Effect of geometrical features various objects on the data quality obtained with measured by TLS

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Abstract. Collecting data on different building structures using Terrestrial Laser Scanning (TLS) has become in recent years a very popular due to minimize the time required to complete the task as compared to traditional methods. Technical parameters of 3D scanning devices (digitizers) are increasingly being improved, and the accuracy of the data collected allows you to play not only the geometry of an existing object in a digital image, but also enables the assessment of his condition. This is possible thanks to the digitalization of existing objects e.g., a 3D laser scanner, with which is obtained a digital data base is presented in the form of a cloud of points and by using reverse engineering. Measurements using laser scanners depends to a large extent, on the quality of the returning beam reflected from the target surface, towards the receiver. High impact on the strength and quality of the beam returning to the geometric features of the object. These properties may contribute to the emergence of some, sometimes even serious errors during scanning of various shapes. The study defined the effect of the laser beam distortion during the measurement objects with the same material but with different geometrical features on their three-dimensional imaging obtained from measurements made using TLS. We present the problem of data quality, dependent on the deflection of the beam intensity and shape of the object selected examples. The knowledge of these problems allows to obtain valuable data necessary for the implementation of digitization and the visualization of virtually any building structure made of any materials. The studies has been proven that the increase in the density of scanning does not affect the values of mean square error. The increase in the angle of incidence of the beam onto a flat surface, however, causes a decrease in the intensity of scattered radiation that reaches the receiver. The article presents an analysis of the laser beam reflected from broken at different angles surface. Scan quality was assessed using check the density of the number of points on the test object's surface.

1. Introduction
Application of a 3D laser scanner to collect data about a building structure is becoming increasing popular. The Terrestrial Laser Scanning (TLS) method allows creating an accurate image of every detail with a precision unattainable by means of the classic measuring methods. By measuring pole coordinates of individual points, laser scanners inscribe them in a 3D space. Each point is represented by at least three coordinates \((X, Y, Z)\) referred to the local scanner system. The laser beam reflection intensity is also measured and is marked as the fourth coordinate [1]. The quality of the laser beam reflected from the surface of an object and returning to the receiver is of great importance. The power and the quality of the beam depend largely on the reflective properties and the shape of the scanned
surface. These properties may result in certain, sometimes even serious errors during scanning of different surfaces.

2. Reflective properties of the target object
Measurements performed by means of laser scanners depend largely on the quality of the beam reflected from the surface of the target object and returning toward the receiver. The power of the returning beam is influenced by the reflective properties of the surface of the target object, including its colour, texture, temperature and the moisture content. These properties may result in certain, sometimes even serious errors during scanning of different surfaces. One way to avoid this is to apply a temporary cover in the form of a special cloth or substance. This, however, is not a universal method. The extent of the impact of the properties of a specific surface on laser scanning may be examined by means of special tests and analyses [2].

Based on the known research results and taking into account only the colour of the scanned surface it has been concluded that bright colours have quite big reflective properties allowing measuring point clouds at high scanning density. Yellow and green are capable of providing a high quality point cloud, whereas red results in a cloud with significantly scattered points. It has been proven that an increase in the scanning density does not impact the value of the mean squared error. Increasing the angle at which the laser beam hits a flat surface causes a decrease in the intensity of diffused radiation which reaches the receiver. Whereas in the case of a rough or uneven surface, the power of the returning laser beam is almost constant. The issue of the moisture content in the scanned object also has a documented impact on the measured intensity. This is connected with the content of water in the materials, which may cause changes to the behaviour of the wave [3].

3. Scanning of different surfaces
The shape of the scanned surface is a significant factor causing deformation of a laser beam in the TLS method. It impacts the value of the intensity of the laser beam reflection, i.e. the fourth coordinate \( I \) defining a point cloud. This issue was investigated based on an analysis of the data collected in the course of scanning of 18th-century church organs (Figure 1).

