UTILIZATION OF NEURAL RADIANCE FIELDS (NERF) FOR THREE-DIMENSIONAL MODELING

(Pemanfaatan Neural Radiance Fields (NeRF) untuk Pemodelan Tiga Dimensi)

Ade Rio Saputra, Muhammad Ulin Nuha, Rizqi Aulia
Department of Geomatics Engineering, Faculty of Regional and Infrastructure Technology, Institut Teknologi Sumatera
Jl. Terusan Ryacudu, Way Huwi, Kec. Jati Agung, Kabupaten Lampung Selatan, Lampung 35365
E-mail: muhammad.nuha@gt.itera.ac.id

Diterima: 4 Februari 2025; Direvisi :24 Juli 2025; Disetujui untuk Dipublikasikan: 14 November 2025

ABSTRACT

3D modeling is widely used in various fields, including urban planning, architecture, cultural heritage, medicine, and virtual reality. In the development of traditional computer vision and photogrammetry methods, several algorithms are used in building 3D models, including Scale Invariant Feature Transformation (SIFT), Speeded Up Robust Features (SURF), Oriented FAST and Rotated BRIEF (ORB), Structure from Motion (SfM), and Multi-view stereo (MVS). However, a promising and interesting new approach for 3D modeling using a set of photos has emerged, namely Neural Radiance Fields (NeRF). This research utilizes the use of Neural Radiance Fields (NeRF) in 3D modeling. The point cloud generated from NeRF was tested with TLS data using parameters such as surface variation, volume density, and point discrepancy. In addition, the geometric accuracy of the 3D model generated from NeRF was evaluated by calculating the RMSE value between the model and the research object. The results show that NeRF produces a point cloud with irregular surface variation, with an outlier rate of 58.712%. The volume density is lower compared to the TLS data. For point discrepancy, an average distance of 0.047 meters and a standard deviation of 0.066 meters were obtained with an outlier data of 6.989%. Furthermore, the geometric accuracy test of the 3D model generated from NeRF shows an RMSE value of 0.045 meters. The tests show that NeRF is capable of performing 3D modeling.

Keywords: 3D Modeling; Photogrammetry; Neural Radiance Fields (NeRF); Point cloud

ABSTRAK

Pemodelan 3D saat ini banyak digunakan di berbagai bidang seperti perencanaan kota, arsitektur, warisan budaya, kedokteran, dan realitas virtual. Dalam pengembangan metode computer vision dan fotogrametri tradisional, beberapa algoritma digunakan dalam membangun model 3D, antara lain Scale Invariant Feature Transformation (SIFT), Speeded Up Robust Features (SURF), Oriented FAST dan Rotated BRIEF (ORB), Structure from Motion (SfM), dan Stereo multi-tampilan (MVS). Namun, ada pendekatan baru yang menjanjikan dan menarik untuk pemodelan 3D menggunakan sekumpulan foto, yaitu Neural Radiance Fields (NeRF). Penelitian ini memanfaatkan penggunaan Neural Radiance Fields (NeRF) dalam pemodelan 3D. Point cloud yang dihasilkan dari NeRF diuji dengan data TLS menggunakan parameter seperti surface variation, volume density, dan point discrepancy. Selain itu, keakuratan geometrik model 3D yang dihasilkan dari NeRF dievaluasi dengan menghitung nilai RMSE antara model dan objek penelitian. Hasil penelitian menunjukkan bahwa NeRF menghasilkan point cloud dengan variasi permukaan tidak beraturan dengan data outlier sebesar 58,712%. Kepadatan volume lebih rendah dibandingkan data TLS, dan untuk perbedaan titik diperoleh jarak rata-rata 0,047 meter dan simpangan baku 0,066 meter dengan data outlier sebesar 6,989%. Selanjutnya uji akurasi geometri model 3D yang dihasilkan dari NeRF menunjukkan nilai RMSE sebesar 0,045 meter. Berdasarkan pengujian yang dilakukan menunjukkan bahwa NeRF mampu melakukan pemodelan 3D.

***Kata Kunci**: Pemodelan 3D, Fotogrametri, Neural Radiance Fields (NeRF), Point Cloud*

INTRODUCTION

Automatic three-dimensional modeling from a collection of 2D images is an active research area in computer graphics (Adipranata & Liliana, 2005). 3D modeling is currently used in various fields such as cultural heritage, urban planning, architecture, medicine, virtual reality, and so on (Pepe et al., 2023). In the field of computer graphics, 3D modeling is the process of mathematically constructing a representation of each three-dimensional surface of an object using specialized software (Suwardhi et al., 2016). However, current 3D modeling still faces many challenges in presenting 3D surfaces, and large-scale work also has some related problems in data storage

(Zainuddin et al., 2024). As developments in algorithms and tools have made the modeling process automatable, accurate, and detailed, 3D modeling is now a growing research topic (Pepe et al., 2023).

