disturbances of roughness parameters resulting from different manufacturing methods and progressive erosion changes on the surface.

3. Results of data harmonization

3.1. Harmonization of geometric data

According to the proposed methodology, the first step included the selection of areas of comparable quality, i.e. areas for which data were acquired in a manner fulfilling the criteria for the expected accuracy. Due to the technology used in the building of the wall and the expected accuracy of the local deformation determination by the construction supervision, 1 cm was assumed as the expected accuracy of mapping. For this purpose, for point clouds we determined the distribution of the angle of incidence of the laser beam (Fig. 5) and the distance of points from the instrument stand (Fig. 6).

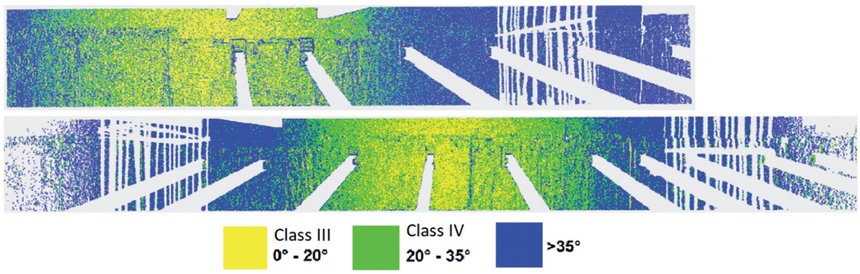


Fig. 5. Incidence angle distribution of the laser beam, ST3 and ST4 respectively

The study started with an analysis of the laser beam incidence angle, which was made for 1 centimeter accuracy assuming the following limits: Class III 0°–20° and Class IV 20°–35°. A limitation of the point clouds due to the incidence angle of the laser beam caused the selected areas to have no sharp boundaries. In the figures, the interpenetration of classes is visible, which is the effect of high surface roughness. Due to its uneven nature, rough surface reflects the laser beam at different angles. As a result, adjacent points may be characterized by a completely different value of the angle of incidence of the laser beam, so that the area scanned at a given angle is more extensive than in the case of a smooth surface, for which the change of laser beam incidence angle has an approximately linear character.

The next step is to analyze the measurement distance of individual points with the terrestrial laser scanner (Fig. 6).

Fig. 6. Distribution of scanning distances

Fig. 6 presents the distribution of the distance of points from the instrument in the adopted color scale, respectively for ST1, ST3 and ST4. For 1 centimeter accuracy it is assumed that the distance from the measured point to the instrument stand should not exceed 20 m. This condition is fulfilled for all points on the test surface.

The point cloud reduction procedure was performed for two measurement cycles, and then the point cloud distances between the cycles were determined. Fig. 7 shows the differential model for the comparison of point clouds from cycle 1 and cycle 2. Fig. 7a is based on point clouds subjected only to filtering, while Fig. 7b shows the results of point cloud comparison for which the point cloud limitation criteria proposed in the methodology were applied.

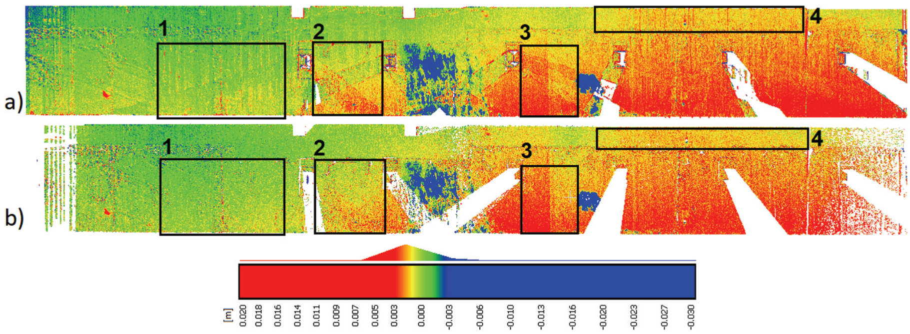


Fig. 7. Differential model of the investigated surface (distances determined with M3C2 algorithm) based on data from cycle 1 and cycle 2: a) point clouds subjected only to filtration, b) with application of point clouds limiting criteria proposed in the methodology. Black boxes (from 1 to 4) mark the areas of the most significant differences in obtained results (own elaboration)

