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Optimization of Artec Leo 3D Scanner parameters for object accuracy using the Taguchi Method

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Abstract: This study focuses on optimizing the scanning parameters of the Artec Leo 3D Scanner to enhance scanning accuracy by minimizing geometric deviations. The experimental design utilizes the Taguchi L4(2^3) orthogonal array method to examine the influence of three scanning factors: distance, angle, and lighting at two levels. A 16-inch car wheel, chosen for its geometric complexity, was scanned under various parameter combinations. The results indicated that the combination of indoor lighting, a 45° angle, and a scanning distance of 100 cm yielded the smallest deviation (0.5%) and the highest signal-to-noise (S/N) ratio (6.02 dB). Analysis of variance (ANOVA) revealed that the scanning distance contributed the most to the variation in scanning accuracy (65.09%), followed by lighting (34.64%) and angle (0.27%). A confirmation test with the optimal parameters further reduced the deviation to 0.4%, validating the effectiveness of the Taguchi method for parameter optimization. This study's findings contribute valuable insights for industries that require high-precision 3D models, such as aerospace, automotive, and healthcare. The research demonstrates the importance of optimizing scanning parameters and offers a practical approach to improving 3D scanning processes. Future research can expand by exploring environmental conditions, scan resolution, and machine learning integration for real-time adjustments.

Keywords: 3D scanner; Artec Leo; scanning accuracy; Taguchi; geometric deviation

1. Introduction

Three-dimensional (3D) scanning technology is rapidly evolving and plays a pivotal role in various fields, including manufacturing, reverse engineering, healthcare, and cultural preservation (Chadha et al., 2022; Diz-Mellado et al., 2024; Kantaros et al., 2023). As an essential data acquisition tool, 3D scanning enables the precise and efficient conversion of physical objects into digital models that can be employed for a wide range of technical and analytical purposes (Bartol et al., 2021; Crisan et al., 2024; Haleem et al., 2022; Verykokou & Ioannidis, 2023). In particular, the Artec Leo, a portable 3D scanner that uses structured light technology and real-time data processing, has garnered attention for its versatility and efficiency in scanning.

However, one of the pressing issues in the field of 3D scanning is the inconsistency in scan quality, which is often a result of inaccuracies in setting scanning parameters such as distance, angle, and lighting (Cui et al., 2021; Maciej Jedlinski et al., 2021; Wang et al., 2021). Even slight misalignments in these parameters can lead to significant geometric deviations between physical objects and their corresponding digital models, compromising data accuracy (Seid Ahmed & Amorim, 2025; M. Zhang et al., 2023). This challenge is especially pertinent in industries that rely on precise 3D models, such as aerospace, automotive, and healthcare, where even minute errors can have costly consequences.

The importance of optimizing scanning parameters has been highlighted in previous studies, which show that scanning results from devices like the Artec Leo are highly sensitive to operational conditions. For instance, (Mahboubkhah et al., 2018) reported deviations of up to

3.4% in turbine blade scans due to variations in scanning parameters. Similarly, (Sabzali & Pilgrim, 2025) emphasized the need for controlling factors such as scanner angle and distance to minimize dimensional errors. These findings point to the critical need for optimizing scanning parameters to enhance the digitalization of physical objects, particularly in industries that require high precision (Hosamo & Hosamo, 2022; Omrany et al., 2023; Zong et al., 2022).

A key issue in the field is the lack of systematic methods for identifying the optimal combination of scanning parameters. While various studies have focused on individual parameters, such as lighting or angle, few have explored how these parameters interact and their collective impact on the accuracy of 3D scanning (Bugeja et al., 2022; Raza et al., 2023). This research gap underscores the need for a more comprehensive approach to parameter optimization, particularly for portable and highly versatile scanners like the Artec Leo, which are often exposed to fluctuating environmental conditions.

