

EDGE EFFECT AND ITS IMPACT UPON THE ACCURACY OF 2D AND 3D MODELLING USING LASER SCANNING

Przemysław Kłapa, Bartosz Mitka

Summary

The edge effect is a measurement error resulting from the reflection of the laser beam on the adjacent walls, or by its breaking on the edges. Coordinates of points in such cases are determined by averaging the measurements in several areas, resulting in their incorrect positioning in space. Corner points are determined with the same accuracy as the other (flat) elements of the scanned object. This effect is frequently mentioned in publications, which typically state the reasons and mechanisms of the error thus occurred. However, there is a lack of specific examples, showing the impact of the edge effect on the quality and accuracy of geodetic and cartographic reports. In this paper, the authors present sample case studies of the 2D and 3D representation of the test object. The selected corner elements, as well as the vector elements fitted into a cloud of points, show the discrepancy between the breaking points in the drawing (model), and the curved surface of the point cloud. On the basis of the known geometry of the building, distances were determined between the corner points and their representatives on the cloud. In this way, we were able to determine the accuracy of corner points' presentation by means of the cloud of points, and therefore, we were able to determine the size of the edge effect in specific cases.

Keywords

Laser scanning • measurement errors • edge effect • cartographic representation

1. Introduction

A number of publications provide information about the measurement errors occurring during laser scanning. The most common of these include: errors related to the impact of the environment on the quality of the measurement; errors derived from a malfunctioning of the instrument; or those resulting from improperly performed observations, for instance, methodological errors.

One of the most common errors that occur during the measurement is the edge effect. We find the explanations of what it is and when it occurs in many published studies. However, there is insufficient literature dealing with the results caused by this type of error, when using the point cloud for geodetic and cartographic studies.

We can distinguish two main types of work involving the vectorization of the point cloud, and performing various kinds of studies on that basis. 2D representations are the first type. These can include, for example: projections, sections of buildings, drawings of elevations or various elements. The second type is the modelling, that is the work that results in developing a 3D model of the given object. In the latter case, the edges are of even larger importance, and their number (compared to the 2D representations) is far greater. Error, in this case no longer refers to the two coordinates (X , Y), but also to the third (Z). This issue is all the more important that especially in the case of historic buildings, or those with rich architectural details, we shall often encounter both sharp edges and curves, and their correct identification will be reflected in the quality of the final result (representation or report). In the article the authors explain, what is the edge effect, where it comes from, and what consequences it entails.

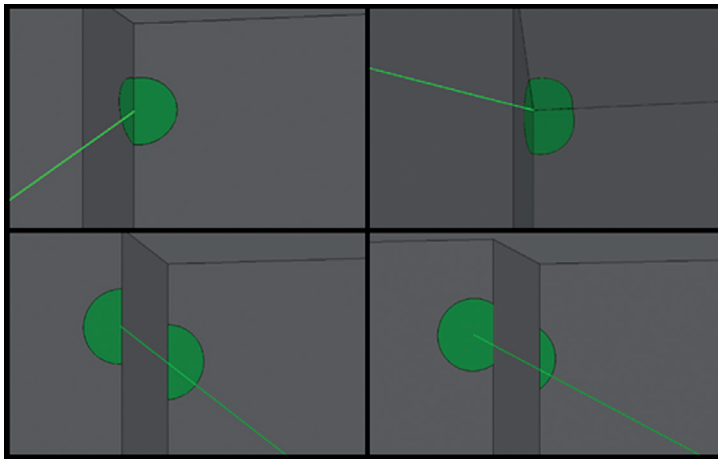
2. Edge effect – its occurrence and its impact on the cloud of points quality

Scanners use mounted rotating mirrors, which reflect the laser beam and perform distance measurements in a certain segment of the surrounding sphere. By conducting the measurement of the angles of the sent beam, the measuring instrument determines the spatial coordinates (X , Y , Z) of points, which reflect the surface of the object being scanned. The cloud of points thus created contains information about: the terrain, the buildings and technical facilities within the range of the scanner's operation.

The TLS technology (where TLS stands for Terrestrial Laser Scanning) makes it possible to measure the position of the spatial points with an accuracy of several millimetres. The quality of the obtained cloud of points is directly linked to the impact of the various stages of its creation and processing. It also depends on four major factors: the operation of the mechanism of the instrument; the weather conditions; the properties of the surface of the object being scanned; as well as the scanning geometry [Soudarissanane et al. 2011]. The possibilities afforded by the TLS technology are almost limitless. Note, however, that the laser scanning, just like any other geodetic measurement is subject to error, which must be properly defined and classified. The size of the modelled error generated during the measurement is influenced by many factors, both physical and empirical. These can include, among others, the rangefinder error (offset), collimation and inclinations errors, vertical and horizontal index errors, and other cyclical and random errors [Lichti and Licht 2006]. Many studies are conducted aiming at the determination of the calibration parameters of individual scanners, and developing methods of auto-calibration of devices in order to configure measurement parameters in such a way that the measurement can be carried out with the highest accuracy possible [Lichti 2007]. This will allow us to avoid confusion during the measurement studies, as well as provide the appropriate level of accuracy and quality of the generated reports/models.

