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The analysis of 3D geometric features on point clouds by using open-source software

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Point Cloud
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3D Model

Abstract

The modeling of point clouds is significant for geomatics engineering and others (such as machinery and construction) engineering and architectural applications. Furthermore, 3D models, which are currently used for various engineering fields, have been increasingly crucial with the introduction of digital twins, virtual reality, 3D city modeling, reverse engineering, and metaverse recently. For this reason, the importance of 3D models is increasing more and more. Range-based modeling (e.g., laser scanning) is one of the most common approaches for generating 3D models. Also, 3D model acquisition (terrestrial and airborne Light Detection and Ranging (LiDAR) or structure-from-motion (SfM)) and 2D imaging techniques are usually transformed into models such as 3D mesh and parameter surface before they are visualized or analyzed for 3D surfaces. This study analyzed 3D point cloud models obtained with terrestrial laser scanners with open source software (Cloud Compare). Also, many approaches to model extraction have been tried to obtain corner points and lines using various 3D geometric analyses.

1. Introduction

3D models, which are currently used for cultural heritage or various engineering fields, have been increasing in importance with the introduction of technologies such as digital twins, virtual reality, 3D city modelling, reverse engineering and metaverse into human life recently. Also, Historical artifacts are exposed to many natural or unnatural destructions from the past to the present. Because; the studies carried out to protect the cultural heritage for informing the next generations about the history are accelerating day by day all over the world, and their (3D Models) importance is increasing to a great extent. (Kuçak, R. A., 2013; Kuçak, R. A., et al., 2016)

Nowadays, the generation of a 3D model for cultural heritage or archaeological sites is mainly achieved using non-contact systems based on light waves, particularly using active or passive sensors. There are currently four alternative methods for object and scene modeling:

1. Image-based rendering, which does not generate the geometry of a 3D model but might be preferred as a promising technique for the generation of virtual aspects
2. Image-based modeling (e.g., photogrammetry), the widely preferred method for geometric surfaces of architectural objects and Cultural Heritage documentation
3. Range-based modeling (e.g., laser scanning) is becoming a widespread approach for the scientific community and non-expert users such as Cultural Heritage professionals.
4. The combination of an image and range-based modeling, as they both have advantages and disadvantages, and their integration can allow the generation of detailed 3D models efficiently and quickly (Almagro A. and Almagro Vidal A., 2007, Kuçak, R. A., et al., 2016).

From the air or the ground, laser scanning is one of those technological developments that enable many 3D measurements to be collected in a short time. It generates a 3D point cloud in a local coordinate system with intensity values; internal or external digital cameras usually provide additional information such as RGB values. Laser scanners can operate from the ground or be integrated into an airplane. However, Laser scanning from any platform generates a point cloud: a collection of XYZ coordinates in a coordinate system that portrays to the viewer an understanding of the spatial distribution of

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a subject. It may also include pulse, amplitude, intensity, or RGB values. Generally, a 3D point cloud contains a relatively large number of coordinates compared to the volume the cloud occupies, rather than a few widely distributed points. (Kuçak, Kiliç, & Kisa, 2016)

Terrestrial laser scanning data can be used by editing in various CAD programs for architectural projects. This study aims to carry out a 3D analysis of the building scanned with 3D terrestrial laser scanning technology. After analyzing object details by scanning with the terrestrial laser scanner, the 3D geometric features of the 3D point clouds were generated. Also, the advantages and disadvantages of open source code software are evaluated for obtaining 3D surfaces and performing various surface analyses using an Open Source program (Cloud Compare).

In this study, the TLS point clouds are selected to gain the 3D Geometric Features. Thus, it is intended a contribution to the geometric accuracy of cultural heritage and 3D city models to be produced with point clouds. The faculty of Civil Engineering in the Ayazaga Campus of ITU in Turkey was selected as the study area. The study area was scanned with Leica C10, which can get 50,000 points per second with 6 mm accuracy. Furthermore, the 3D geometric features of the 3D point cloud were carried out.

