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The Feature Extraction from Point Clouds using Geometric Features and RANSAC Algorithm

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Keywords
LiDAR
TLS
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RANSAC
3D Model

ABSTRACT

The feature extraction of point clouds is essential for geomatics engineering as well as other engineering and architectural applications. Furthermore, with the recent entrance of digital twins, virtual reality, 3D city modeling, reverse engineering, and metaverse into human existence, 3D models, which are currently used in numerous technical sectors, have become increasingly important. As a result, the 3D model generating methods become more important. One of the most prevalent methodologies used by scientists is range-based modeling (e.g., laser scanning). Additionally, before being visualized or analyzed for 3D surfaces, 3D model acquisition (Light Detection and Ranging (LiDAR) or structure-from-motion (SfM)) and 2D imaging approaches are commonly converted into models such as 3D mesh and parameter surface. This study analyzed 3D point cloud data obtained with terrestrial laser scanners. Also, many approaches to model extraction have been tried to obtain 3D models, planes, corner points, and lines by using various 3D surface analyses and Random Sample Consensus (RANSAC) Algorithm.

1. INTRODUCTION

With the recent entrance of technologies such as digital twins, virtual reality, 3D city modeling, reverse engineering, and metaverse into human existence, 3D models, which are currently employed for cultural heritage or diverse engineering sectors, have grown in importance. From the past to the present, historical artifacts have been subjected to a variety of natural and artificial destructions. Because research into preserving cultural assets for enlightening future generations about history is accelerating around the world, and its (3D Models) relevance is overgrowing. (Kuçak, R. A., 2013; Kuçak, R. A., et al., 2016; Alptekin and Yakar., 2020; Alptekin et al., 2019a; Alptekin et al., 2019b)

Nowadays, non-contact approaches based on light waves, notably active or passive sensors, are used to produce 3d models for cultural heritage or archaeological sites. For object and scene modeling, there are now four options:

1. Image-based rendering, which does not build the geometry of a 3D model but could be used to construct virtual aspects.
2. Image-based modeling (e.g., photogrammetry), the preferred method for preserving architectural structures' geometric surfaces and cultural heritage.
3. Range-based modeling (e.g., laser scanning) is becoming a typical approach for scientists and non-expert users such as Cultural Heritage personnel.
4. The combination of image and range-based modeling, as each has advantages and weaknesses, and their integration can allow for the efficient and rapid development of detailed 3D models. (Almagro A. and Almagro Vidal A., 2007, Kuçak, R. A., et al., 2016, Korumaz, S. A. G. 2021; Altuntas et al., 2007; Ulvi and Yakar, 2014)

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Laser scanning is a modern technology that allows multiple 3D scans to be acquired in a short amount of time, whether from the air or on the ground. It creates a 3D point cloud with intensity values in a local coordinate system; internal or external digital cameras usually provide extra information such as RGB values. Laser scanners can be used on the ground or as component of an aircraft. Laser scanning, on the other hand, produces a point cloud, which is a set of XYZ coordinates in a coordinate system that depicts to the observer a knowledge of a subject's spatial distribution. Pulse, amplitude, intensity, and RGB values may also be included. (Kuçak, Kiliç, & Kisa, 2016; Ulvi et al., 2014, Yakar et al., 2009, Yakar et al., 2014))

The Random Sample Consensus (RANSAC) method (Fischer and Bolles, 1981) extracts forms by constructing candidate shape primitives by drawing minimal data points at random. If the primitives have some semantic meaning, a categorization is also performed. Then, the candidate shapes are compared to all points in the dataset to establish a value for the number of points that reflects the most excellent match. Locally fitting primitives like planes, cylinders, and cones using RANSAC-based algorithms is a popular reverse engineering strategy (Schnabel et al. 2009). (Grilli, E., et al.,2017).

Terrestrial laser scanning (TLS) data can be used by editing in various CAD programs for architectural projects. The purpose of this study is to be 3D analyze of the building scanned with 3D terrestrial laser scanning technology, after analyzed object details by scanning with the terrestrial laser scanner, the 3D models and 3D surfaces of the 3D point clouds were generated with RANSAC Algorithm. Also, the advantages and disadvantages of open source code software is to evaluate for obtaining 3D surfaces and performing various surface analysis by using an Open Source program.