Photogrammetric techniques are known to create geometrically dense and accurate 3D point clouds using a series of overlapping photographs taken from different perspectives of the actual scene (Remondino et al., 2023). Photogrammetric methods in the field of geodesy make extensive use of close-range photogrammetry in 3D object modeling because it can share distance, area, and volume data (Roziqin et al., 2022). While photogrammetry records objects on earth with the camera position in the air, close-range photogrammetry records objects on earth with the camera position on earth (Prastyo et al., 2022). Close-range photogrammetry is used to describe photogrammetric techniques where the distance between the object and the camera is below 100 meters (Bagus et al., 2021). With the development of photogrammetric technology, it is expected to make it easier to do three-dimensional modeling of an object (Mulia & Hapsari, 2014). The development of 3D modeling based on overlapping photos still relies on traditional methods of computer vision and photogrammetry (Guo, 2023). There are several algorithms that have also been used in building 3D models, including Scale Invariant Feature Transformation (SIFT), Speeded Up Robust Features (SURF), Oriented FAST and Rotated BRIEF (ORB) (Pepe et al., 2023).

Photogrammetry has been completely revolutionized in recent decades with the introduction of computer vision and dense Multi-view stereo (MVS) reconstruction algorithms (Sambodo, 2024). The method can generate a point cloud by using bundle adjustment to calculate the camera position and object structure through image matching (Zainuddin et al., 2024). However, this method also still has shortcomings, especially in creating point cloud points on reflective surfaces that are still difficult to overcome (Murtiyoso & Grussenmeyer, 2023). To accelerate the calculation of point clouds and detailed and textured 3D models, the MVS process requires a relatively long time and high computational capabilities (Zainuddin et al., 2024). A new approach that is currently emerging and interesting to discuss, using a series of photos for 3D modeling, is Neural Randiance Fields (NeRF).

NeRF is a new method based on deep learning from the field of computer vision, which allows forming complex 3D modeling by synthesizing new scenes with the help of neural networks (Vandenabeele et al., 2023). NeRF is a neural network that aims to generate a new view of a complex three-dimensional scene based on a partial set of 2D images (Palestini et al., 2022). The method involves training Artificial Intelligence (AI) algorithms to allow 2D photos to be made into 3D objects (Pepe et al., 2023). NeRF generates volume density and radiance using an artificial neural network that is based on appearance, i.e., the amount of light emitted or reflected by a surface (Croce et al., 2023). Several studies have shown NeRF to be superior on textureless, metallic, highly reflective, and transparent objects (Remondino et al., 2023). The NeRF method also offers superior processing times, some of which are shorter than the MVS method (Murtiyoso & Grussenmeyer, 2023).

The increasing need for 3D modeling requires realistic and accurate 3D model results. The 3D reconstruction process is expected to produce high-quality point clouds effectively and efficiently. The use of non-metric cameras can be used to support accurate and low-cost mapping. Therefore, this research is expected to analyze the use of NeRF for 3D modeling. This study used photo data captured with a fisheye camera, obtained from previous research (Nuha et al., 2024), for SFM processing. The goal was to explore NeRF's ability to reconstruct 3D models using a non-metric camera for data collection. This process helped assess whether NeRF could support low-cost mapping needs.The research conducted helps in the development of 3D modeling techniques by analyzing the potential and utilization of NeRF.

METHODS

This research was conducted at Pangga Park, W.R. Supratman Street, Telukbetung, Lampung City. Objects used in 3D modeling as research material are a heritage object of the 1883 Krakatoa eruption – the Krakatoa monument can be seen in a specific location in **Figure 1.**

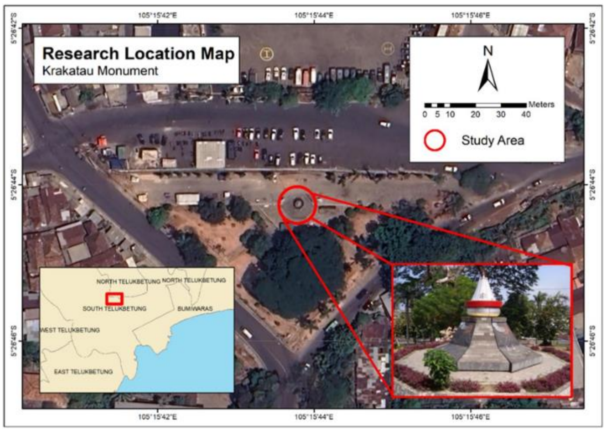


Figure 1. Research location.

Figure 1 shows the location of the research conducted. This research uses the Krakatau Monument as the object of research. It should be noted that the objects used have a homogeneous shape with several characteristics such as homogeneous, complex homogeneous, and textured homogeneous. According to RS et al., (2024), variations in objects with different radiometric characteristics will affect the results of NeRF-based 3D reconstruction. The materials used in this research are presented in **Table 1**.

Table 1. Research data.

No	Data	Description
1	Photos of Krakatoa Monument	A total of 323 photos were acquired using the Yi Xiaomi Action Camera with a resolution of 16 MP.
2	Marker Coordinates	Scattered in the measurement object area, measured using a Total Station with 4 control points that have been carried out GNSS observations of Jarring mode for 2 hours and 15 minutes.
3	TLS (*Laz)	Acquired using the Leica BLK360 TLS series with a ranging accuracy of 4mm – 10mm/ 7mm – 20mm and 3D point accuracy of 6mm – 10mm/ 8mm – 20mm.

The material that has been collected in the research is then processed using the Nerfacto workflow available in the GitHub directory. The flow of research implementation can be seen in **Figure 2**.

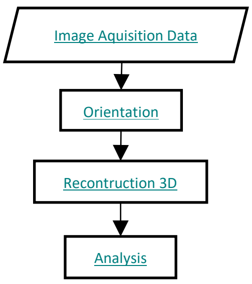


Figure 2. Research flow chart.