One of the fundamental characteristics of the scanner is the width of the beam used in the laser instrument, along with its divergence. The latter has a significant impact on the resolution of the point cloud, and on the accuracy of mapping of the measured object.

Laser pointer - formed during the operation of the scanner – when hitting an object, takes a certain value. Since the laser beam is not a point but an ellipse, when it is hampered by the break of the surface, it gets divided into two or more parts (Figure 1). Different grades of breaking from the surface of the object cause various distortions to the exact determination of the location of the laser's incidence [Cosarca et al. 2008]. When we direct the laser beam to the edge of the break of the object, the result is that only a part of the range of the laser point hits its edge. The remaining part is reflected from the adjacent walls, and it can even go unregistered by the instrument [Boehler et al. 2004].



Source: authors' study

Fig. 1. Possible situations of the laser beam hitting the edge: the laser point hits simultaneously two or three adjacent walls, in various proportions of surface

The energy of the laser point, reflected from the object, and returning from it, gets recorded. Either based on the time of its return, or based on the information about the phase shift, spatial coordinates are designated, which are incorrectly calculated. This happens, because the information is derived not only from the corner of the element, but also from its surroundings. The averaged result leads to the situation, where the point in the cloud is not in the right place, and thus creates the edge effect. This effect rounds the corners. Information is obtained about locations around the edge, whereby averaged results are given to the points. Then, the latter are entered into the point cloud as an alleged representative of the edge. In the case of TLS technologies, depending on the position of the measuring stand with respect to the object being scanned, the size of such error may vary from a few millimeters to a few centimeters in extreme cases [Boehler et al. 2004].

The size of the edge effect is affected by many factors: beginning with the shape, texture and color of the object being scanned, to the scanning distance, to the type and quality of the scanner. Many examples and experiences drawn from the analysis and

subsequent conclusions can be found in publications by, among others: [Boehler et al. 2004, and Voegtle et al. 2008]. The accuracy and the quality of the obtained point cloud are also affected by the amount of noise that arises during the measurement. Noise is a distributed laser beam, causing interference to the recording of points. Noise can be an additional problem, which in combination with the edge effect causes difficulties in determining the precise position of the corner points of the scanned object. These are usually caused by: bad conditions of the scanning, the surface, texture, or color of the object being scanned that is wrong for the given type of laser. The resulting noise, combined with the edge effect, contributes to difficulties in determining the precise position of the corner points of the scanned object [Soudarissanane et al. 2007].

In the case of the large number of points defining the spatial position of the object in its surroundings, it is almost impossible to precisely register the corner points and edges. These data must be subjected to a modelling process based on a cloud of points, in order to obtain their spatial geometry as well as accurately marked edges and breaking points. It is possible to measure one object from different measurement stations, and subsequently combine the results thereof. It is impossible to obtain exactly the same measurement points. They are only used to supplement the information about the surface of the object. Deviations from the positions of points on the cloud, and the actual dimensions of the object, presented in the form of models, can be identified and measured. In order to do this, we need to know the geometrical parameters of the scanned object. For conducting such experiments, in terms of the best properties, it would be ideal to use an object with a flat surface and well-defined shapes. Therefore, almost any object could be considered provided that it lies within the range of the scanner [Boehler et al. 2004].

3. Research methodology

For the present study, we have used Z + F Imager 5010 and Leica P40 scanners. The first of the scanners was used to scan a fragment of a housing estate within the city, located in the north-eastern part of Kraków. The cloud of points in this area includes within its scope a number of spatial elements, which are located directly in our environment. The second device was used to scan the area of the Comparatorium unit at the University of Agriculture in Krakow, featuring spatial elements with known geometrical parameters. They constitute examples of studies on the elements, which have been carefully measured, and the size of breaking points, as well as exact locations of edges and corners are known. The juxtaposition of these two extremely different types of objects will illustrate what level of edge effect has an impact on the quality and accuracy of geodetic and cartographic modelling.