In this study, the TLS point clouds are selected to model the 3D Surfaces. Thus; it is intended a contribution to the accuracy of cultural heritage 3D model and 3D city models produced with point clouds. So, the faculty of Civil Engineering located in Ayazaga Campus of ITU in Turkey was selected as study area. The study area scanned with Leica C10, which can get 50,000 points per second with 6 mm accuracy. With the RANSAC algorithm primitive shapes was extracted from the point cloud and the primitive shapes are assigned to colors that have been discovered. Also, The 3D surface analysis of 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 a study area which is an indoor data (Figure 1). The study area scanned with Leica C10, which can get 50,000 points per second with 6 mm accuracy. The study area is indoors data. The 3D surface analysis of 3D point cloud were carried out.

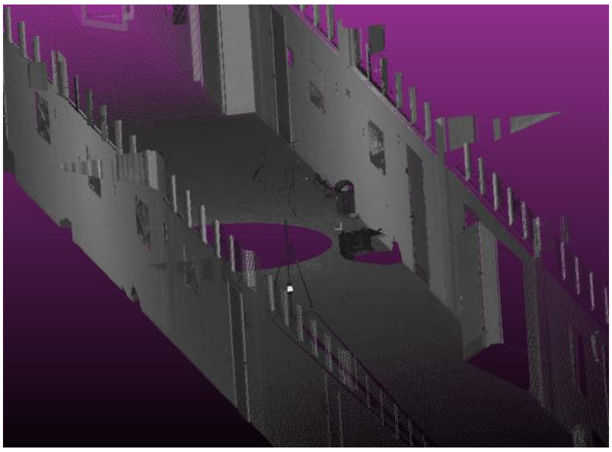

Figure 1. TLS Point Cloud indoor data (Leica C10)

2.1. Terrestrial laser scanning (TLS)

Light Detection and Ranging (LiDAR), which can be used on the ground or in the air, is an advanced technology that enables it to gather much 3D data quickly. In the local coordinate system, it generates a point cloud with intensity values; additional data, such as RGB values, are typically provided by internal or external digital cameras. (Kuçak, Kiliç, & Kisa, 2016; Kuçak, Özdemir, & Erol, 2017)

TLS is an effective technology for rapidly gathering 3D data distributed across a vast area (Kuçak et al., 2013, Kuçak et al., 2016, Kuçak et al., 2020). TLSs consist of lasers, carefully calibrated receivers, precise timing, rapid micro-controlled motors, and accurate mirrors (Fowler & Kadatskiy, 2011). The virtual point cloud generated by all of the 3D points from the surfaces that were scanned harmoniously is the fundamental data gathered from each scan (Scaioni, 2005). TLS is an effective technology for producing a 3D dense point cloud using traditional measuring techniques because of its precision and accuracy (Çelik et al., 2020). The quality of the 3D models is affected by registration errors; hence the registration of TLS scans must be done correctly.

2.2. 3D Surface Parameters

Surface parameters are used to explain the surface's local geometry. In point cloud analysis, these surface features are now routinely used. These geometric features are intended to be extracted (surfaces, lines, corners, and key points). The eigenvalues (λ_1, λ_2, λ_3) of the eigenvectors (v_1, v_2, v_3) produced from the covariance matrix of any point p of the point cloud can be used to calculate surface parameters (Table 1). (Atik, M. E., Duran, Z., & Seker, D. Z. 2021).

Table 1. Surface parameters 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
1st order moment	see Eq. (1)

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

$$m \uparrow = \sum_{n \in P_n} (p_n - p_i).,v_2, \quad (1)$$

where P_n denotes the set comprising the N nearest neighbours of each individual point p_i , (.,) denotes the scalar product, v_2 is egeinvector, m ↑ is the first order moment of p_i.

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)

For the curvature estimation, one of the most preferred methods 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).

2.3. RANSAC Algorithm

The Random Sample Consensus (RANSAC) method (Fischer and Bolles, 1981) extracts forms by constructing candidate shape primitives by drawing minimal data points at random. If the primitives have some semantic meaning, a categorization is also performed. Then, the candidate shapes are compared to all points in the dataset to establish a value for the number of points that reflects the most excellent match. Locally fitting primitives like planes, cylinders, and cones using RANSAC-based algorithms is a popular reverse engineering strategy (Schnabel et al. 2009). (Grilli, E., et al.,2017).