The photo orientation process is carried out to adjust the position between one photo and another. Through this photo orientation process, the position and viewing angle of the photos can be determined accurately, so that a more precise and realistic 3D model reconstruction can be carried out. This process is done by aligning the photos based on the Structure from Motion (SfM) algorithm in aerial photography processing software. This is because the data previously used was based on SfM processing, making it easier to input camera calibration parameters to correct for errors in non-metric lenses. Next, data processing is done to represent the 3D scene using a multi-layer perceptron (MLP) to learn the geometry and lighting of objects. In this process, Nerfstudio will also copy the input photo data into several folders with different photo qualities. One set of input photos will be copied into four folders, with each folder having photos with reduced quality from the original photo quality used. This is done because Nerfstudio utilizes Artificial Intelligence (AI) to form point clouds, and AI requires data with various resolutions and viewpoints to produce accurate models.

Then, data training is carried out, which aims to train the neural network to form a point cloud from the photos that have been processed in the previous stage. At this stage, Nerf-studio builds a neural network called "radiance field" to learn the relationship between the position of a point in 3D space and the corresponding pixel color in the photo. This artificial neural network is trained using photos of the Krakatoa Monument. Nerfstudio will also run volumetric rendering to process the photos into a point cloud. This process uses the trained neural network to predict each point, resulting in a dense 3D representation. The point cloud generated from NeRF is then exported and tested with TLS point cloud data as a reference data that is considered correct to measure the quality of the point cloud. Point cloud testing was conducted with the parameters of surface variation, volume density, and point difference. Furthermore, the 3D model generated from NeRF is calculated for its RMSE value to test how much geometry quality is generated from processing with the NeRF method. RMSE is the square root calculation of the sum of the squares of the difference between the coordinate values of the data obtained from the software and the coordinate values of the field data, divided by the amount of data (Kafiar et al., 2020). The calculation of the RMSE value can use **Equation 1** (Pardamean & Tolle, 2021).

$$RMSE = \sqrt{\frac{(yi-y)^2}{n}} \quad \text{..(1)}$$

Where:

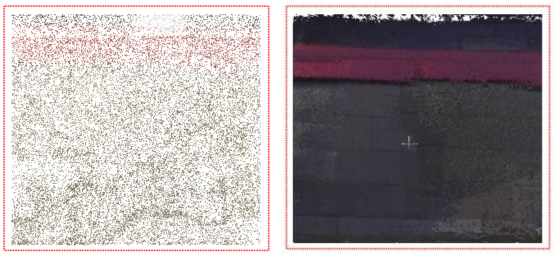
yi = Field Size (m)
y = 3D Model Size (m)
n = Amount of Data

From **Equation 1** which will be used in calculating the RMSE value of the object of research. The smaller the RMSE value obtained, the better the level of accuracy (Parmadi & Sukojo, 2016).

RESULTS AND DISCUSSION

Point Cloud Quality Analysis

The quality of the point cloud obtained from NeRF is compared with the point cloud from Terrestrial Laser Scanner (TLS), data which is the reference data that is considered to be truly accurate or close to the actual object. The number of point clouds generated from TLS is 33,064,672 points, while the point cloud generated from NeRF processing is 767,569 points. The difference in the number of point clouds produced by NeRF is certainly very significant compared to the TLS data. This is due to the data collection method in NeRF, which uses photo data in the form of a camera with a non-metric lens, while TLS is a special device for 3D modeling with the use of active sensors that directly send position information to the instrument. However, the number of point clouds from NeRF processing can be set to determine how many points will be exported. In this study, exporting is done by default because the point cloud results obtained from NeRF certainly have a lot of errors, so it is necessary to pay attention to the number of points exported to produce quality point cloud points. The quality of the point cloud results can also be seen from the density value generated from the point cloud density in m². The more point cloud data sets produced will be better and can present a more detailed model shape. The research was conducted by taking point cloud samples on a flat area with a size of 1 x 1 m², to determine the density of point cloud data generated from the NeRF method. The sample point cloud area is presented in **Figure 3**.



(a) (b)

Figure 3. Density difference of NeRF (a) and TLS (b) point clouds.

The point cloud density shown in **Figure 3** is the difference in point cloud data generated by the NeRF (a) and TLS (b) methods. In terms of point cloud data density, the results of processing with the NeRF method result in a point cloud that looks less dense than the point cloud produced by TLS. The point cloud from NeRF processing has a fairly high error rate, judging from the irregular density of the point cloud. The error rate of point clouds that have irregular distribution can affect the shape of the resulting 3D model. The point cloud produced by TLS has a fairly high density, as evidenced by the results of the point cloud produced from TLS getting a more detailed model. Comparison of the density of point clouds generated from NeRF and TLS, on a flat area taken per m², the number of NeRF point clouds is only 27,876 pts/m², while TLS gets a point cloud of 2,308,635 pts/m². It can be concluded that the density value generated from NeRF is not comparable to the point density obtained from TLS.

In this study, the quality of point clouds from several homogeneous areas in the research object used was analyzed as shown in **Figure 4**.

