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ACCURACY ANALYSIS OF 3D COORDINATES FROM TERRESTRIAL LASER SCANNER (TLS) AND AIRBORNE LASER SCANNING (ALS) MEASUREMENTS (CASE STUDY: TRANSMISSION TOWER)

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ABSTRACT

Transmission towers on high-voltage power lines serve as supporting structures for electrical conductors and insulators, requiring routine maintenance to ensure safety and reliability. This study aims to analyze the 3D coordinates of transmission towers using Terrestrial Laser Scanner (TLS) and Airborne Laser Scanning (ALS) methods. The calculation of the Root Mean Square Error (RMSE) against Total Station (TS) measurements showed that TLS achieved higher accuracy, with an RMSE of 0.0037 m, compared to ALS at 0.0136 m. Statistical testing using the t-distribution on 21 data points showed that the t-values for TLS and ALS were 1.967255 and -0.385437, respectively, both of which fall within the critical value range at a 5% significance level. It was therefore concluded that there was no significant difference compared to the Total Station (TS) measurements. The confidence interval analysis at a 95% confidence level indicated that 95% of the TLS data and 61% of the ALS data fell within the acceptable range. In terms of visualization, TLS produced a denser and precise point cloud with texture details, while ALS excelled in point cloud color representation. Each method has its advantages, with TLS being superior in detailed accuracy and ALS being efficient for large-area data acquisition.

Keywords*: *Airborne Laser Scanning, Point Cloud, Terrestrial Laser Scanner, Transmission Tower

1. INTRODUCTION

Transmission towers play a crucial role in delivering electrical energy from power generation facilities to end users (Idris et al., 2021). The main components of transmission towers include conductors, which function to transmit electric current, and insulators, which serve as protective elements to prevent unintended electrical discharge (Tuwaidan et al., 2023). Structural damage to transmission towers may arise from various factors such as aging, soil conditions, wind loads, earthquakes, changes in land use, and construction errors (Rohmat, 2020). Therefore, routine structural monitoring is required to ensure the safety and reliability of transmission systems in accordance with operational standards (Prasetia et al., 2024).

One of the essential measures to maintain the feasibility of transmission towers is structural inspection using 3D measurement techniques that generate point clouds representing detailed geometric information. The Terrestrial Laser Scanner (TLS) is a technology that uses laser beams to capture millions of three-dimensional points from ground-based positions (Samudra & Kurniawan, 2024). TLS allows rapid and efficient acquisition of high-density spatial data, thereby optimizing measurement time in specific areas (Kersten & Lindstaedt, 2022). Its measurement principle is based on the travel time of laser pulses emitted and returned to the sensor, enabling precise distance calculation and point coordinate determination (Alexander et al., 2022). However, TLS has limitations in capturing data on the upper sections of tall structures due to restricted viewing angles (Hidayat, 2022).

In addition to TLS, the Airborne Laser Scanning (ALS) method can also be utilized. ALS is an active remote sensing technology that uses laser pulses emitted from airborne platforms, such as drones, to record the coordinates of object surfaces, making it highly efficient for large-area data acquisition (Baharuddin, 2016). ALS provides an effective approach for infrastructure inspection, including transmission towers, by generating point clouds with high efficiency and satisfactory accuracy (Arrofiqoh & Muryamto, 2020).

Both ALS and TLS are LiDAR-based measurement instruments capable of producing detailed spatial data. LiDAR datasets can be automatically classified, supporting their application in various fields, particularly 3D modeling (Lewandowicz, 2022). Three-dimensional modeling involves constructing digital representations of real-world objects, including their geometry, texture, and dimensional characteristics (Satyadinoto, 2020; Sholihin, 2023).

In this study, a comparative analysis of 3D coordinate accuracy from TLS and ALS measurements of transmission towers is conducted. Such comparison is crucial because the two methods differ in acquisition techniques, sensor specifications, and achievable point density. Research on the comparative accuracy of TLS and ALS for vertical structures such as transmission towers remains limited. Therefore, this study aims to evaluate the accuracy and visualization quality of both methods to provide insights for the power transmission industry in selecting efficient, accurate, and field-applicable inspection strategies.

2. DATA AND METHODS

2.1 Research Location

The study was conducted in Surabaya City, focusing on three transmission towers located along Jalan Raya Kedung Baruk in Kedung Baruk Subdistrict, Rungkut District. The research location map is presented in Figure 1.