To address this gap, this study proposes the use of the Taguchi Method, a systematic experimental design approach, to optimize the scanning parameters for the Artec Leo 3D scanner. The Taguchi Method, known for its efficient use of orthogonal arrays and the Signal-to-Noise (S/N) ratio approach, is particularly well-suited for evaluating multiple factors affecting output with a minimal number of experiments (Altawil & Olgun, 2025; K et al., 2024; Rifelino et al., 2021). Given that 3D scanning is highly susceptible to fluctuations in environmental conditions and external noise, the Taguchi Method provides a robust framework for identifying the optimal parameter combination, including lighting, angle, and distance, that will yield the highest scanning accuracy.

The main objective of this research is to identify the optimal combination of scanning parameters that maximizes the accuracy of 3D scanning using the Artec Leo. The study evaluates the interaction of lighting, angle, and distance by employing the Taguchi $L4(2^3)$ orthogonal array method (Hisam et al., 2024; Rajesh et al., 2021). The expected outcome is to provide insights into the effective implementation of 3D scanning optimization in both industrial and academic contexts. This research aims to fill the current gap by providing a comprehensive, systematic approach to parameter optimization, thereby improving the overall performance of 3D scanning processes.

The novelty of this study lies in applying the Taguchi Method to optimize the scanning parameters for the Artec Leo 3D scanner, an approach that has not been extensively explored in previous research. By focusing on a combination of factors and leveraging the Taguchi $L4(2^3)$ orthogonal array method, this research contributes to the field of 3D scanning by offering a new perspective on how to optimize scanning accuracy. The main contribution of this research is the identification of the best combination of scanning parameters, which will help improve the accuracy and efficiency of 3D scanning in various applications, particularly in industries where precision is critical.

2. Methods

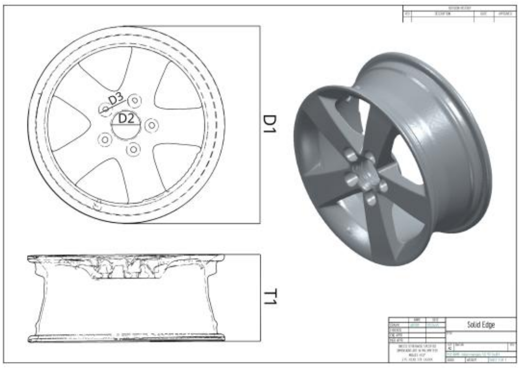
2.1 Research design

This study aims to optimize the scanning parameters of the Artec Leo 3D Scanner to achieve the highest possible accuracy in scanning by minimizing geometric deviation. The parameters under investigation include scanning distance, angle, and lighting conditions, with each parameter tested at two levels (Koseoglu et al., 2021; Q. Li et al., 2022; Wesemann et al., 2021). The experimental design utilizes the Taguchi method, which is renowned for its efficiency in evaluating the influence of multiple factors on output quality with a limited number of trials (Rashid, 2023; F. Zhang et al., 2021). The method is particularly useful in this context where 3D scanning can be affected by various environmental factors, including lighting and scanning angle.

2.2 Test object and equipment preparation

The test object selected for this study is a 16-inch car wheel, chosen due to its geometric complexity, which includes curved surfaces, holes, and sharp edges. These characteristics are typical of industrial applications (Belodedenko et al., 2023). The wheel was selected for its complex contours and reflective surfaces, which pose a challenge to the scanning process. The actual dimensions of the object were measured using a caliper with an accuracy of ±0.1 mm as a reference.

(a)



(b)

Figure 1. (a) Car wheel test object, and (b) Reference dimension position on the test object

Table 1. Test object measurement result data

Parameter	Symbol	Value	Unit
Outer diameter	D1	440.5	mm
Inner hole diameter	D2	64	mm
Bolt hole diameter	D3	32.1	mm
Wheel height	T1	192.5	mm

These dimensions were selected because they comprehensively represent the geometric features of the object, including both macro and micro features, as well as vertical and horizontal elements. They serve as indicators for evaluating the success of the scanning process (Onyia et al., 2025). The analysis of deviations between the scanning results and these actual values will allow for an objective evaluation of the scanner's performance and help identify the parameter combinations that yield the highest accuracy (Oh et al., 2020). Thus, these four parameters are essential for achieving the research objectives.