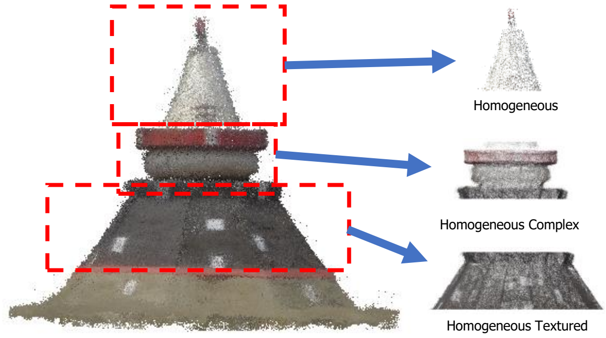


Figure 4. Analysis of point cloud quality

Figure 4 shows the point cloud quality analysis, where the point cloud quality is performed on several homogeneous areas of the research object used. The homogeneous areas analyzed are divided into three categories, namely homogeneous, textured homogeneous, and complex homogeneous. The characteristics of homogeneous areas are taken in the upper area of the object, which has no texture and tends to be white. The characteristics of textured homogeneous objects are taken in the area of objects that have good texture. While the characteristics of complex homogeneous objects are taken in the area of objects that are considered more complex, judging from the shape and color displayed. The comparison between NeRF and TLS results is analyzed from various areas of research objects, such as objects in homogeneous, textured homogeneous, and complex homogeneous areas. This is done to analyze the quality of the point cloud produced by NeRF with several areas that have different characteristics. Integration of information and visualization of analysis results is also important to facilitate interpretation and application. The results of the NeRF and TLS point cloud quality analysis on several homogeneous areas are shown in **Table 2**.

Table 2. Analysis of point cloud quality on some homogeneous areas.

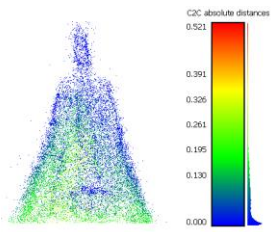
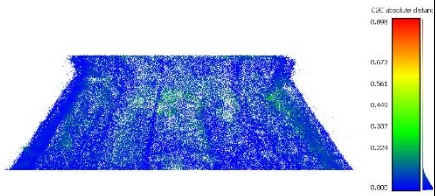
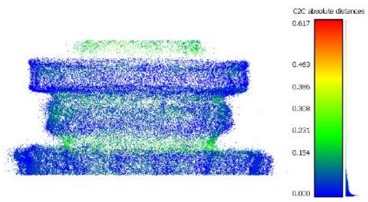
Results	Homogeneous	Homogeneous Textured	Homogeneous Complex
TLS	 849,741 points	 1,249,549 points	 4,061,201 points
NeRF	 16,988 points	 236,251 points	 91,887 points
C2C	 Average distance: 8.9 cm	 Average distance: 5.1 cm	 Average distance: 4.9 cm

Table 2 shows the results between NeRF and TLS on object areas that have homogeneous characteristics of white color, textured homogeneous, and complex homogeneous. From the results on the homogeneous area, it can be seen that the point cloud results from NeRF are not so dense, with the number of points clouds produced as many as 16,988 points. Meanwhile, when viewed in the point cloud produced by TLS, there are 849,741 points in the same area. The point cloud results from NeRF are then analyzed using the distance between point clouds (C2C) with the TLS point cloud as a reference, showing that NeRF has a good level of accuracy with an average distance of 8.9 cm and a standard deviation of 8.1 cm.

Furthermore, the point cloud results from NeRF are also analyzed in areas with textured homogeneous characteristics. It can be seen that the point cloud results from NeRF are not so dense, with the number of points in each point cloud generated as many as 236,251 points. Whereas when viewed on the point cloud produced by TLS, as many as 1,249,549 points are in the same area. The point cloud results from NeRF are then analyzed using the distance between point clouds (C2C) with the TLS point cloud as a reference, showing that NeRF in this area has a better level of accuracy with an average distance of 5.1 cm and a standard deviation of 6 cm.

As for the analysis of NeRF and TLS point cloud quality in complex homogeneous areas, it can be seen that the point cloud results from NeRF are not so dense, with the number of points in each point cloud produced as few as 91,887 points. Meanwhile, when viewed at the point cloud produced by TLS, as many as 4,061,201 points are in the same area. The point cloud results from NeRF are then analyzed using the distance between point clouds (C2C) with the TLS point cloud as a reference, showing that NeRF in this area has a better level of accuracy with an average distance of 4.9 cm and a standard deviation of 5.2 cm. Thus, in this study, the quality of the point cloud produced by NeRF is still not good for homogeneous areas.

Analysis of 3D Model Results

The 3D mesh model is a geometric representation of the object that has been reconstructed by NeRF. The mesh model generated from Nerfstudio has generated a point cloud that will be used in making the mesh model. After conversion using Poisson surface reconstruction, a 3D mesh model is obtained from NeRF processing. The 3D mesh model generated from Nerfstudio can be seen in **Figure 5**.