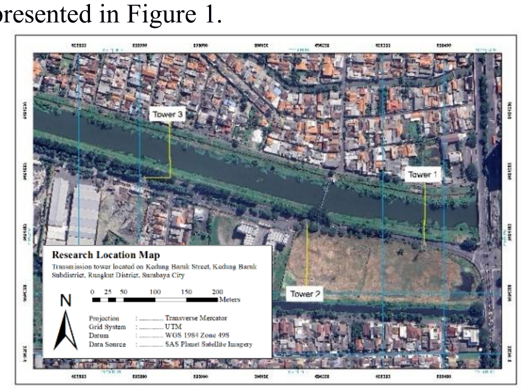


Figure 1. Research location map

2.2 Research Instruments

The equipment required for data acquisition and processing in this study is as follows:

1. Hardware
   a) DJI Matrice 350 RTK drone equipped with the Zenmuse L2 LiDAR sensor.
   b) Leica RTC360 Terrestrial Laser Scanner.
   c) Topcon Total Station.
2. Software
   a) Cyclone 360+ Register for point cloud processing of Terrestrial Laser Scanner (TLS) measurements.
   b) DJI Terra for processing ALS point cloud data.
   c) Autodesk ReCap Pro for filtering.
   d) CloudCompare for point cloud processing and analysis.

2.3 Research Method

This study involved direct field data acquisition. For the ALS measurements, positioning was performed using the Post-Processed Kinematic (PPK) method. Meanwhile, the TLS data were processed using the cloud-to-cloud registration technique, which aligns multiple scanner setups based on overlapping point features. To ensure an effective and efficient workflow, a structured data acquisition procedure was developed. The workflow for the data acquisition process in this study is illustrated in the flowchart shown in Figure 2.

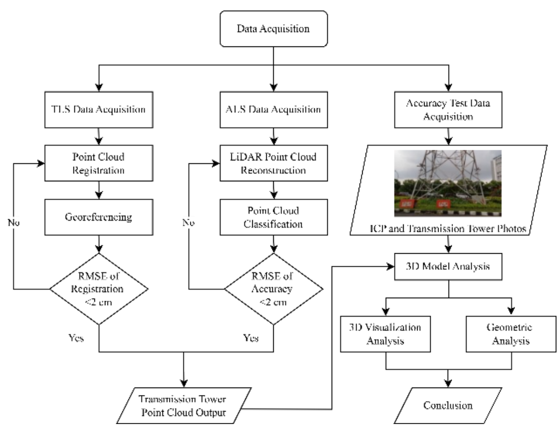


Figure 2. Research workflow diagram

2.4 Terrestrial Laser Scanner (TLS)

The Terrestrial Laser Scanner (TLS) is a laser-based scanning method that records three-dimensional coordinates (X, Y, Z) to generate a 3D model of an object (Simbolon et al., 2017). Point clouds obtained from multiple scanner positions are merged through registration, georeferencing, and filtering processes using cloud-to-cloud or target-to-target techniques to produce a precise geometric model (Maulidin, 2016).

2.5 Airborne Laser Scanning (ALS)

LiDAR is an active remote-sensing technology that has advanced with the development of compact sensors, enabling deployment on drone platforms (Arrofiqoh & Muryamto, 2023). Airborne Laser Scanning (ALS) and Terrestrial Laser Scanner

(TLS) operate on similar principles by emitting laser pulses that are reflected by objects to generate three-dimensional point clouds. The primary difference lies in the data acquisition approach: ALS collects data from the air, making it suitable for large-area coverage, whereas TLS collects data from the ground and requires additional registration processes to integrate multiple scan positions (Alexander et al., 2022).

2.6 Accuracy Assessment

Geometric accuracy assessment is essential in measurement activities to ensure the reliability of the collected data. One commonly used method is the Root Mean Square Error (RMSE), which calculates the average squared differences between measured values and reference values. A smaller RMSE indicates higher accuracy (Panjaitan & Supit, 2021). In addition, to determine whether there is a significant difference between TLS and ALS measurements relative to Total Station reference data, a paired t-test is employed. This statistical method compares two paired datasets obtained from the same objects or locations (Nuryadi et al., 2017). The accuracy assessment formulas used in this study are presented below.

a) RMSE

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}} \quad (1)$$

b) T-distribution

$$t_{hit} = \frac{\overline{x}}{\frac{SD}{\sqrt{n}}} \quad (2)$$

c) Standard Deviation

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n-1}} \quad (3)$$

3. RESULTS AND DISCUSSION

3.1 Polygon Coordinates

GPS observations were conducted to obtain reference coordinates for the polygon survey. The polygon network consists of a Horizontal Control Network and a Vertical Control Network. The horizontal network was measured using a Total Station, while the vertical network was measured using a digital level (Waterpass). The coordinates obtained from the polygon survey were adjusted using the least squares method. The final coordinates are presented in Table 1.