The RANSAC algorithm works by searching a 3D point cloud for primitive shapes (plane, sphere, cylinder, cone, and torus). It extracts primitive shapes from point cloud data by randomly picking minimal groupings of points and fitting primitive shapes. The RANSAC algorithm computes the parameters of a basic shape by randomly drawing the least number of points (a minimum set) that may uniquely define it. The program next looks for more points in the point cloud and decides whether or not they correspond to the fitted primitive shape. The generated potential primitive forms are compared to all points in the data to see how many of them the primitive can accurately approximate. The RANSAC approach compares the recognized potential primitive shape with the last saved one in each round of iteration. If the new shape is more suitable, it will replace the old one. The best possible shape is the primitive shape that approximates the most significant number of points; its parameters were generated during the segmentation process, and the points that correspond to it can be projected onto the surface. The RANSAC algorithm extracts a primitive shape from the point cloud and continues the segmentation procedure on the remaining points. The primitive shapes that have been discovered are assigned to Colors. (Liu, J., 2020)

In the classic RANSAC formula, The starting value of t is 0, and the number of times the current iteration is calculated is t (Li, M., et al.2019).

- When t is less than the target iteration number r, data points are chosen randomly from the data collection, and a model appropriate for the data is built.
- Data points that satisfy the model are located and counted in the number of data points suitable to the model from the remaining (N num) points.
- The ideal model in this iterative process is found when the number of data points suitable to the model exceeds the stated standard number "m".
- The first step is repeated to find the best model until the iterative calculation is complete.

The probability "w" that each point taken from the point cloud data set "N" is exactly an inner point is assumed in the original RANSAC algorithm. The value of w is typically unknown; however, it can be approximated using an equation (2). (Li, M., et al.2019)

$$w = m/N \quad (2)$$

P denotes the ideal probability that the initial RANSAC method will produce a helpful model once executed. The number of iterations "r" is determined by the theoretical results (3) (Li, M., et al.2019).

$$r = \text{In}(1-P) \;/\; \text{In}(1-w^{min}) \quad (3)$$

3. RESULTS

We calculated the geometric features (Table 1) of a surface. Then, we filtered and segmented the data according to optimum values. In this way, we could quickly obtain vertices, boundary lines, and 3D surfaces 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, 1st order moment and curvatures (Figure 3) etc.) Since the datasets used contained only geometric information (3D coordinates).

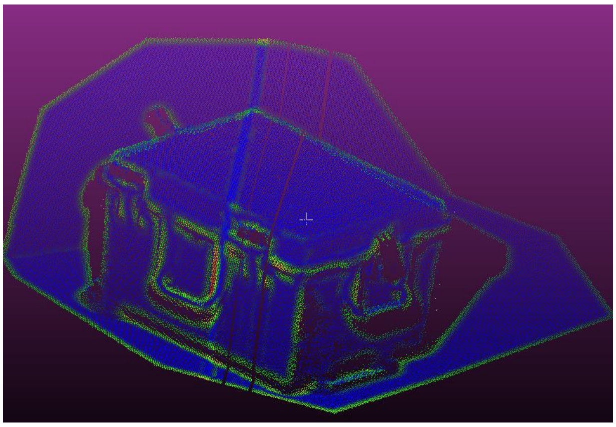

Figure 2. TLS Data According to 1st Moment (Leica C10)