The black boxes (numbers 1–4) indicate the areas of most significant differences in the elaboration based just on the filtered data (Fig. 7a), and on the data elaborated according to the proposed methodology (Fig. 7b). Based on the presented figures, it can be concluded that the use of data acquired at the wrong angle, from the wrong distance, or with the wrong density for the analysis can lead to showing non-existent differences, which is well exemplified by the point cloud fragments highlighted in black boxes 1 and 4, within which vertical stripes appear in Fig. 7a but which are not visible in Fig. 7b. These stripes were created as a result of using fragments of scans acquired between stamps and struts that obscure the analyzed surface (on which the emitted laser beam was sliding at a high angle of incidence). Therefore, this is the effect of determining the difference of point clouds on the basis of data acquired with insufficient accuracy. On the other hand, the diagonal stripes visible in rectangles 2 and 3 are areas for which blind spots caused by the occurrence of struts were supplemented with data from other stations, so these areas were dominated by points acquired at the wrong angle and with poor resolution. A comparison of the differential models completes the TLS data processing.

3.2. Harmonization of spectral data

Similarly to the spectral harmonization, we start with the selection of reference fields. This selection begins with choosing the position with the best imaging geometry and then indicating the least contaminated areas. According to our assumption, the reference field will be an arbitrarily oriented strip of a width selected depending on the surface roughness and expected accuracy of analyses. In the experiment, the selected point cloud was divided into 10 cm wide strips starting at the point of the scanner projection on the surface under investigation, propagating according to the circle radii (Fig. 8). It was assumed that the distribution of the influence of the laser beam incidence angle and distance has a concentric character.

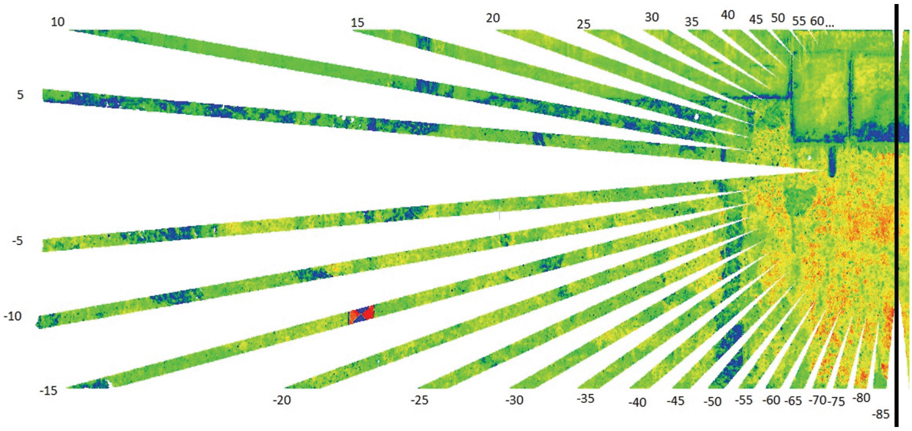


Fig. 8. Division of the point cloud into 10 cm wide stripes and distribution according to the direction of rays propagating from the center point, which is the projection of the scanner on the examined surface

On the basis of statistical analysis of the individual strips divided into homogeneous areas of 10 × 10 cm, we selected reference fields characterized by the lowest surface contamination and a calculated standard deviation not greater than 5% of the average recorded intensity for a single area (Fig. 9).