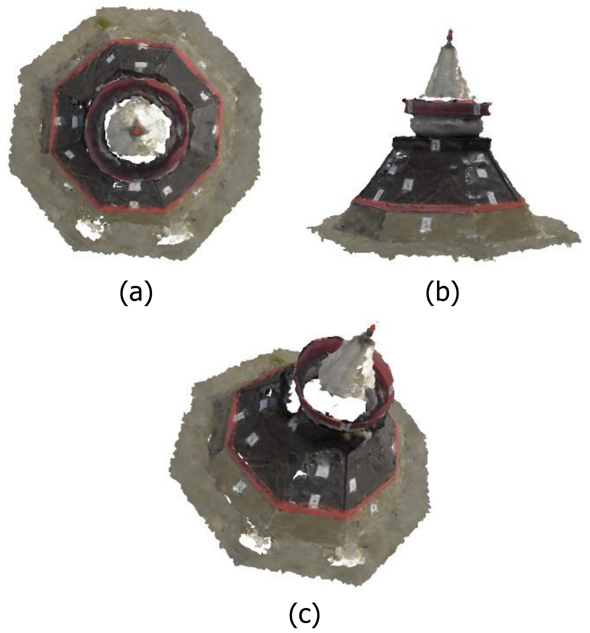


Figure 5. 3D mesh model results (a) top view (b) side view (c) oblique view.

The 3D model is expected to represent the actual object both visually and geometrically. In **Figure 5**, it can be seen that the results obtained from the NeRF process, seen from several sides, still have incorrect and uncomplete shape. The model obtained is also not very detailed, with details of small images that are not visible. The lack of 3D model results obtained is an evaluation material that needs to be developed. The non maximized texturing process could produced ill-defined data.

The data used in creating the 3D model was processed with NeRF and subjected to some degradation of the quality of the photos used in the training data. The details of the information used in creating the 3D model are shown in **Table 3**.

Table 3. Detail information of 3D model creation.

Folder Name	Total	Resolution	GSD (mm)
images	323	4608 x 3456	1.73

Table 3 shows the details of the information that has been processed in the NeRF processing for 3D modeling. It can be seen that the GSD generated from the NeRF processing of the 3D model is 1.73 mm. This value is a very small value to get detailed 3D model results. The 3D model generated from NeRF processing, after binding the point to the ground coordinates, obtained the RMSE value of the point error shown in **Table 4**.

Table 4. RMSE value of the marker point error

Parameters	Values
Total Error	0.851 m
Number of points	20 points
RMSE	0.048 m

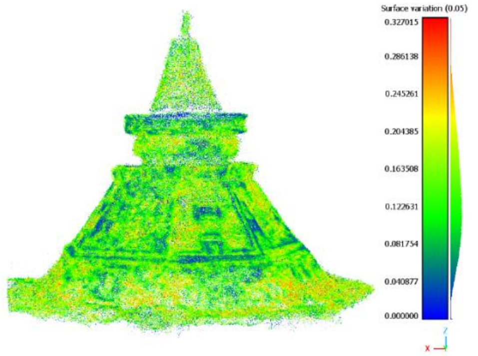
Table 4 shows the RMSE value of the point error performed at the georeferencing stage of the 3D model. Based on the RMSE value of the error, it can be seen that the value obtained is very significant compared to the GSD value of the resulting 3D model. The RMSE value obtained is 48 mm while the GSD value of the resulting 3D model is 1.73 mm. This shows that the error value of the model obtained is twenty-eight times greater than the GSD value of the model. The resulting error value is very large when viewed from the difference in GSD values. The large difference between the RMSE and GSD values indicates a systematic error in the georeferencing process. A possible contributing factor is that the georeferencing process is not optimal, because the marker pointing process is carried out on a model with a texture that is obtained less clearly.

The model error value obtained from NeRF processing results can be caused by the input data used not being good enough in NeRF processing. Because the photo data used was taken for the needs of Structure from Motion (SfM) data in previous studies using a fisheye camera with a resolution of 16 MP, the quality of the photos obtained is not good. Then, the shooting technique is also not good for NeRF processing, with the distance from the photo to the object being too far away, and some positions of object details that are not visible. The more photo data that presents the shape of the object, the better the NeRF method is in learning image details and producing accurate 3D models. Errors in the 3D model georeferencing process can also cause large model errors. This is because the matching of ground control points with the model is not good. After all, the resulting 3D model displays the marker points less clearly.

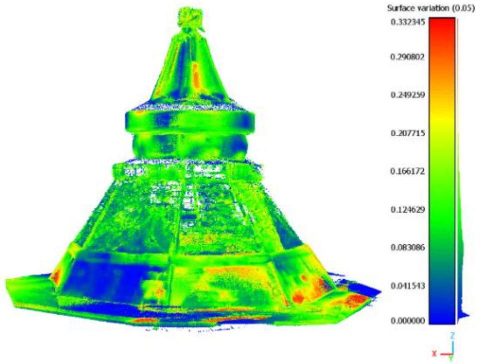
Testing Point Cloud Quality

Surface Variation

Testing with the surface variation parameter is used to see the irregularity value of the point cloud generated from the average line located between the highest and lowest points. In this process, it can be seen that the resulting point cloud tends to be flat or irregular in the shape of the resulting object. The test results with surface variation are in **Figure 6**.



(a)



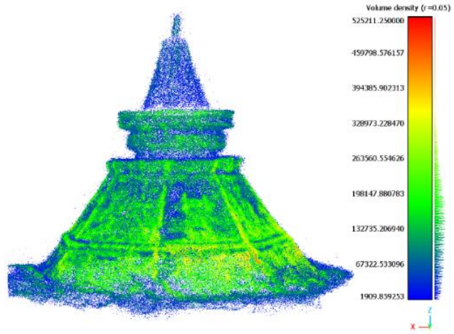
(b)

Figure 6. Surface variation test results (a) NeRF (b) TLS.