![Figure 1. Church organs - test object no. 1.](image)

Additionally, an analysis of the impact of the shape of the object on the concentration of points over a specific area was performed. In addition to the organ pipes, a 15th century stone baptismal was subjected to the tests (Figure 2). It consists of two elements with different tilt angles. In a perpendicular view, the top part of the baptismal, i.e. the bowl, is oval, slightly truncated at the bottom and top, whereas the lower part, i.e. the stand, is shaped like a pyramid cut in the middle and slightly leaning to the back. Both elements had influence on each other during the tests. The diameter of the
bowl extends beyond the edges of the lower part, covering up a small area of the stand at the joining point of the two elements, as a result of which this area couldn't be penetrated by the laser beams. The laser scanner was positioned in such a way as to ensure that the distance from the tested object and the tilt angle of the laser were constant. The pipes and the baptismal were scanned from the distance of 16 m and 5 m, respectively. The test focused on analysing the laser beam reflected from uneven surfaces and on the concentration of points over a specific area.

As a result of scanning the two objects by means of a 3D laser scanner, a set of data in the form of a point cloud was obtained, forming an intensity map. The intensity map of a part of the church organs clearly shows the difference in the values obtained for the flattened part of the pipes (Figure 3).

Given that the pipes are made entirely of one type of material and have the same colour, this could not have had any influence on the concentration. The factor that impacted the laser beam reflection was in this case the curved shape of the pipes. The analysis was performed on a randomly selected pipe, and was narrowed down to its concave part. The other, oval part was not tested. The concave part was divided into four rectangular test areas of 0.03m by 0.06m, numbered 1 to 4. Each of the areas was tested against the intensity and concentration of points (Figure 4), and the values were included in the table (Table 1).
Figure 4. Organ pipes - the distribution of intensity on the curved surface divided into test areas.

Table 1. Data measured for a part of the pipe.

| Test area number | 1        | 2        | 3        | 4        |
|------------------|----------|----------|----------|----------|
| Description of   | Bottom   | Flat     | Flat     | Top edge |
| the surface      | edge     | flat     | flat     | toward   |
| curvatures       | toward   | flat     | flat     | back     |
| Number of        | 595      | 545      | 552      | 475      |
| points in the    |          |          |          |          |
| area of 0.03x0.06 [m] |        |          |          |          |
| Minimum          | 0.5946   | 0.3396   | 0.3310   | 0.2488   |
| intensity value  |          |          |          |          |
| Maximum          | 0.9491   | 0.5514   | 0.5428   | 0.4650   |
| intensity value  |          |          |          |          |

On the basis of the values presented in table 1 and on the basis of a visual analysis of the tested parts of the pipe, a significant relationship was discovered between the level of surface curvatures, the intensity values and the number of points per area. The biggest differences in values were discovered in the first and the fourth area. They result from the surface curvatures. The area with the biggest number of points has also the highest intensity values (test area no. 1), whereas the area with the smaller number of points has the lowest intensity values (test area no. 4). The results for the nearly flat areas no. 3 and 4 were almost identical and averaged, which proves that they are similar.

Due to its shape, the baptismal was divided into two parts - the bowl and the stand, which were tested separately. The figures show a division of the bowl (Figure 5) and the stand (Figure 6) into test areas. The bowl was divided into 13, while the stand into 12 squares of 0.05m by 0.10m. The division covered the surfaces perpendicular to the laser beam, hence they may appear flat and may not reflect the real curvatures.