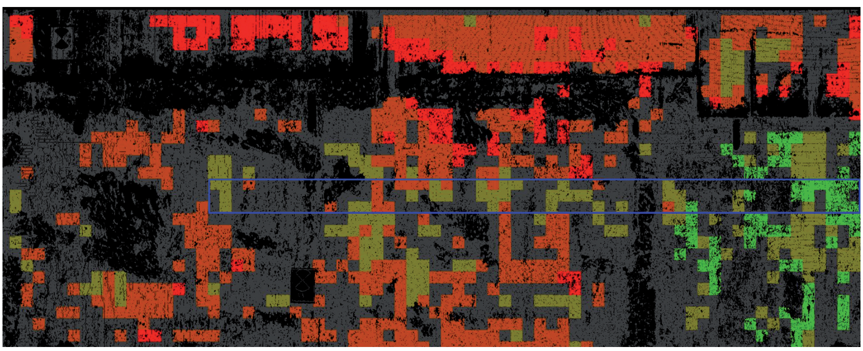


Fig. 9. Selected reference data with the lowest surface contamination (areas in green within the blue box)

The selected reference data were divided into square fields (5 × 5 cm and 10 × 10 cm) using Janina Zaczek-Peplinska's Scanner_Reflection_Intensity_Fix (SRIF) software. Then, for each field, the intensity histogram distribution was analyzed (Fig. 10). On the basis of the histogram distributions, we eliminated the fields on which there was some dirt or other surface disturbance which revealed itself in the form of irregularity and asymmetry of the histogram. SRIF is a proprietary software developed for the needs of research carried out at the Department of Engineering Geodesy and Measurement Systems of the Warsaw University of Technology, the software is made available at the request of employees of other scientific institutes conducting research in a similar scope (application of TLS in engineering geodesy).

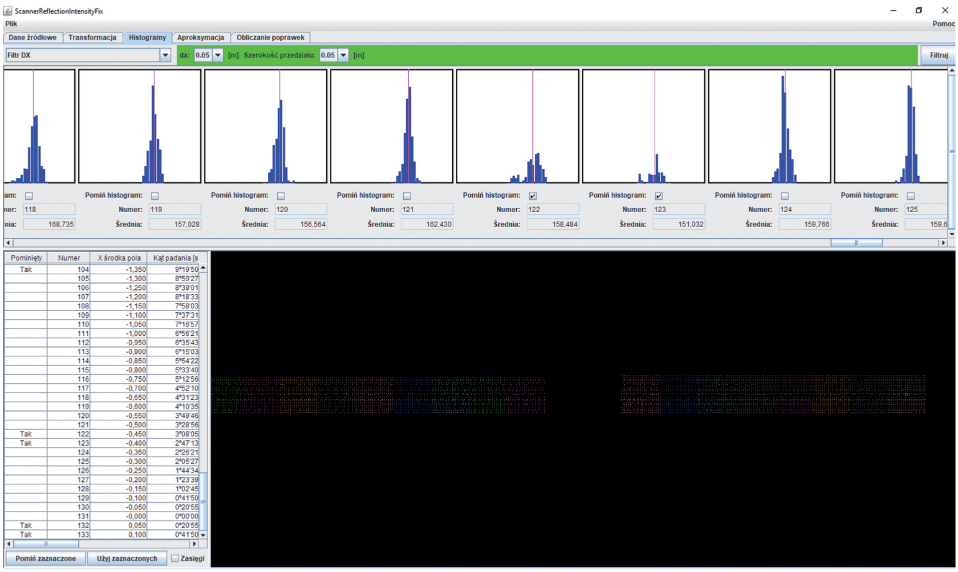


Fig. 10. Example of histogram distribution analysis of intensity values for 10 by 10 cm fields developed in proprietary Scanner_Reflection_Intencity_Fix (SRIF) software

The performed selection yielded stripes of reference fields representing the uncontaminated wall surface (an example strip of reference fields is shown in Fig. 11).