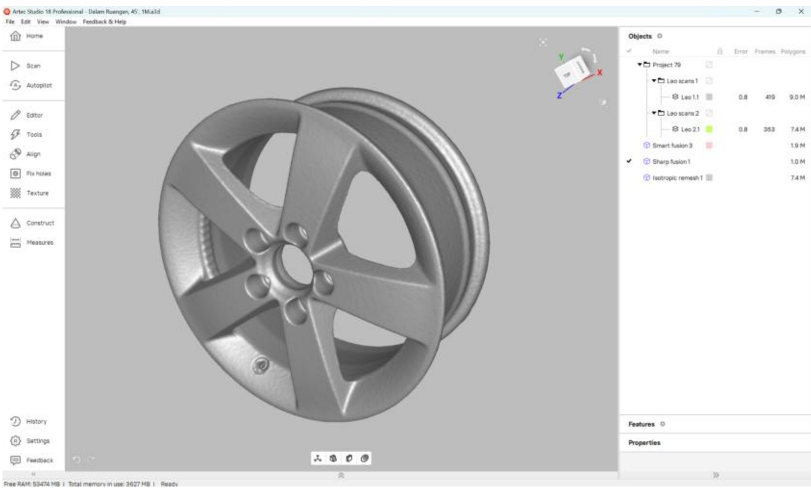


Figure 2. Scanning results in Artec Studio 21

The scanning was carried out using the Artec Leo scanner, paired with Artec Studio 21 software for 3D model reconstruction. The supporting computer specifications followed the manufacturer's recommendations (Intel Core i9, 32GB RAM) to ensure optimal data processing (Diara, 2023). This configuration minimizes the possibility of lag or data loss during the processing of high-resolution meshes, ensuring that alignment, fusion, and export processes are efficient and accurate.

2.3 Experimental design with the Taguchi method

The Taguchi method is applied using the Orthogonal Array L4(2^3), which includes three factors, each with two levels, resulting in four experimental combinations. The parameter combinations are arranged using the $L_4(2^3)$ Orthogonal Array, allowing for the evaluation of all factors with only 4 experiments (J. Li et al., 2024). The selection of this orthogonal array reduces the number of experiments from 8 (full factorial design) to 4 without sacrificing analytical accuracy (Jankovic et al., 2021). The experimental matrix is designed in Table 2.

Table 2. Orthogonal array $L_4(2^3)$

No.	Lighting (P)	Angle (A)	Distance (D)
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

Descriptions:

L1 = Indoor Lighting
A1 = 90° Scanning Angle
D1 = 50 cm Scanning Distance

L2 = Outdoor Lighting
A2 = 45° Scanning Angle
D2 = 100 cm Scanning Distance

2.4 Scanning procedure and deviation measurement

Each parameter combination is applied to the test object following these steps: first, calibrate the scanner using the built-in calibration target to ensure initial accuracy. Furthermoere, scan the object at a constant speed with ≥60% data overlap to minimize missing data. Then, reconstruct the 3D model in Artec Studio using the Outlier Removal and Small Object Removal filters to reduce noise. Finally, calculate the geometric deviation based on the difference between the actual dimensions and the scanned results at specific reference points. This deviation value is expressed as a percentage error and used as the main response variable in the analysis, with the formula:

$$\delta = \left(\frac{|x-y|}{y}\right) x\ 100\% \quad (1)$$

Descriptions:

δ = Deviation (%)
x = Scanned Dimension (mm)
y = Reference Dimension (mm)

Deviation measurements between the 3D model and the physical object are taken using SolidEdge software, and the 3D model is exported in .obj file format.

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2.5 Data analysis with S/N ratio and ANOVA

Data analysis is conducted in two stages. First, the average deviation and S/N ratio values for each parameter combination are calculated. To measure the stability and consistency of the system against variations, a Signal-to-Noise Ratio (S/N) approach is used with the "Smaller is Better" category, as the goal is to achieve the smallest possible deviation value (Pampanoni et al., 2024).

$$S/N = -10.\,log\;10\left(\frac{1}{n}\sum_{i=1}^{n} y_{i^2}\right) \tag{2}$$

Descriptions:

S/N = Signal-to-noise ratio (dB)
n = Number of measurements per parameter combination
y_i = Geometric deviation for the *i*-th measurement (%)

Second, an analysis of the influence of each factor is performed using a main effects diagram and Analysis of Variance (ANOVA) to determine the contribution of each parameter to the scanning results (Rust et al., 2021). To measure the effect of each factor on the total variation, response analysis is conducted. All analyses are performed using Minitab software.