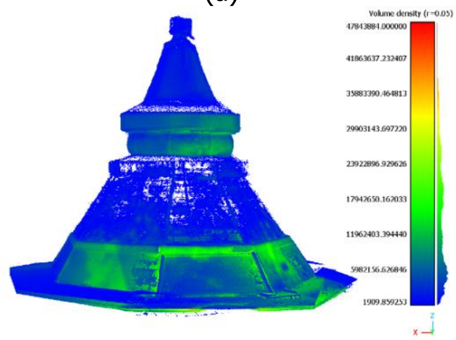
Based on the quality test with surface variation in **Figure 6,** the NeRF and TLS point cloud results show significant differences in the mean value, standard deviation, and percentage of accepted data. The surface variation test results on the point cloud from NeRF show an average value of 0.137 meters and a standard deviation value of 0.059 meters. From this data, the percentage of acceptable data is 41.288% and the percentage of outlier data is 58.712%. The results of surface variation testing on the point cloud from TLS obtained an average value of 0.096 meters and a standard deviation of 0.068 meters. From this data, the percentage of acceptable data is 76.595% and the percentage of outlier data is 23.405%. The percentage of outlier point cloud data from NeRF is greater than the point cloud data from TLS, indicating that the point cloud data from NeRF is more inconsistent with the mean and standard deviation values obtained. These results show that the quality of the point cloud generated from NeRF is not good in surface variation because it has data that is less smooth and less precise, and significant values compared to data from TLS. This may be due to the limitations of the camera with the non-metric lens used and the limited photo resolution.

Volume Density

Volume density testing can be used to determine shape recognition on objects. Volume density is the density value of the point cloud point density obtained. The results of point cloud testing using the volume density parameter from NeRF processing can be seen in **Figure 7**.



(a)



(b)

Figure 7. Volume density testing results (a) NeRF (b) TLS.

Based on the results presented in **Figure 7**, using a radius value of 0.05 m, in (a) NeRF, the lowest value is 1909.859 pts/m³ and the highest value is 525211.250 pts/m³. The results obtained in the NeRF processing point cloud show that the average value obtained is 146803.656 pts/m³. While (b) TLS point cloud volume density shows a wider range of values compared to NeRF, which is between 1919,859 pts/m³ to 47843884,000 pts/m³. The average volume density value obtained from the TLS point cloud is 15651521,000 pts/m³. This shows that the point cloud generated from NeRF is still poorly influenced by several factors. NeRF uses a set of photos of the object to perform reconstruction, while TLS uses laser scanner technology. Lower photo resolution can produce point clouds with lower density. Complex object surfaces can also result in higher variations in volume density values. The volume density is affected by the distance from the image to the object, causing the dot density to also vary. The closer the photo is to the object, the smaller the dot distance (Petras et al., 2023).

Point Discrepancy

The accuracy value of the point cloud can be seen from the point density comparison, while the accuracy value of the point cloud model comparison can be seen in the estimated error of the model formed (Antova, 2019). The error can be calculated by comparing the distance between the point cloud generated from the processing with the reference point cloud model. In this study, the point cloud data from the TLS measurement is used as a reference to assess the accuracy of the point cloud model generated from the NeRF processing shown in **Figure 8**.

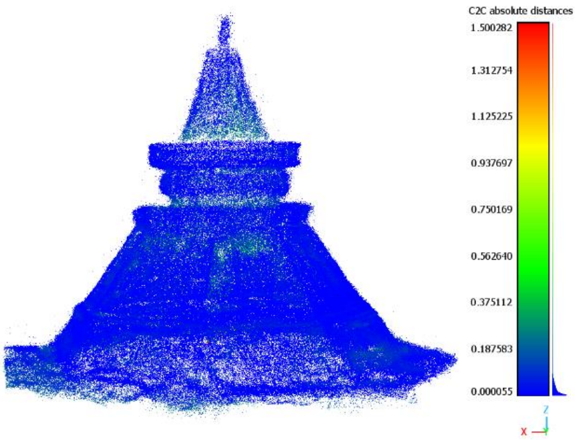


Figure 8. Point discrepancy testing results.

The results show that NeRF produces good-quality point clouds. **Figure 8** shows a visualization of the blue objects that represent the low distance between point clouds. The distance range obtained is between 0.000 meters and 1.500 meters. The results of testing the point discrepancy value using the C2C parameter can be presented in the graph in **Figure 9**.

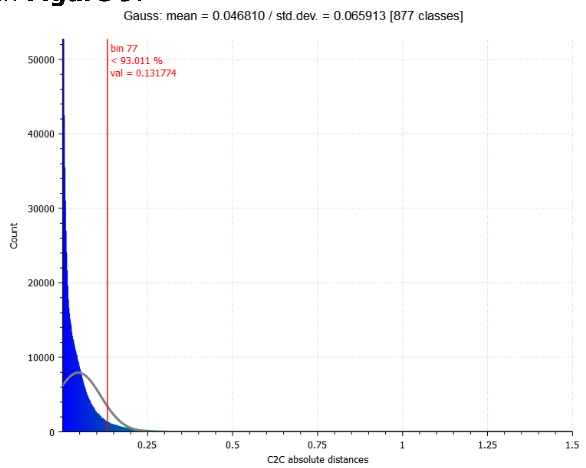


Figure 9. Histogram of point discrepancy testing.