Fig. 11. View of selected master strips in intensity colors

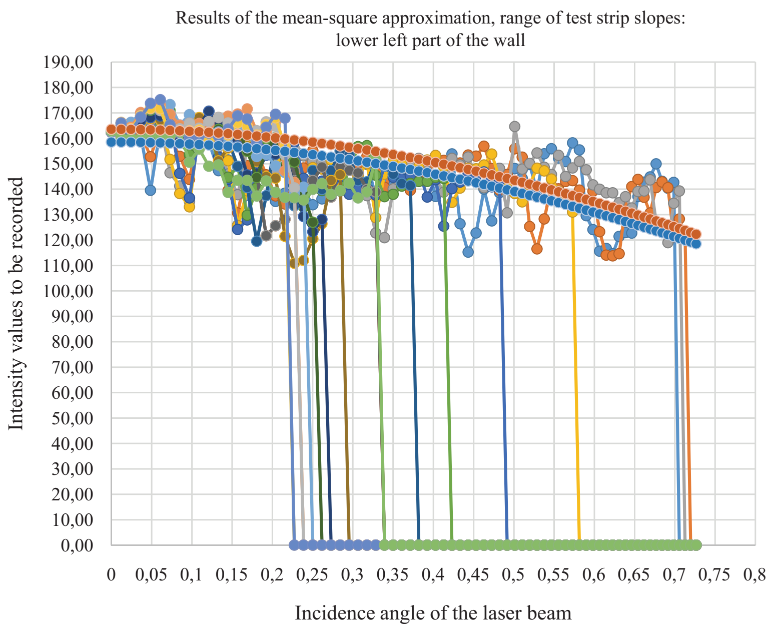
According to the proposed methodology, data correction was performed based on least squares approximated models according to Lambert's law Eq. (3.1).

$$I(\gamma) = I_0 \cdot \cos(\gamma) \tag{3.1}$$

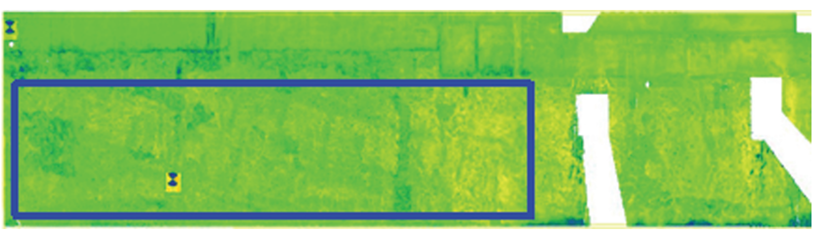
where: $I(\gamma)$ – light I in the direction forming the angle γ with the normal to the radiating surface, I_0 – luminous intensity perpendicular to the radiating surface, γ – angle between the direction of the incident light beam and the normal to the radiating surface.

The next step of the study was a mean-square approximation based on data strips from a beam angle of 0° – 85° (the lower part of the wall, with smaller deformations of the geometric layer of the data, containing the benchmark data strip (Fig. 8) with weighting for the reference fields. The approximation (Fig. 12) resulted in a Lambert I_o of 158.53 and a standard deviation of 11.71. The standardized corrections are in the range –2.65, 2.25.

Fig. 12 highlights the role of the reference data. An absence shifts the line of approximation results from red to blue and consequently changes the classification for individual homogeneous areas (here of 10 × 10 cm size).