Factor Sum of Squares (SS)

$$SS_{faktor} = 2\,.\,(\bar{Y}_{level\,1} - \bar{Y})^2 + 2\,.\,(\bar{Y}_{level\,2} - \bar{Y})^2 \tag{3}$$

Descriptions:

$\bar{Y}_{level}$ = Average response at a certain level (dB²)

Total Sum of Squares (SST)

$$SST = \sum_{i=1}^{n}(Y_i - \bar{Y})^2 \tag{4}$$

Descriptions:

SST = Total variation in the data (dB²)
Y_i = Response value (S/N) in the *i*-th experiment
$\bar{Y}$ = Average of all response values

Percentage contribution of factors

$$\%Contribution = \left(\frac{SS_{faktor}}{SST}\right)\,x\;100\% \tag{5}$$

3. Results

Three factors were tested: scanning distance, scanning angle, and lighting conditions, each at two levels. The measurement and analysis results are presented in the form of deviation values and signal-to-noise (S/N) ratios, categorized as Smaller is Better.

Table 3. Deviation Analysis Results on Car Wheel

No	Lighting	Angle	Distance	Deviation (%)	S/N Ratio (dB)
1	P1	S1	J1	1.1	-0.82
2	P1	S2	J2	0.5	6.02
3	P2	S1	J2	0.9	0.91
4	P2	S2	J1	1.8	-5.11

The negative values in the S/N Ratio in Table 3 indicate that the resulting deviations are relatively large. In the context of the Taguchi method, a negative S/N ratio suggests that the test condition leads to unstable performance, with significant deviation from the target values. The larger the deviation, the smaller the S/N ratio becomes, which could even result in negative values.

The experimental results show a significant variation in the average deviation values across the four parameter combinations. The second experiment (indoor lighting, 45° angle, 100 cm distance) resulted in the smallest deviation of 0.5%, while the last experiment (outdoor lighting, 45° angle, 50 cm distance) showed the largest deviation of 1.8%. The highest S/N ratio was observed in the second experiment, with an S/N value of 6.02 dB, indicating high stability and resistance to noise. Conversely, the lowest S/N ratio (-5.11 dB) occurred in the final experiment, reflecting low consistency in the scanning results for that configuration.