2. Data and Method

The faculty of Civil Engineering located in Ayazaga Campus of ITU in Turkey was selected as study area (Figure 1). The study area scanned with Leica C10, which can get 50,000 points per second with 6 mm accuracy. The 3D surface analysis of 3D point cloud were carried out.

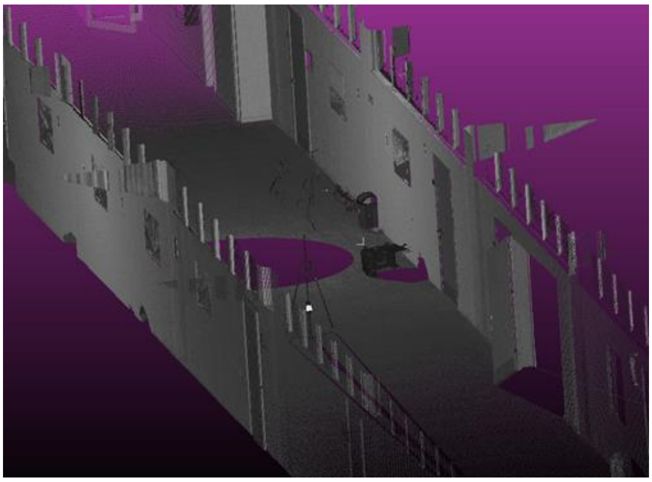

Figure 1. TLS Point Cloud (Leica C10)

2.1. TLS

LiDAR (Light Detection and Ranging), from the airborne or terrestrial, is one of technical systems that enables to collect a large quantity of 3D data in a short space of time. It creates a point cloud with density values in the local coordinate system; additional information such as RGB values are usually provided by internal or external digital cameras.(Kuçak, Kiliç, & Kisa, 2016; Kuçak, Özdemir, & Erol, 2017)

TLS is a powerful technology for collecting 3D data spread over a large area in a short time. (Kuçak et al., 2013, Kuçak et al., 2016, Kuçak et al., 2020). TLSs consist of lasers, precisely calibrated receivers, precision timing, high-speed micro-controlled motors, and precise mirrors (Fowler & Kadatskiy, 2011). The basic information obtained from each scan is the virtual point cloud formed by all of the 3D points of the surfaces measured in harmony with each other (Scaioni, 2005). The precision and accuracy of TLS make the TLS system a powerful technology for creating a 3D dense point cloud according to the conventional measuring methods (Çelik et al., 2020). However, the registration of TLS scans must be done carefully because the registration errors affect the 3D model quality.

2.2. 3D Geometric Features

Surface parameters help explain the local geometry of the surface. These surface features are nowadays widely applied in point cloud analyses. They are aimed to extract these geometric features (surfaces, lines, corners and key points). Surface parameters (Table 1) can be calculated by the eigenvalues (λ_1, λ_2, λ_3) of the eigenvectors (v_1, v_2, v_3) derived from the covariance matrix of any point p of the point cloud (Atik, M. E., Duran, Z., & Seker, D. Z. 2021).

Table 1. Geometric Features derived from eigenvalues

Sum of eigenvalues	$\lambda_1 + \lambda_2 + \lambda_3$
Omnivariance	$(\lambda_1.\lambda_2.\lambda_3)$^1\3
Anisotropy	$(\lambda_1 - \lambda_3)/\lambda 1$
Planarity	$(\lambda_2 - \lambda_3)/\lambda 1$
Linearity	$(\lambda_1 - \lambda_2)/\lambda 1$
Surface variation	$\lambda_3/(\lambda_1 + \lambda_2 + \lambda_3)$
Sphericity	λ_3/λ_1
Verticality	λ_1.In λ_1+ λ_2.In λ_2+ λ_3.In λ_3

Many values are calculated using eigenvalues (Table 1). (Sum of eigenvalues, omnivariance, roughness, anisotropy, planarity, linearity, surface variation, sphericity and curvatures etc.) these parameters derived from only 3D coordinates.