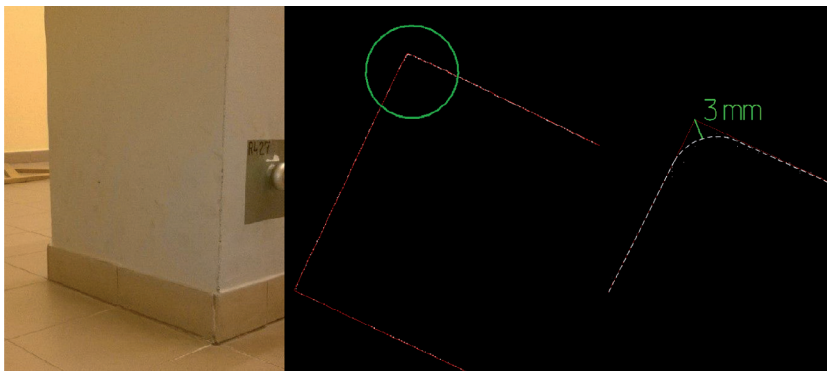
4. Impact of the edge effect on 2D modelling

Flat (two-dimensional) modelling constitutes the most commonly performed representation in geodesy. This group includes not only maps, performed for various purposes,

but also plans, cross-sections, and elevation drawings of buildings. These drawings are developed using the data points obtained through the work of Total Stations, GPSs, and – increasingly often – also the laser scanning technology. When drawing subsequent items, we use spatial point data, whose positional accuracy is determined using precision analysis. The points, whose location accuracy is too low, are removed from the study, because they do not provide an appropriate accuracy level in terms of the representation of reality.

During the deskwork on collating and reporting the measurements from terrestrial laser scanning, we are able to determine the accuracy of the position for individual points in the cloud. The edge effect introduces some degree of difficulty in mapping individual buildings. In addition to the errors that it carries, it also causes difficulties in obtaining a clear indication of the breaking points and edges of the measured objects.

The figure below (Figure 2) shows a fragment of the plan of the Comparatorium unit at the Agricultural University. The object was scanned using Leica P40 scanner. The facility includes such elements as: measurement pillars; a large rectangular platform, which is a concrete platform used to perform geodetic and measurement studies; and other items that are part of the Comparatorium unit equipment. The aforementioned concrete platform and a measuring pillar were subjected to the analysis. The report on the measurement results, using the cloud of points, was presented in the form of the 2D presentation, which shows the scanned object and its reflection in the form of a portion of the point cloud, with the superimposed geometric model of the object.



Source: authors' study

Fig. 2. Accuracy of determination of the platform's edges (fragment of the plan, accuracy analysis of the edges' fit, view of the studied object)

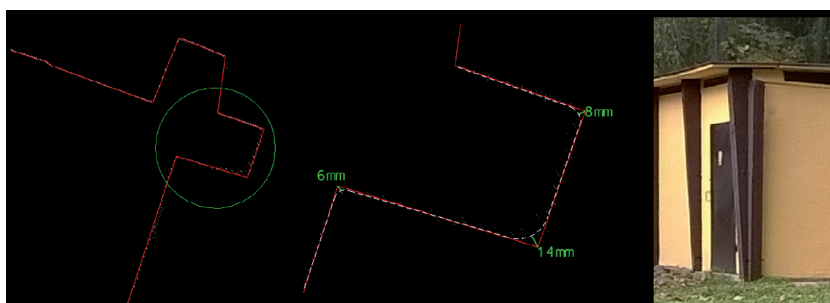
In Figure 2, attention should be paid to the edges of the concrete platform. In these places there is a noticeable inconsistency of the developed report, compared to the cloud of points. Our knowledge of the elements' breaking points in these places (that is to say, our knowledge of the geometry of the object) allows us to determine the error that edge effect introduces to the point cloud. The measurement between the tip of

the breaking point (the actual location of the corner points), and the curve of points from the scanning, allows us to determine the accuracy of mapping the position of the measuring points.

An error of several millimetres is a relatively small error, given the well-known geometry of the measured object. This allows for an almost perfect fit with the actual edge.

Another example illustrating this effect is developing the plans of buildings, scanned with the Z+F 5010 scanner. Figure 3 shows a fragment of a representation developed for a number of edges and corners of buildings, as well as the measurement of the difference between the actual position of points (lines of the drawing), and the position of their counterparts in the point cloud.

The white dashed line, indicated in Figure 3, represents the outline of the point cloud, which has been compared with the continuous red line, showing the outlines of the object. The differences between the theoretical position of the object's corner and its counterpart on the cloud of points allowed us to determine the accuracy of mapping the edges. Errors are observed at the level of several millimetres.