Figure 9 shows the resulting point discrepancy value, with the average distance value of 0.047 m. After calculating the point cloud data, the standard deviation value on the point cloud results is 0.066 m. From the results of point cloud testing with the obtained point discrepancy parameters, it is known that the acceptable point cloud is 93.011% of the point cloud data generated from NeRF processing. Then some data that is out of it (outliers) as much as 6.989%.

The point cloud results obtained that NeRF is able to do 3D modeling by testing using the point discrepancy parameter, which obtained outlier data of 6.989% with an average distance of 0.047 meters and a standard deviation of 0.066 meters. But the point cloud produced by NeRF still has a large noise/error with the test results using the surface variation parameter, obtaining outlier data of 58.712% with an average of 0.137 meters and a standard deviation of 0.059 meters. Based on testing using the volume density parameter, the NeRF point cloud gets an average of 146803.656 pts/m³ while the TLS is 15651521,000 pts/m³.

The RMSE value of the 3D model generated from the NeRF method uses a sample size of 12 in the research object area. After the calculation, the RMSE value obtained is 0.045 meters. Although the accuracy value of the 3D model geometry produced is quite good, the resolution of the model obtained has a texture that is still unclear.

Geometry Accuracy Testing of 3D Models

The 3D model geometry accuracy test was carried out by calculating the RMSE (Root Mean Square Error) value of the direct size in the field with the size in the 3D model result software from NeRF processing. The sample size taken is 12 sizes by measuring the sides of the object using a roll meter. Meanwhile, the measurement of the 3D model from NeRF processing was carried out using cloud compare software. The measurement of the 3D model uses the distance feature, which takes measurements between two points on the 3D model from NeRF. From the data, the RMSE value was calculated, as shown in **Table 5**.

Table 5. Calculation of RMSE value.

Dimensions	Field Size (m)	3D Model Size (m)	Difference	RMSE
D1	1.840	1.841	0.001	0.045
D2	1.750	1.659	-0.091	
D3	1.840	1.882	0.042	
D4	1.640	1.604	-0.036	
D5	1.905	1.918	0.013	
D6	1.675	1.668	-0.007	
D7	1.915	1.983	0.068	
D8	1.298	1.288	-0.010	
D9	0.300	0.302	0.002	
D10	0.150	0.123	-0.027	
D11	1.246	1.243	-0.003	
D12	1.268	1.183	-0.085	

From the calculation of the RMSE value, an RMSE value of 0.045 meters was obtained. The RMSE value obtained from the 3D model generated with NeRF processing is quite accurate. Where the results obtained from the calculation are less than 0.5 meters, the results of the geometry accuracy test on the 3D model of the Krakatoa Monument made by NeRF processing are close to the shape of the actual Krakatoa Monument object in the field.

CONCLUSION

The point cloud results obtained that NeRF is able to do 3D modeling by testing using the point discrepancy parameter, which obtained outlier data of 6.989% with an average distance of 0.047 meters and a standard deviation of 0.066 meters. But the point cloud produced by NeRF still has a large noise/error with the test results using the surface variation parameter, obtaining outlier data of 58.712% with an average of 0.137 meters and a standard deviation of 0.059 meters. Based on testing using the volume density parameter, the NeRF point cloud gets an average of 146803.656 pts/m³ while the TLS is 15651521,000 pts/m³.

Furthermore, it can be concluded from the comparison results in several homogeneous areas, the quality of the point cloud produced by NeRF is not good in homogeneous areas, as evidenced by the results of the analysis of the distance between point clouds (C2C) in homogeneous areas obtaining an average distance of 8.9 cm; in textured homogeneous areas 5.1 cm; and in complex homogeneous areas 4.9 cm.

The RMSE value of the 3D model generated from the NeRF method uses a sample size of 12 in the research object area. After the calculation, the RMSE value obtained is 0.045 meters. Although the accuracy value of the 3D model geometry produced is quite good, the resolution of the model obtained has a texture that is still unclear.

ACKNOWLEDGEMENTS

We are grateful for the assistance of the BIG Geomatics journal team at all stages.

REFERENCES

Adipranata, R., & Liliana. (2005). PEMODELAN OBYEK TIGA DIMENSI DARI GAMBAR SINTETIS DUA DIMENSI DENGAN PENDEKATAN VOLUMETRIC. *Jurnal Informatika*, 7–11.

Antova, G. (2019). Application of Areal Change Detection Methods Using Point Clouds Data. *IOP Conference Series: Earth and Environmental Science*, *221*(1). https://doi.org/10.1088/1755-1315/221/1/012082

Arif RS, Hariantaka, Maharani M. (2024). Investigating the Impact of Enhanced Images on 3D Reconstruction of non Lambertian Object Using Neural Radiance Fields. IOP Conf. Series: Earth and Environmental Science1486, 1-12.

Bagus, I., Pascima, N., Lanang, I. G., Raditya, A., Teknik, F., & Ganesha, U. P. (2021). *MODEL 3 DIMENSI UKIRAN BALI BENTUK KARANG GAJAH MENGGUNAKAN FOTOGRAMETRI JARAK DEKAT*. *10*, 340–347.