2.2.1. Gauss and Mean curvatures

Curvatures are a surface's geometrical features that are invariant according to rotation, translation, and scaling. There are many methods to calculate the Curvature of a surface. The Curvature can be calculated easily when the analytical formula is available for a surface, but these methods are not usually applicable to point clouds' surfaces. So, the surface fitting method depending on a point and its neighbors is a good way. (Foorginejad & Khalili, 2014)

$$Z = r(x,y) = a_0x^2 + a_1y^2 + a_2xy + a_3x + a_4y \qquad (1)$$

This quadratic surface's (1) parameters $(a_0, a_1, a_2, a_3, a_4,)$ is estimated by the least square method, and the Gaussian (K)(2) and Mean Curvature (H) (3) can be calculated by the differential geometry (He, Lin, & Li, 2013):

$$K = \frac{\mathrm{LN} - M^2}{2(\mathrm{EG} - F^2)} \quad (2)$$

$$H = \frac{\mathrm{EN} - 2FM^2 + GL}{2(\mathrm{EG} - F^2)} \quad (3)$$

where $E=r_x.r_x$, $F=r_x.r_y$, $G=r_y.r_y$, $L=r_{xx}.n$, $M=r_{xy}.n$, $N=r_{yy}.n$, and r_x, r_y, r_{xx}, r_{yy}, r_{xy} are the partial derivatives of the quadratic surface. (He, Lin, & Li, 2013)

For the curvature estimation, another method is the covariance analysis method (Hoppe, DeRose, Duchamp, McDonald, & Stuetzle, 1992), which uses the ratio between the minimum eigenvalue and the sum of the eigenvalues. This method is known as the surface variance (Pauly, Gross, & Kobbelt, 2002). The surface variance is appropriate for point clouds because it uses the coordinate of a point and its neighbors, and it is not expensive to process. (Foorginejad & Khalili, 2014).

3. Results

In this study, we calculated the curvatures of a surface by using TLS point clouds. Also, the TLS base distances were compared with the total station base distance using statistical methods to determine the TLS data accuracy. Then, the coarse errors had removed from both data. Thus, the standard deviation of the difference of the base distances was calculated. As a result, the standard deviation for TLS data was obtained as 0.005 m. Then, we filtered and segmented the data according to optimum curvatures. In this way, we could quickly obtain vertices and boundary lines from 3D point clouds.

Many values are calculated using eigenvalues (Table 1). (Sum of eigenvalues, omnivariance, roughness, anisotropy, planarity, linearity, verticality (Figure 2) surface variation, sphericity and curvatures (Figure 3) etc.) Since the datasets used contained only geometric information (3D coordinates).

By using 3D geometric features, corner lines of 3D point clouds and various curved surfaces are obtained as in figure 4. These lines can serve many purposes by automatically converting them into lines and key points in various engineering works.

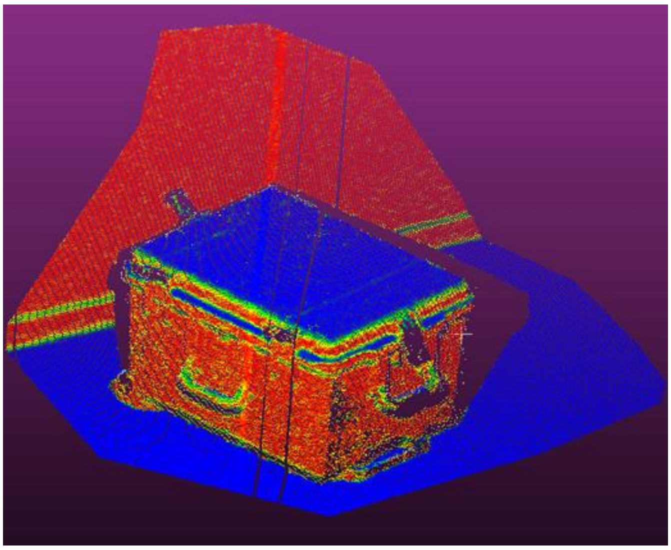

Figure 2. TLS Data According to verticality (Leica C10)