Source: authors' study

Fig. 3. The impact of the edge effect on the accuracy of determining the corner points (fragment of the plan, accuracy analysis of the edges' fit, view of the studied object)

5. Impact of the edge effect on 3D modelling

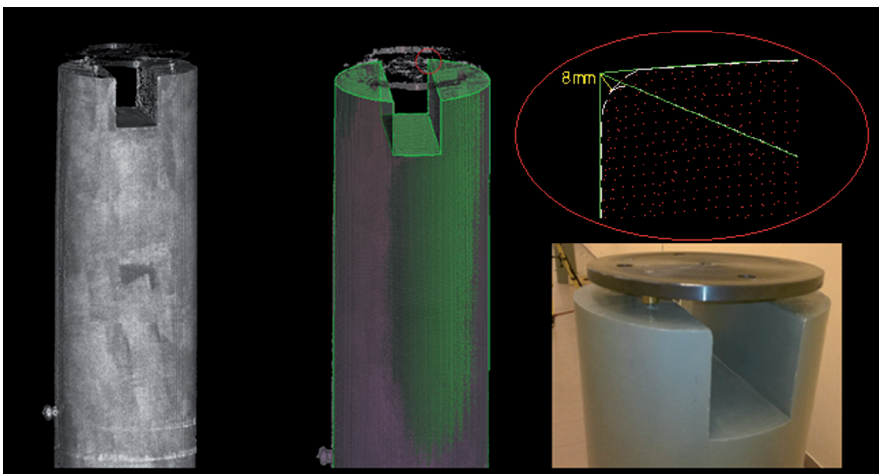
3D modelling of different types of buildings has become very popular, as a fast and accurate tool to perform a full inventory of objects. Much work has been put into developing automated 3D modelling processes that could use digital maps and the cloud of points obtained from the measurement in order to automatically create objects. With a detailed and dense cloud of points, it is possible to precisely create the actual mapping of spatial objects [Pu and Vosselman 2006, Pu 2008]. Increasingly often, possibilities of auto-fit of the corresponding geometric elements (e.g. the planes) in the cloud of points are being applied. For the latter purpose, algorithms are developed that recognize specific objects in point clouds. In their breaking points and discontinuities, outlines are drafted, representing the edges of the object [Tang et al. 2010]. Unambiguous inter-

pretation of the edge is difficult due to the occurrence of the edge error – therefore the intersection of planes helps to determine them unequivocally. The geospatial data, obtained using laser scanners, serve not only for the creation of 2D and 3D models of individual objects, but also their larger sets and combinations. Examples of such studies are presented, among others, in the work of [Arayici 2007].

The edge effect, as shown in 2D representations, here too, has its impact, and that impact is felt to a greater extent. It does not affect only two edges, but the three, which contain between them a rounded sphere of points – instead of the designated points of the edges. In this case especially, we need to pay attention to whether the object has naturally rounded edges or not. If yes, then the cloud of points, and the developed model should reflect such rounded edges. If the edge effect occurs, it must be identified and eliminated from the study. In order to be fully satisfied as to the shape of the corners and the edges, we need to know the object, or conduct a supplementary scan to fill in the measurement data, for instance, of the images that contain dubious elements, or ones that are likely to cause problems at the stage of the further deskwork.

An example of a 3D model of an object of known geometry is the measuring pillar located in the Comparatorium unit at the University of Agriculture in Kraków. This is a concrete pillar in the shape of a cylinder with a height of 1.421 [m], and a diameter of 0.458 [m] with an indent extending through the entire width of the column; indent dimensions being the following: width – 0.135 [m], height – 0.165 [m].

The marked, actual edges (in the presented model) were compared with the edges represented by the cloud of points. Figure 4 shows the cloud of points representing the measuring pillar; the theoretical model of the object; and their comparison, which made it possible to determine the value of the error arising from the edge effect.



Source: authors' study

Fig. 4. Determining the value of the edge effect between the 3D model and the cloud of points, being the image of the measurement pillar

Measuring the pillar is only possible by comparing the measurement between the upper base and the surface of the floor on which the object is embedded. Accurate and precise measurement of the cloud of points representing the edge of the column is made difficult by the rounding of the edges, visible in the cloud of points. Multiple measurements of the individual elements of the pillar, carried out on the basis of the cloud of points, allowed us to determine the dimensions and their respective accuracies. The measurements of the height and the width of the pillar remain in the range of: $\pm 0.002\text{m}$ with respect to the adopted reference value. The indentation of the pillar is determined with the accuracy of ± 0.004 [m] for the height, and the accuracy of ± 0.002 [m] for the width. The least accurate measurement concerns the indication on the edge of the object, and the determination of the distance between the actual point and the area represented by the cloud of points. The corner of the object, presented in the drawing (Figure 4), has been subjected to comparison. Measurement of the accuracy (result of the edge effect on the developed model) was measured as the distance from the centre of the sphere of the cloud of points (for visualisation purposes, presented as a dashed white line) to the edge represented by the model (the actual edge - marked in green). The error amounting to an average of 8 mm was possible to determine through the modelling of the solid object of known geometrical parameters.