Table 1. Polygon Coordinate Points

Point	X (m)	Y (m)	Z (m)
BM 1	696256.0891	9191462.4664	2.100
BM 2	696235.2848	9191485.6970	2.4881
BM 3	696151.4774	9191509.8947	2.3722
BM 4	696133.6107	9191524.2309	2.5452
BM 5	696248.4482	9191490.7370	2.8424
BM 6	696366.6507	9191456.9039	2.1876
BM 7	696434.0693	9191435.3756	2.2617
BM 8	696351.6446	9191441.6318	2.0679

The adjusted polygon coordinates served as the reference for determining the positions of the Ground Control Points (GCP) and Independent Check Points (ICP). These GCP and ICP coordinates were subsequently used to derive the transmission tower dimensions, which functioned as validation data for the accuracy assessment.

3.2 TLS Data Processing Results

The TLS point cloud data acquired in the field were processed using Cyclone REGISTER 360 PLUS through a cloud-to-cloud registration workflow. A total of 17 scanner set-up positions were used, consisting of 5 set-ups for Transmission Towers 1 and 2, and 7 set-ups for Transmission Tower 3, with spacing between set-ups ranging from 10–15 m. Following registration, the dataset was georeferenced to the UTM coordinate system, and a filtering process was performed in Autodesk Recap Pro to remove unnecessary objects. This processing workflow produced the final point cloud dataset for each transmission tower.

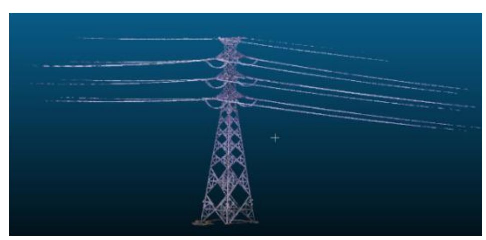


Figure 3. TLS point cloud of transmission tower 1

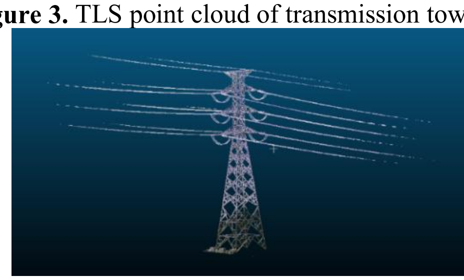


Figure 4. TLS point cloud of transmission tower 2

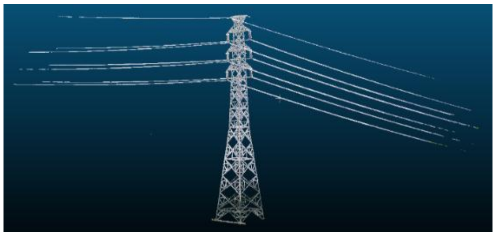


Figure 5. TLS point cloud of transmission tower 1

Based on the visualization in Figures 3–5, the remaining point cloud consists only of the transmission tower structure and several concrete objects used as dimensional references for the accuracy assessment. In addition to removing unnecessary objects, the filtering process also serves to reduce file size, resulting in a more efficient and manageable data processing workflow.

3.3 Airborne Laser Scanning (ALS) Data Processing Results

The Airborne Laser Scanning (ALS) data were processed using DJI Terra, with point cloud density determined by a percentage-based setting representing the proportion of points used during processing. In this study, the ALS data were processed using a high-density setting (100%) to match the density of the Terrestrial Laser Scanner (TLS) data, which were also acquired at high resolution. This ensured that all available point cloud data were utilized. The resulting ALS point cloud was then subjected to a filtering process using Autodesk Recap Pro.