Croce, V., Caroti, G., De Luca, L., Piemonte, A., & Veron, P. (2023). Neural radiance fields (nerf): Review and potential applications to digital cultural heritage. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *48*(M-2–2023), 453–460. https://doi.org/10.5194/isprs-Archives-XLVIII-M-2-2023-453-2023

Guo, J. (2023). Deep Learning Application in Image-based Modeling. *Research Square*, 1–14.

Kafiar, M. T., Tjahjadi, M. E., & M Yuliananda, A. (2020). Visualisasi 3D Modelling dari Hasil Kombinasi Kamera DSLR dan UAV Dengan Metode Close Range Phtogrametry (Studi Kasus : Objek Plengsengan, Bendungan Sengkaling, Desa Tegal Gondo, Kecamatan Karang Ploso, Kabupaten Malang). *ITN Malang*, 1–8.

Mulia, D., & Hapsari, H. (2014). STUDI FOTOGRAMETRI JARAK DEKAT DALAM PEMODELAN 3D DAN ANALISIS VOLUME OBJEK. *GEOID*, *10*, 32–39.

Murtiyoso, A., & Grussenmeyer, P. (2023). Initial assessment on the use of state-of-The-Art nerf neural network 3d reconstruction for heritage documentation. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *48*(M-2–2023), 1113–1118. https://doi.org/10.5194/isprs-Archives-XLVIII-M-2-2023-1113-2023

Nuha, M. U., Pramudya, A. F., Laia, B. E., Husain, R., Setiaji, D., Isnaini, E. L., Perdana, R. S., Atmojo, A. T., & Jatmiko, R. H. (2024). Comparative Assessment on the Use of Videogrammetry and Photogrammetry for Rapid and Low-Cost Three-Dimensional Modeling. *Indonesian Journal of Geography*, *56*(3), 368–375. https://doi.org/10.22146/ijg.87960

Palestini, C., Basso, A., & Perticarini, M. (2022). Machine Learning As an Alternative To 3D Photomodeling Employed in Architectural Survey and Automatic Design Modelling. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *48*(2/W1-2022), 191–197. https://doi.org/10.5194/isprs-archives-XLVIII-2-W1-2022-191-2022

Pardamean, B. S., & Tolle, H. (2021). Pembuatan Objek 3D Candi Badut Menggunakan Metode Photogrammetry. *Physics and Science Education Journal (PSEJ)*, *5*(6), 1–2.

Parmadi, W. T., & Sukojo, B. M. (2016). Analisa Ketelitian Geometrik Citra Pleiades Sebagai Penunjang Peta Dasar RDTR (Studi Kasus: Wilayah Kabupaten Bangkalan, Jawa Timur). *Jurnal Teknik ITS*, *5*(2). https://doi.org/10.12962/j23373539.v5i2.17213

Pepe, M., Alfio, V. S., & Costantino, D. (2023). Assessment of 3D Model for Photogrammetric Purposes Using AI Tools Based on NeRF Algorithm. *Heritage*, *6*(8), 5719–5731. https://doi.org/10.3390/heritage6080301

Petras, V., Petrasova, A., McCarter, J. B., Mitasova, H., & Meentemeyer, R. K. (2023). Point Density Variations in Airborne Lidar Point Clouds. *Sensors*, *23*(3), 1–18. https://doi.org/10.3390/s23031593

Prastyo, A. D., Subiyanto, I. S., & Suprayogi, A. (2022). *Aplikasi Fotogrametri Jarak Dekat untuk Pemodelan 3D Candi Gedong Songo*. *10*(1), 1–52. https://doi.org/10.21608/pshj.2022.250026

Remondino, F., Karami, A., Yan, Z., Mazzacca, G., Rigon, S., & Qin, R. (2023). A Critical Analysis of NeRF-Based 3D Reconstruction. *Remote Sensing*, *15*(14). https://doi.org/10.3390/rs15143585

Roziqin, A., Gustin, O., Pratama, R. W., Dewa, A., Saputra, N., Pernadi, R., Junaika, D. T., Al, M. I., Syahrani, A., Amelia, R., Aritonang, F. L., & Ilyasa, N. (2022). Rekonstruksi Model 3D Menggunakan Foto Udara untuk Visualisasi Kawasan Pesisir Sembulang Kota Batam. *Prosiding The 13th Industrial Research Workshop and National Seminar*, 889–898.

Sambodo, G. (2024). *Penggunaan Fotogrametri dan Reflectance Transformation Imaging (RTI) dalam Membaca Pahatan Batu Prasasti*. *May*.

Suwardhi, D., Mukhlisin, M., Darmawan, D., Trisyanti, S. W., Brahmantara, B., & Suhartono, Y. (2016). Survey dan Pemodelan 3D (Tiga Dimensi) untuk Dokumentasi Digital Candi Borobudur. *Jurnal Konservasi Cagar Budaya*, *10*(2), 10–22. https://doi.org/10.33374/jurnalkonservasicagarbudaya.v10i2.150

Vandenabeele, L., Häcki, M., & Pfister, M. (2023). Crowd-sourced surveying for building archaeology: The potential of structure from motion (SFM) and neural radiance fields (NERF). *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *48*(M-2–2023), 1599–1605. https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-1599-2023

Zainuddin, K., Ghazali, M., Marzukhi, F., Samad, A., Ariff, M. M., & Majid, Z. (2024). *EVALUATION OF NERF 3D RECONSTRUCTION FOR ROCK ART DOCUMENTATION*. *XLVIII*, 21–23.