(a)

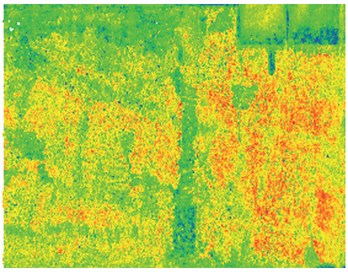
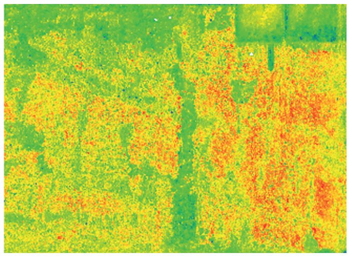
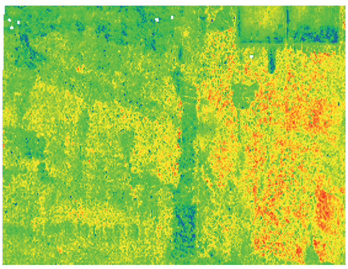
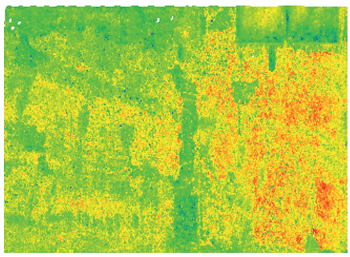


(b)

Fig. 12. Analysis of the dependence of the recorded laser beam reflection intensity on the beam incidence angle, (a) plot of the dependence of the recorded intensity on the laser beam incidence angle for the lower part of the wall, the red color indicates the result of the mean-square approximation and the intensity determined according to Lambert's law (blue color), (b) the analyzed area, excluding the measurement mark on the surface

Based on the results of the approximation, harmonization of the intensity values recorded for the whole wall was performed, and a graphical representation with raw data and harmonized data (selected part of the wall) is summarized in Table 2. Figures showing harmonized data for two sites with different geometries (after geometric and spectral harmonization) show smaller color contrasts, mainly due to differences in beam incidence angles (raw data vs. harmonized data). At the same time, the harmonized data are characterized by a lack of influence of the geometry of the stand.

Table 2. Summary of raw and harmonized data in intensity colors for scenes recorded at scanner stations St2 and St3

	Raw data (before correction)	Harmonized data
St2		
St3		

4. Summary and conclusions

The presented research allows drawing a number of conclusions and defining the occurring problems in the case of both geometric and spectral layer harmonization. in the case of geometric harmonization of tls data, the basic question that arises based on the analyses presented is which data should we harmonize. is it the coordinates of the points or the raw data, and therefore the directions and distances recorded in the instrument? in our research we used coordinates which were used to determine the laser beam incidence angle and the distance. however, it should be remembered that the coordinates are values calculated by the instrument, so we cannot be sure whether corrections have not already been introduced. in the case of mathematical harmonization, the developed corrections should be based on the raw data.

Another important aspect is the impact of surface roughness, which significantly affects the distribution of the angle of incidence of the laser beam. Also depending on the surface roughness should be the selected scanning resolution, so that too low a point density would not obscure the actual shape of the surface. Surface roughness is a complex issue of a varied nature, both in micro-scale and a few centimeters. In the case of periodic measurements we usually deal with raw untreated surfaces and therefore very rough, which should be taken into account in the evaluation of the obtained results.

Additionally, the quality of the acquired data and thus its accuracy is greatly affected by the color of the surface. Even in the case of concrete surfaces we cannot speak of a uniform color on the whole object. The surface color, and thus its reflectivity influences the distance measurement. This influence is very difficult to model because for such large surfaces we do not know local differences in reflectivity and therefore we assume a certain average value.

The last element to keep in mind in the context of geometric data harmonization is the translation of the TLS data orientation accuracy to individual point cloud points. When harmonizing the data, we may get results that are not fully consistent, which may be caused by the accuracy of the point cloud mutual orientations. Least-square approximation removes any systematic bias with regard to the observation material and partially eliminates the effect of these factors influencing the recorded intensity.

The primary task of spectral harmonization of TLS data is the proper selection of reference fields taking into account the location of the fields, the nature of contamination and primary changes, and statistical analysis of histograms of the means Intensity and standard deviations. This task is significantly hampered by the fact that in the case of field work the reference spectral properties of the surface are usually unknown (often no data on material properties are available). Additionally, the tested surface includes various impurities resulting from different batches of material and production technology, technological contamination, environmental contamination, as well as other variables such as time lapse, vegetation periods, and external conditions.