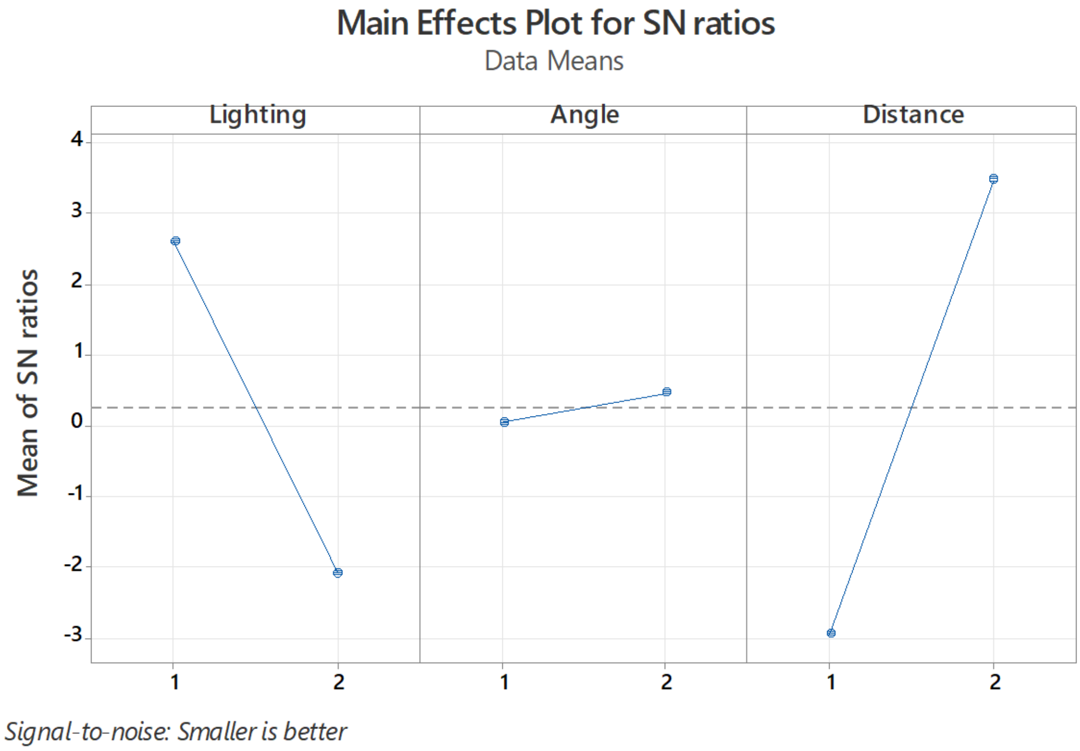

Figure 3. Factor Influence on S/N Rati

The response graph in Figures 3 and 4 of the parameters against the S/N values shows that scanning distance has the most significant impact on deviation, followed by angle and lighting conditions. This indicates that variation in distance directly influences the stability of the geometric data captured by the sensor, particularly in capturing the entire contour of the object. Meanwhile, angle and lighting appear to play supporting roles that influence the detail and sharpness of the scanned result, but they do not have as profound an effect as distance changes. To substantiate these findings, an analysis of the percentage contribution of each parameter through ANOVA was conducted to quantitatively measure each factor's impact on the variation in the scanning results (Gerbino et al., 2016). In performing ANOVA analysis, the SS Factor and SS Total values need to be determined.

$SS_{Lighting} = (4.69)^2 = 22.00$
$SS_{Angle} = (0.41)^2 = 0.17$
$SS_{Distance} = (6.43)^2 = 41.34$
$SS_{Total} = 22.00 + 0.17 + 41.43 = 63.51$