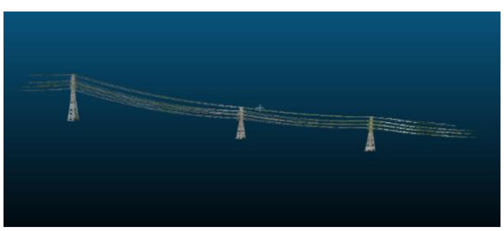
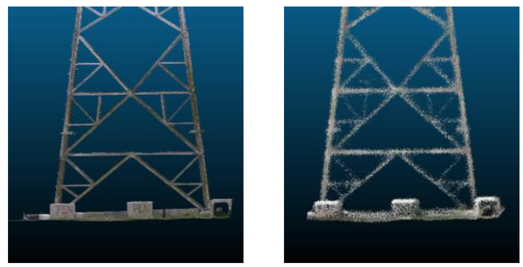


Figure 6. ALS point cloud

ALS point cloud processing was performed comprehensively for all three transmission towers, as the airborne acquisition captured the entire study area in a single flight.

3.4 3D Visualization Comparison

The 3D model of the transmission tower generated from ALS and TLS shows a significant difference in the number of point cloud data captured. TLS produced 27,946,883 points for the three towers, whereas ALS generated only 3,046,291 points for the entire area. This difference in point density directly affects the quality of the 3D visualization; higher point density produces a more detailed and solid 3D representation. After filtering, both TLS and ALS point clouds were reduced by more than 96% for each tower. This reduction results in relatively small remaining tower structures in the data, leaving only a limited number of points for visualization. Consequently, point cloud density plays a crucial role in determining the quality of the resulting 3D model. The following figure illustrates the visual comparison of filtered TLS and ALS point clouds for a section of the transmission tower.



TLS ALS

Photo of Object

Figure 7. Comparison of TLS and ALS point cloud visualization

Based on the visualization in Figure 7, the TLS data produce a highly solid model with clearly visible and readable text on the concrete structure. In contrast, the ALS point cloud forms only a general representation of the transmission tower, appearing less smooth, less solid, and lacking readable detail due to its lower point density. The following figure shows the overall point cloud visualization for one transmission tower.

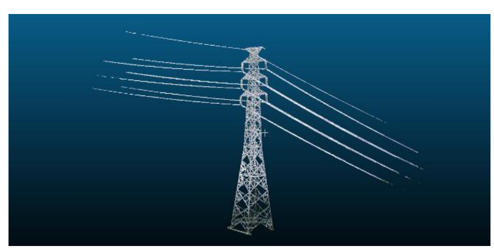


Figure 8. TLS point cloud visualization

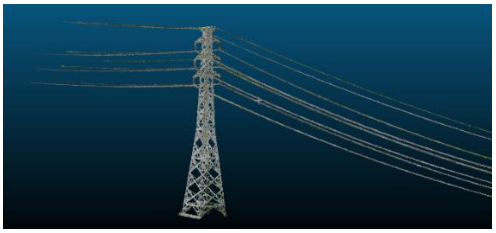


Figure 9. ALS point cloud visualization

Figure 8 & 9 present the 3D visualization of the transmission tower based on measurements obtained using ALS and TLS methods. The TLS visualization shows point clouds with nearly uniform color across the tower structure. The lower section appears darker, while the middle to upper sections and the conductor cables display a shiny gray appearance. In contrast, the ALS results exhibit point cloud colors that more closely resemble real field conditions darker gray, consistent with the aged metallic surface of the transmission tower. However, TLS measurements exhibit several limitations. Some empty areas appear in the upper parts of the tower due to restricted instrument viewing angles at ground level. Additionally, several cables are not fully captured in the TLS visualization, resulting in an incomplete representation. These findings illustrate that both methods possess distinct advantages and limitations in generating 3D visualizations.

3.5 Accuracy Assessment

Geometric analysis was conducted to compare the measurements obtained from the Terrestrial Laser Scanner (TLS) and Airborne Laser Scanning (ALS) with the Total Station validation data. A total of 21 tower-side dimensions were selected as samples and processed using CloudCompare. The resulting dimensional values were then evaluated using the Root Mean Square Error (RMSE) to determine the degree of deviation between the TLS/ALS measurements and the Total Station reference. The RMSE was calculated using Equation 1, based on the measurement differences between TLS and ALS relative to the Total Station data, as presented in the Table 2 & 3:

Table 2. RMSE calculation for TLS data

Side	TS (m)	TLS (m)	TS-TLS (m)
A	7.4341385	7.434028	0.00011048
B	6.1319695	6.129522	0.00244754
C	6.0082656	6.007613	0.00065265
D	6.1074616	6.106255	0.00120664
E	1.1994849	1.197313	0.00217192
F	1.9874526	1.98723	0.00022256
G	1.1833361	1.184232	-0.00089585
H	6.8052048	6.804878	0.00032683
I	3.0407838	3.040179	0.00060481
J	5.9952198	5.995899	-0.00067920
K	3.0322342	3.031131	0.00110322
L	1.2017791	1.200631	0.00114815
M	2.6302494	2.630396	-0.00014656
N	3.0056970	3.006097	-0.00040001
O	4.1888362	4.18293	0.00590614
P	4.1484515	4.149967	-0.00151549
Q	4.5222736	4.523298	-0.00102440
R	4.5857474	4.583264	0.00248342
S	7.5043028	7.489169	0.01513376
T	0.4451878	0.444248	0.00093977
U	8.5033546	8.501458	0.00189658
Minimum Difference			0.0001105 m
Maximum Difference			0.0151338 m
Total Difference			0.0410160 m
RMSE			0.0037481 m

Table 3. RMSE calculation for ALS data

Side	TS (m)	ALS (m)	TS-ALS (m)
A	7.4341385	7.442629	-0.0084905
B	6.1319695	6.145124	-0.0131545
C	6.0082656	6.002065	0.0062006
D	6.1074616	6.111321	-0.0038594
E	1.1994849	1.20097	-0.0014851
F	1.9874526	1.987239	0.0002136
G	1.1833361	1.183164	0.0001721
H	6.8052048	6.8084	-0.0031952
I	3.0407838	3.036466	0.0043178
J	5.9952198	6.005246	-0.0100262
K	3.0322342	3.023122	0.0091122
L	1.2017791	1.20871	-0.0069309
M	2.6302494	2.630581	-0.0003316
N	3.0056970	3.047265	-0.0415680
O	4.1888362	4.183369	0.0054671
P	4.1484515	4.143629	0.0048225
Q	4.5222736	4.51582	0.0064536
R	4.5857474	4.573786	0.0119614
S	7.5043028	7.516422	-0.0121192
T	0.4451878	0.451581	-0.006392
U	8.5033546	8.469066	0.0342886
Minimum Difference			0.0001721 m
Maximum Difference			0.0415680 m
Total Difference			0.190563312 m
RMSE			0.013611 m

The RMSE value obtained from TLS measurements is smaller than that from ALS, indicating that TLS provides higher accuracy relative to the Total Station reference data. Nevertheless, both RMSE values remain within the ASPRS accuracy tolerance of <2 cm. The RMSE results also show that differences exist in the measured tower dimensions; therefore, a statistical test is required to determine whether these differences are statistically significant. In this study, a paired t-distribution test with a 95% confidence level was applied to compare the TLS and ALS measurements against the Total Station data. The computed critical t values are shown in the Table 4.

Table 4. Results of the t-distribution analysis

Tools	Mean Difference (m)	Standard Deviation (m)	t-krit
TLS	0.0015092	0.0035156	1.96725
ALS	-0.0011688	0.0138958	-0.38544

Based on the paired t-distribution test at a 95% confidence level, the resulting t values are 1.96725 for TLS and -0.38544 for ALS relative to the Total Station measurements. Since both values fall within the acceptance range of -2.086 to 2.086, there is no statistically significant difference between TLS and ALS measurements when compared with Total Station data. The negative t value for ALS indicates a tendency for ALS measurements to be slightly larger than the Total Station results, whereas TLS tends to be slightly smaller. Following the t-distribution test, a 95% Confidence Interval (CI) analysis was performed. The CI was calculated using the absolute differences between the TLS/ALS results and the Total Station measurements to obtain a consistent deviation measure. The results are presented in the Table 5.