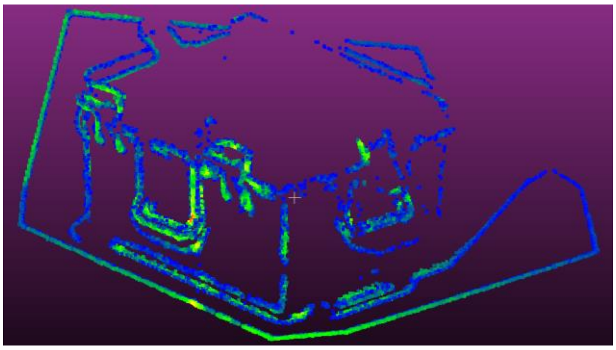

Figure 2a. Boundary lines According to 1st order Moment

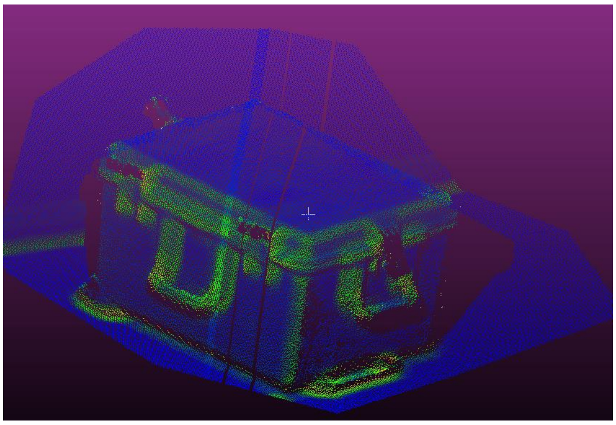

Figure 3. TLS Data According to Surface Normal (Leica C10)

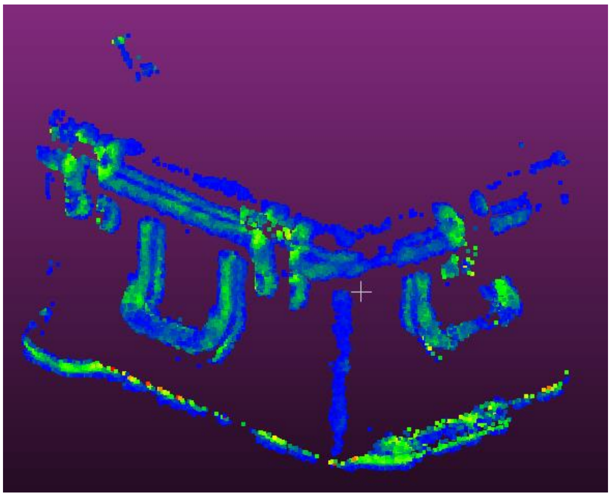

Figure 3a. Boundary and corner lines according to Surface Normal

As seen above, boundary points and corner points, which can be used in many studies, can be obtained by surface analysis (Figure 2a and Figure 3a). After these analysis, lines can be drawn automatically from the obtained points used in surveying and restoration works. On the other hand, specific primitive shapes can be extracted from point clouds to use in different engineering studies. For this purpose, the RANSAC algorithm have been tested in this study by using the Cloud compare program. Obtained results are presented at Figure 4. Locally fitting primitives like planes, cylinders, and cones using RANSAC-based algorithms is a popular. As seen from this case study, since there are only plane surfaces, the other cylinder, sphere etc. this application could not be tested either.

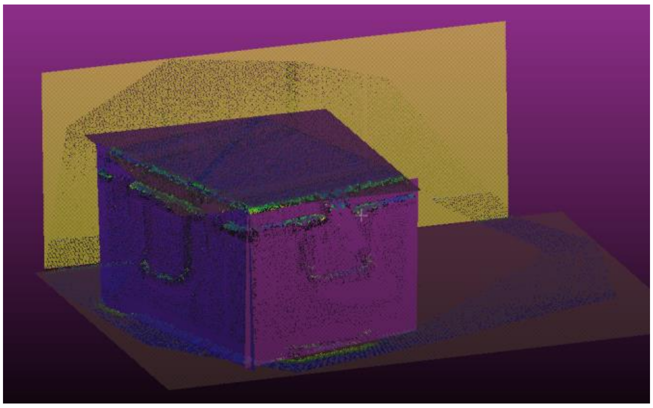

Figure 4. The primitive shapes (planes) with RANSAC Algorithm for small point cloud data

According to the results obtained from the studies with the RANSAC algorithm, the performance of the RANSAC algorithm in big data has been tested. Since there are only plane features in the case study data, plane surfaces can be obtained accurately in extensive data as follows (Figure 5).