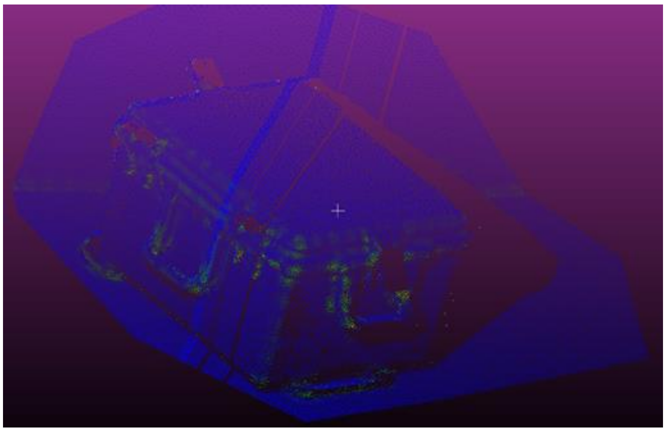

Figure 3. TLS Data According to Gauss Curvature (Leica C10)

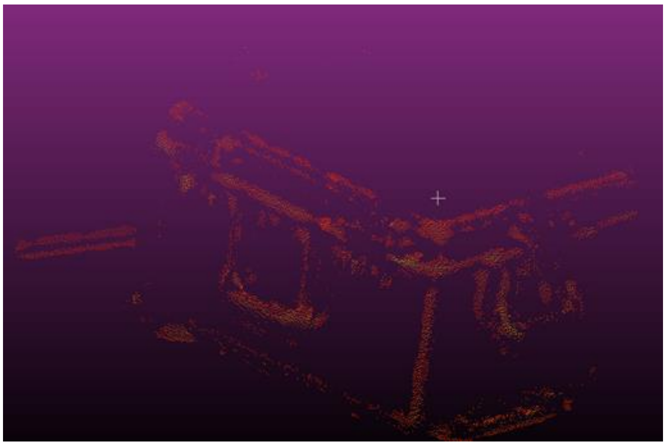

Figure 4. Vertices and boundary points from 3D point clouds.

4. Discussion

In this study, the TLS point clouds are selected to gain the 3D Geometric Features. Thus, it is intended a contribution to the geometric accuracy of cultural heritage and 3D city models to be produced with point clouds. The faculty of Civil Engineering in the Ayazaga Campus of ITU in Turkey was selected as the study area.

Then, the curvatures of a surface were calculated. the data was filtered and segmented according to optimum curvatures. In this way, we could quickly obtain vertices and boundary lines from 3D point clouds.

The resolution and accuracy of point clouds are very important to generate 3D accurate models and surface parameters. For this reason, to work with high resolution and accuracy point clouds is the basis of studies to be done in the point clouds rather than more point clouds in the 3D modeling. So, the use of high-precision point and sufficient point clouds for data modeling is very important. Various filtering methods can be applied for modeling and interpolation and surface pass-through operations; however, if the data were missing or incorrectly measured, modeling or interpolating the data is always a challenge. There are a few methods to correct this deficiency; either the resolution of data should be increased, or the accuracy analysis of point clouds should be done. According to the obtained results, combining the point clouds and performing the interpolations will pave the way for more correct models.

5. Conclusion

To work with high-accuracy points to model point clouds and enough data is very important issue for point cloud studies. Also, in point cloud studies which accuracy or resolution is enough for modelling important. If the point clouds are sufficient for the desired works, the registration or modeling steps can be realized. However; if the desired surface data in the existing point cloud is missing and not in sufficient accuracy and resolution, it will be a more accurate approach to produce a more accurate point cloud from the existing point cloud and integrate it into the reference data for interpolation or modeling.

The experiments performed in this study show that one unique technique or geometric feature cannot be recommendable for the 3D Surface parameters or models of a 3D point cloud. However, geometric features of point clouds produced at multi scales can be used for vertices, boundary lines, and 3D surfaces from 3D point clouds.

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