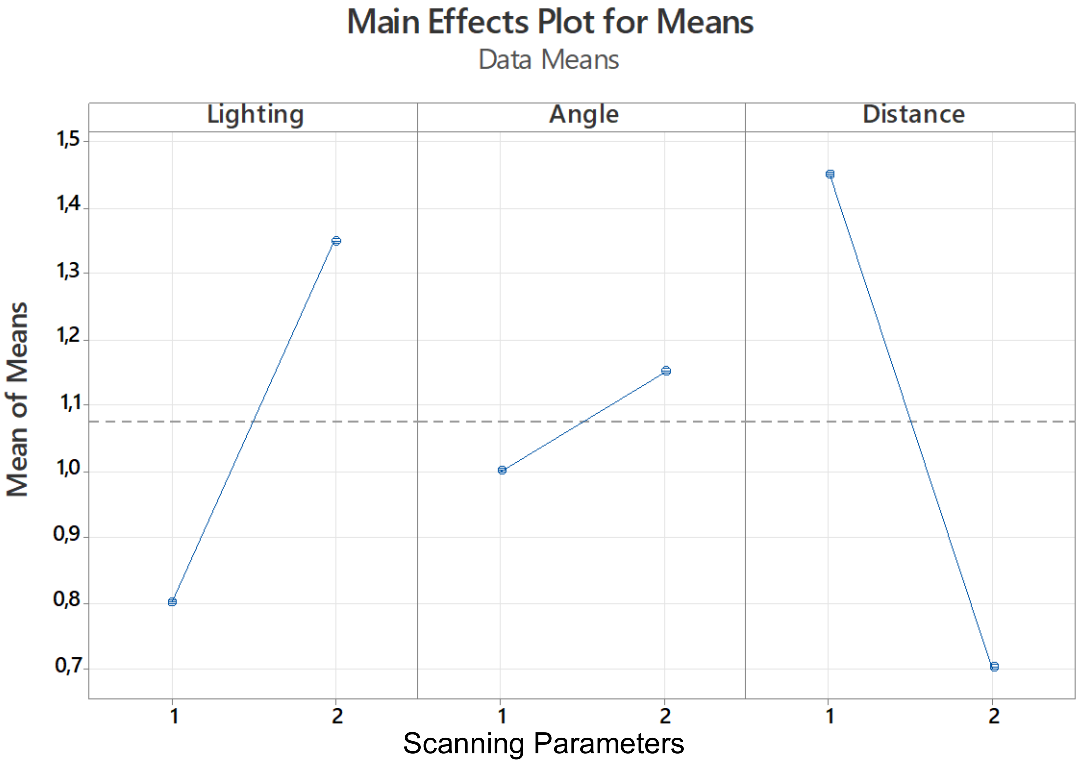

Figure 4. Graph of average factor influence on response

Table 4. ANOVA results

Source of variation	Degrees of freedom (Df)	Contribution	Adj SS	Adj MS
Lighting	1	34.64%	0.3	0.3
Angle	1	0.27%	0.02	0.02
Distance	1	65.09%	0.56	0.56
Error	0	-	-	-
Total	**3**	**100%**	**0.88**	**-**

Table 4 shows that the distance factor has the largest contribution to the total variation, accounting for 65.09%. Lighting contributes 34.64%, while the angle factor only contributes 0.27%, indicating its relatively small effect in this context. These results align with previous studies, which found that scanning distance and angle significantly affect scanning accuracy (Helle & Lemu, 2021; J. Li et al., 2024). To verify the parameter optimization results, a confirmation experiment was conducted using the best combination to ensure that the resulting deviation was indeed lower compared to other experiments. The confirmation experiment was conducted using the optimal combination of indoor lighting, a 45° angle, and a scanning distance of 100 cm.

Table 5. Scanning confirmation results

Lighting	Angle	Distance	Deviation (%)
P1	S2	J2	0.4

The measurement results show that this configuration resulted in a geometric deviation of 0.4%, lower than the smallest deviation in the previous experiments, which was 0.5%. This reduction indicates that the combination of parameters not only provides the best statistical accuracy but also consistently produces 3D models that closely match the original geometric shape. These findings reinforce the importance of selecting the correct operational parameters to enhance 3D scanning quality (Helle & Lemu, 2021).

4. Discussion

This study aimed to optimize the scanning parameters of the Artec Leo 3D scanner to improve scanning accuracy by minimizing geometric deviations. The three factors under investigation scanning distance, angle, and lighting were systematically tested using the Taguchi method. The experimental results demonstrated significant variations in scanning accuracy depending on the combinations of these parameters, with the smallest deviation observed in the combination of indoor lighting, a 45° angle, and a scanning distance of 100 cm, yielding a deviation of 0.5%. In contrast, the combination of outdoor lighting, a 45° angle, and a 50 cm distance produced the largest deviation of 1.8%. These findings underscore the importance of optimizing these parameters to achieve more consistent and accurate results in 3D scanning.

The analysis of the signal-to-noise (S/N) ratios further revealed that scanning distance had the most significant impact on scanning accuracy, followed by lighting conditions and scanning angle. This suggests that variations in scanning distance directly affect the stability of geometric data, particularly in capturing the full contour of complex objects. Meanwhile, lighting and angle, though important, played more of a secondary role in determining the quality and sharpness of the scanned result. This aligns with previous research, such as (Bartol et al., 2021; Jedliński et al., 2021), which highlighted the critical influence of scanning distance and angle on 3D scan accuracy. However, this study's comprehensive approach, which considers the combined effects of multiple factors, provides new insights and a more robust framework for optimizing 3D scanning.