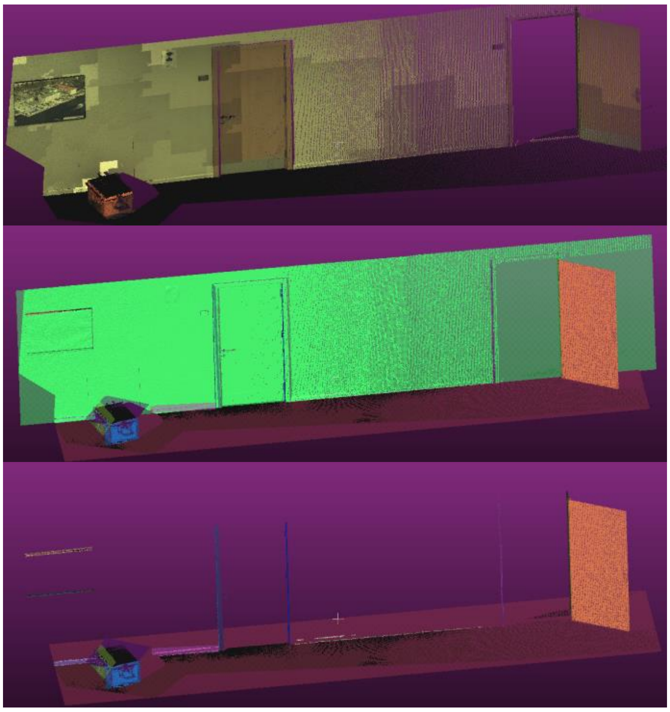

Figure 5. The primitive shapes (planes) with RANSAC Algorithm for dense point cloud

As seen in Figure 5, it is the topmost original point cloud. The figure in the middle is RANSAC applied. In the middle picture, the algorithm could extract the walls and doors clearly as a plane. The bottom picture can be seen that it can extract the plane surfaces of the doors and the painting on the wall. According to the results above, the RANSAC algorithm can easily extract plane surfaces on LiDAR data.

In this study, Total station measurements also were made to determine the accuracy of the laser point clouds. The accuracy of the laser point clouds was calculated by taking the differences from about ten distances at specific points (Table 1). TLS data was found to have a standard deviation of 0.007 m.

Table 1. The base distances of points and the differences

Points (m)	Total_Station	Lazer	Diffrence (m)
23-22	5.496	5.490	0.005
23-21	6.551	6.542	0.008
23-20	4.554	4.557	-0.002
23-19	4.657	4.635	0.021
22-21	1.694	1.697	-0.002
22-20	2.660	2.655	0.005
22-19	4.783	4.775	0.007
21-20	4.315	4.312	0.002
21-19	4.516	4.509	0.007
20-19	6.180	6.168	0.012

4. DISCUSSION

For architecture projects, terrestrial laser scanning data can be edited in various CAD systems. This research aims to perform a 3D analysis of a building scanned with 3D terrestrial laser scanning technology. After analyzing object features with a terrestrial laser scanner, RANSAC Algorithm was used to construct 3D models and 3D surfaces from 3D point clouds. The benefits and drawbacks of open source code software are also being assessed for getting 3D surfaces and doing various surface analyses utilizing an Open Source program.

Statistical methods were used to compare the base distances, and the coarse mistakes were removed from both sets of data. For TLS, the standard deviation of the base distances was computed. TLS data was found to have a standard deviation of 0.007 m. All standard deviations of the 3D models are acceptable; compared with the data accuracy acquired by the scanner of Leica.

Point cloud resolution and accuracy are critical to building 3D precise mesh models and surface characteristics. As a result, working with high resolution and accuracy point clouds rather than additional point clouds in 3D modeling is the foundation of research in point clouds. As a result, it is critical to use high-precision point clouds, plenty of them for data modeling. Various filtering algorithms can be used for modeling, interpolation, and surface fitting operations; however, modeling or interpolating data that is missing or wrongly measured is always challenging. The results show that the RANSAC Algorithm can produce high-precision and complete three-dimensional geometric models, resulting in reliable 3D data that is important for restoration and other engineering works.

5. CONCLUSION

Working with high-accuracy points to model point clouds and having enough data is a critical aspect of point cloud research. In point cloud investigations, it is also crucial to know the precision or resolution required for modeling. The registration or modeling processes can be completed if the point clouds are sufficient for the desired works. If the needed surface data is absent or of insufficient precision and resolution in the existing point cloud, it will be a more accurate technique to create 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 features cannot recommendable for the 3D Surface parameters or 3D models of 3D point cloud. In the process of surface reconstruction, Random Sample Consensus (RANSAC) is frequently applied. Geometric features of point clouds produced at multi scales can be used for vertices and boundary lines from 3D point clouds.

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Author contributions

The authors contributed equally.

Conflicts of interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The authors declare that this study complies with Research and Publication Ethics

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