Table 5. Confidence interval of TLS and ALS measurement differences

Side	TLS Diff (m)	Decision	ALS Diff (m)	Decision
A	0.0001	Accepted	0.00849	Rejected
B	0.0025	Accepted	0.01315	Rejected
C	0.0007	Accepted	0.00620	Accepted
D	0.0012	Accepted	0.00386	Accepted
E	0.0022	Accepted	0.00149	Accepted
F	0.0002	Accepted	0.00021	Accepted
G	0.0009	Accepted	0.00017	Accepted
H	0.0003	Accepted	0.00320	Accepted
I	0.0006	Accepted	0.00432	Accepted
J	0.0007	Accepted	0.01003	Rejected
K	0.0011	Accepted	0.00911	Rejected
L	0.0012	Accepted	0.00693	Accepted
M	0.0002	Accepted	0.00033	Accepted
N	0.0004	Accepted	0.04157	Rejected
O	0.0059	Accepted	0.00547	Accepted
P	0.0015	Accepted	0.00482	Accepted
Q	0.0010	Accepted	0.00645	Accepted
R	0.0025	Accepted	0.01196	Rejected
S	0.0151	Rejected	0.01212	Rejected
T	0.0009	Accepted	0.00639	Accepted
U	0.0019	Accepted	0.03429	Rejected
n			42	
Mean			0.00551379	
Standard Deviation			0.00842272	
t-krit (*df = n - 1*)			2.021	
Maximum Interval			0.00922839	
Minimum Interval			-0.0037146	

The Confidence Interval was calculated by first determining the mean difference, which was obtained as 0.005513793 m. The critical *t*-value of 2.021 was derived from the *t*-distribution table at a 95% confidence level with 41 degrees of freedom (df), calculated using $df = n - 1$ for a sample size of 42. Since *t*-distribution tables typically round degrees of freedom above 30 to the nearest standard value, $df = 40$ was used. After computing the standard deviation and mean difference, the upper bound of the 95% Confidence Interval was determined to be 0.009228390 m. This result indicates that several difference values exceed the upper limit. Specifically, in the TLS dataset, 1 out of 21 measurements lies outside the Confidence Interval, whereas in the ALS dataset, 8 out of 21 measurements exceed the interval limit.

3.6 Research Implementation

This study evaluates the accuracy, efficiency, and effectiveness of Terrestrial Laser Scanner (TLS) and Airborne Laser Scanning (ALS) measurements for 3D modeling of transmission towers. The analysis examines measurement accuracy as well as the strengths and limitations of each method. Effectiveness refers to the extent to which an activity achieves its intended objective, while efficiency describes the optimal balance between resources used and the results obtained (Hidayat et al., 2021). The comparison of TLS and ALS implementation is summarized in the Table 6:

Table 6. Comparison of TLS and ALS survey implementation

Category	TLS	ALS
Instrument	Leica RTC 360	Zenmuse L2 mounted on DJI Matrice 350 RTK
Equipment Cost	± IDR 1.500.000.000	± IDR 950.000.000
Rental Cost (per day)	± IDR 12.000.000	± IDR 9.000.000
Data Acquisition Duration	± 120 minutes	± 30 minutes
Minimum Surveyors Required	2 persons	2 persons
Data Processing Duration	± 6 hours	± 2 hours
File Size	± 25.2 GB	± 6 GB
Software	Cyclone REGISTER 360 PLUS (licensed)	DJI Terra (open source)

Each measurement method offers distinct advantages and limitations based on its operational characteristics. Terrestrial Laser Scanner (TLS) provides high accuracy and detailed 3D representations, but requires longer acquisition and processing times, as well as more extensive hardware support. In contrast, Airborne Laser Scanning (ALS) is more efficient for larger areas, requiring less time and labor, although its accuracy is generally lower compared to TLS.

4. CONCLUSIONS

Based on the analysis and data processing results, the Terrestrial Laser Scanner (TLS) produced a smaller Root Mean Square Error (RMSE) of 0.0037 m compared to the Airborne Laser Scanning (ALS), which recorded an RMSE of 0.0136 m. The t-distribution test indicated that there is no statistically significant difference between TLS and ALS measurements relative to the Total Station data. Furthermore, the Confidence Interval analysis shows that 95% of the TLS data (20 out of 21 observations) fall within the confidence range, whereas only 61% of the ALS data (13 out of 21 observations) lie within the interval. In terms of visualization, TLS generates a denser and more detailed point cloud comprising 27.946.883 points, while ALS produces 3.046.291 points for the three transmission towers. The 3D model generated from TLS data appears smoother and more consistent with actual field conditions, although it exhibits limitations in areas with restricted scanner visibility, particularly near the upper sections of the towers. Conversely, ALS provides more realistic color representation but has lower point density, resulting in a less solid and less detailed point cloud.

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