When harmonizing spectral data, one must consider the effect of surface roughness, and the effect of surface color on distance measurements. The starting point for developing harmonizing corrections is Lambert's law. There is no uniform approach to harmonization that is appropriate for all objects of any material, so this paper presents a harmonization method intended only for concrete surfaces.

In the next stages of the research, the authors plan to develop an amendment harmonizing the recorded intensity values, which can be used for various types of building materials with a similar color and structure for the entire captured scene, e.g. massive surfaces made of hydrotechnical concrete, diaphragm walls, facade surfaces, finishing materials (panels, stoneware, surface reliefs). The limitation of the application of this type of correction is the distinction on the measured surfaces of areas that can be considered as reference and the locations of which are differentiated in terms of the distance from the main point of the scan and the angle of incidence of the beam. In the case of highly eroded or contaminated surfaces, it may not be possible to define reference areas. Incorrect adoption of reference areas will result in a shift of the approximated values describing the dependence of the

Intensity value on the beam incidence angle and a disturbance of the size of the introduced corrections. In this case, the spectral harmonization of the data in order to supplement the so-called blind spots beyond the reach of the scanner will disrupt the results of surface condition analyzes.

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Wybrane aspekty harmonizacji danych z naziemnego skanowania laserowego (TLS)

Słowa kluczowe: intensywność odbicia promienia laserowego, harmonizacja danych, naziemne skanowanie laserowe

Streszczenie:

Okresowe pomiary inwentaryzacyjne i kontrolne powierzchni obiektów inżynierskich metodą naziemnego skaningu laserowego wymagają wykonania skanowania z wielu stanowisk instrumentu. Pomiar obiektu powinien być tak zaplanowany, aby uzyskać pełne pokrycie mierzonej powierzchni chmurą punktów o odpowiedniej gęstości. Ze względu na znajdujące się w bliskim otoczeniu mierzonego obiektu przeszkody terenowe, elementy konstrukcyjne i techniczne a także maszyny i urządzenia budowlane, których usunięcie na czas wykonywania pomiaru jest niemożliwe np. służące realizacji i zabezpieczeniu obiektu często niezbędne jest łączenie skanów pozyskanych ze stanowisk o różnej geometrii sceny pomiarowej i wykonanych w różnych warunkach oświetlenia. Skutkuje to koniecznością uzupełniania martwych (pustych) pól danymi o różnej jakości spektralnej i geometrycznej. W artykule zaprezentowano wybrane aspekty harmonizacji danych z naziemnego skaningu laserowego. Jako parametry wpływające na jakość danych przyjęto kąt padania wiązki laserowej oraz odległość skanowania. W oparciu o przyjęte minimalne parametry dla danych spektralnych wyznaczono przykładową funkcję harmonizującą dla betonowej powierzchni ściany szczelinowej oraz opisano metodykę wyznaczania jej parametrów. Prezentowane rozwiązanie dla harmonizacji danych spektralnych opiera się na wyborze reprezentatywnych dla danej powierzchni pól referencyjnych i ich klasyfikacji w odniesieniu do wybranych parametrów geometrycznych zarejestrowanej chmury punktów. Dla danych geometrycznych przeanalizowano możliwe rozwiązania problemu harmonizacji oraz określono kryteria ograniczania chmur punktów w celu uzyskiwania spójnych jakościowo danych. Na podstawie zaprezentowanych wyników wykazano, że harmonizacja pojedynczych chmur punktów pozyskanych z różnych stanowisk jest konieczna przed ich wspólną rejestracją (register points clouds) w celu podniesienia wiarygodności analiz wykonywanych na podstawie wyników pomiarów kontrolnych do oceny stanu technicznego powierzchni, jej deformacji oraz spękań i rys.

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