The analysis data was included in the following tables: the bowl (Table 2) and the stand (Table 3).
The difference for the bowl between the area displaying the highest concentration and the area displaying the lowest concentration is 1465 points. When calculating the differences, the areas numbered 11 through 13 were left out due to the fact that they had been scanned twice, resulting in an increase in the number of points in these areas of 75% on average.
Table 2. Concentration of points on the bowl.

| Test area number | 1  | 2  | 3  | 4  | 5  |
|------------------|----|----|----|----|----|
| Number of points | 4079 | 4524 | 5486 | 4896 | 4694 |

| Test area number | 6  | 7  | 8  | 9  | 10 |
|------------------|----|----|----|----|----|
| Number of points | 4021 | 4241 | 5017 | 4635 | 4273 |

| Test area number | 11 | 12 | 13 |
|------------------|----|----|----|
| Number of points | 7069 | 7447 | 7147 |

Table 3. Concentration of points on the stand.

| Test area number | 1  | 2  | 3  |
|------------------|----|----|----|
| Number of points | 3927 | 4349 | 4108 |

| Test area number | 4  | 5  | 6  | 7  | 8  |
|------------------|----|----|----|----|----|
| Number of points | 4115 | 4176 | 4262 | 3922 | 3237 |

| Test area number | 9  | 10 | 11 | 12 |
|------------------|----|----|----|----|
| Number of points | 3804 | 4337 | 4155 | 3953 |

The results show that the difference in the extreme values for the stand of the baptismal is 1112 points. In this case, the decrease in the number of points in horizontal series in the remaining areas is uneven, unlike in the horizontal series on the bowl. The tests have shown that this is due to the rough surface of the object. A good example of that are the following test area pairs on the stand: 1 and 2 and 9 and 10, which show a significant decrease in the number of cloud points compared to areas 5 and 6.

By comparing the data from the measurements of the organs and the baptismal one can conclude that the way in which a laser beam is reflected from a surface depends on its shape and its tilt angles. A bigger angle of incidence of a laser beam on such surface results in a decrease in the intensity and dispersion of the radiation returning to the receiver. Consequently, the resulting point cloud may be distorted and inaccurate. The density of a point cloud is also dependent on the distance of the measuring instrument from the tested object. The analysis has shown that the number of the collected data is inversely proportional to the distance between the scanner and the tested object.

4. Summary and conclusions

The tests presented above have shown that the concentration of points in test areas situated perpendicular to the laser beam is greater, while in the test areas situated more to the right or left, the concentration is gradually reduced (the concentration of points changes with the change of the shape of the tested object, which is clearly visible on the example of the baptismal).

Additionally, the more the tested object's surface was curved, the more the points slipped away from the right position. Where there was a curvature, there was the so-called edge effect, where the beam of light was frequently dispersed. This resulted in incorrect data in the point cloud, i.e. the so-called noise. This noise requires verification and removal from a scan at the digitization stage. If not removed, such incorrect data may affect the quality of a virtual 3D model when applying reverse engineering. However, a large concentration of points is not required in the majority of cases of this
sort. Their bigger concentration may be useful if a more detailed model of a scanned object is required. Such precise data is important when determining the deformations, deflections or cracking of an object, as well as when performing reverse engineering of architectural details or ornaments. Therefore, prior to taking the measurements one should first familiarize themselves with the object to be tested, decide on the best spot in which to place the laser to make sure that its beam falls perpendicularly to the measured surfaces. It is also important to adjust the accuracy of the measurement (which affects the number of the points collected) to the type of the study that is to be based thereon.

In consequence, it was confirmed that the geometrical features of the tested sample have an influence on the quality and quantity of the data obtained in the course of measurements. A relationship was shown between the angle of incidence of a laser beam and the intensity of the reflection. Additionally, it was observed that the distance between the measuring instrument and the tested object has an influence on the quantity of the data in a respective point cloud. The baptismal and the organs are subject to the historic preservation programme. They are located in a historic church and still in use. Documentation describing the parameters and the characteristics of such artefacts is often prepared for preservation and conservation purposes. 3D laser scanning is an ideal tool to create such documentation and assess the condition of such artefacts by non-invasive means. They do not have to be displaced for test purposes, which means that they can be used throughout the test period. Application of reverse engineering, in turn, allows recording the shape and details of objects in the form of virtual 3D models accessible any time by means of a computer.

5. References

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