6. Conclusions

Edge effect obstructs the proper determination of the breaking points and corner points of the objects. In the aforementioned publications, you will find information on the impact of various factors on the size of the measurement error. In 2D representations, we can see a varying degree of impact of the edge effect on the accuracy of the drawings as they are developed. In most of these, the error remains in the range of several millimetres. The errors that arise are lesser when we know the exact geometry of the drawn solids, because we have the necessary knowledge about their edges. By drawing the lines denoting the object's plane elements, and combining them together, we are able to properly set the edges. This is not the case, if instead of having sharp edges, the corners are rounded. In the latter case, the knowledge of geometry is necessary in order to avoid an error during the study.

3D modelling, which is a three-dimensional drawing, allows for accurate representation of the scanned object via a three-dimensional solid. The impact of the edge effect influences the quality of the developed representations and reports. Errors of several millimetres typically result from the disappearance of the corner points, which is most particularly felt in the peak points.

To a large extent, in order to avoid errors caused by the edge effect, in the measurements we conduct we should use high quality laser scanners, which register high-resolution cloud of points. The greater the density of the points that map the measured object is, the clearer the selected edges. The material, the texture and the environment all have an impact on the quality of the measurement. Also the amount of noise gener-

ated is of great importance to the precision issues, particularly in the emerging edge effect, which is formed at each measurement with laser scanners.

References

- Arayici Y. 2007. An approach for real world data modelling with the 3D terrestrial laser scanner for built environment. *Automat. Construct.*, 16, 816–829.
- Boehler W., Bordas Vincent M., Marbs A. 2004. Investigating laser scanner accuracy. XIX CIPA Symposium at Antalya, Turkey, 30 Sep–4 Oct 2003. Updated for Web presentation April 2004. i3Mainz, Institute for Spatial Information and Surveying Technology.
- Cosarca C., Jocea A., Savu A. 2008. Analysis of error sources in Terrestrial Laser Scanning. *J. Geod. Cadastre*, 115–124.
- Lichti D. 2007. Error modeling, calibration and analysis of an AM-CW terrestrial laser scanner system. *ISPRS J. Photogram. Remote Sens.*, 61, 307–324.
- Lichti D., Licht M. 2006. Experience with terrestrial laser scanner modeling and accuracy assessment. *The International Archives of the Photogrammetry. Remote Sens. Spatial Inform. Sci.*, 36(5), 155–160.
- Pu S., Vosselman G. 2006. Automatic extraction of building features from terrestrial laser scanning. *The International Archives of the Photogrammetry. Remote Sens. Spatial Inform. Sci.*, 36(5), 25–27.
- Pu S. 2008. Generating building outlines from terrestrial laser scanning. *The International Archives of the Photogrammetry Remote Sens. Spatial Inform. Sci.*, 37(B5), 451–455.
- Soudarissanane S., Ree J., Bucksch A., Lindenbergh R. 2007. Error budget of terrestrial laser scanning: influence of the incidence angle on the scan quality. *Proceedings 3D-NordOst*, 1–8.
- Soudarissanane S., Lindenbergh R., Menenti M., Teunissen P. 2011. Scanning geometry: Influencing factor on the quality of terrestrial laser scanning points. *ISPRS J. Photogram. Remote Sens.*, 66(4), 389–399.
- Tang P., Huber D., Akinci B., Lipman R., Lytle A. 2010. Automatic reconstruction of as-built building information models from laser-scanned point clouds. A review of related techniques. *Automat. Construct.*, 19, 829–843.
- Voegtle T., Schwab I., Landes T. 2008. Influences of different materials on the measurements of a terrestrial laser scanner (TLS). *The International Archives of the Photogrammetry. Remote Sens. Spatial Inform. Sci.*, 37(B5), 161–166.

Mgr inż. Przemysław Kłapa
Uniwersytet Rolniczy w Krakowie
Katedra Geodezji
30-198 Kraków, ul. Balicka 253a
e-mail: przemyslaw.klapa@wp.pl

Dr inż. Bartosz Mitka
Uniwersytet Rolniczy w Krakowie
Katedra Geodezji Rolnej, Katastru i Fotogrametrii
30-198 Kraków, ul. Balicka 253a
e-mail: bartosz.mitka@ur.krakow.pl