In comparison with earlier studies that focused on individual parameters, this research fills a gap by examining how the interaction between lighting, angle, and distance influences scanning accuracy. The Taguchi method, known for its efficiency in experimental design, was particularly effective in evaluating the combined effects of these factors with minimal experimentation (Alafaghani & Qattawi, 2018; Hisam et al., 2024). By employing the L4(2^3) orthogonal array, the study was able to reduce the number of trials required, making it a cost-effective and practical approach to parameter optimization (Alzyod et al., 2025; Aslam et al., 2025; Nikhila Sri et al., 2025). This method offers valuable contributions to improving the performance of 3D scanners like the Artec Leo, which are often exposed to fluctuating environmental conditions.

The implications of this study are substantial for industries that rely on 3D scanning, such as aerospace, automotive, and healthcare, where precision is crucial. Optimizing scanning parameters, especially scanning distance, can lead to more accurate and stable scans, thereby improving the quality of 3D models used in various applications. Furthermore, the study emphasizes the value of systematic methods like the Taguchi method, which can help standardize the process of parameter optimization across different industries, ensuring consistent results in 3D scanning.

Looking ahead, future research should consider expanding the range of factors influencing 3D scanning accuracy. Environmental conditions, such as temperature, humidity, and surface reflectivity, could have a significant impact and should be tested. Moreover, investigating the influence of additional factors, such as scan resolution and object geometries, would further enhance our understanding of the scanning process. Integrating advanced technologies like machine learning with the Taguchi method could allow for real-time parameter adjustments, offering even greater flexibility and precision in 3D scanning processes. This combination could prove especially useful in dynamic and uncontrolled environments where conditions fluctuate.

In conclusion, this study provides valuable insights into the optimization of 3D scanning parameters, offering a practical framework for improving scanning accuracy. The findings reinforce the importance of carefully selecting operational parameters and demonstrate how systematic methods like the Taguchi method can be effectively applied to optimize 3D scanning processes. These results contribute significantly to the field of 3D scanning, especially in industries where precision is of paramount importance. Future research can build on this work by exploring additional parameters and integrating advanced technologies to further enhance the accuracy and efficiency of 3D scanning.

5. Conclusion

This study successfully optimized the scanning parameters of the Artec Leo 3D scanner, focusing on three key factors: scanning distance, angle, and lighting. Using the Taguchi method with an $L4(2^3)$ orthogonal array, the research identified the optimal combination of indoor lighting, a 45° angle, and a scanning distance of 100 cm, resulting in the smallest geometric deviation of 0.5%. The analysis revealed that scanning distance had the greatest influence on accuracy, contributing 65.09% to the total variation. The Taguchi method proved effective in minimizing experimentation while providing reliable results, highlighting its potential for optimizing 3D scanning processes across industries. The findings emphasize the importance of optimizing scanning parameters for industries that require high-precision 3D models, such as aerospace, automotive, and healthcare. Future research should explore additional factors such as environmental conditions and the integration of machine learning to enhance real-time parameter adjustments. Overall, this study contributes to improving the accuracy and consistency of 3D scanning, offering a practical framework for future applications and research in this field.

Author's Declaration

Author contribution

Ananda Jafron Rhionaldo: Conceptualization, formal analysis, software, data Curation, writing - original draft, formal analysis, visualization. **Rifelino:** Data validation, investigation, methodology, supervision, writing - review & editing, software, visualization. **Delima Yanti Sari:** Conceptualization, supervision, validation, resources, writing - review & editing. **Febri Prasetya:** Data curration, resources, project administration, writing - review & editing, visualization.

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Competing interest

The authors declare that there are no competing interests related to the research or publication of this article.

Ethical clearance

This research did not involve human participants or animals. The study adhered to ethical guidelines and standard laboratory practices during the use of the 3D scanner. All data, including measurements, were handled with transparency and integrity, ensuring privacy. The test object used was a non-living object (car wheel), and no informed consent was required. The study was approved by the ethics committee of the Department of Mechanical Engineering, Universitas Negeri Padang.

Data availability

Raw data supporting the findings of this study are available from the corresponding author upon reasonable request.

AI statement

No artificial intelligence tools were used in the creation of this manuscript.

Publisher's and Journal's Note

Researcher and Lecturer Society as the publisher, and the editor of Journal of Engineering Researcher and Lecturer state that there is no conflict of interest towards this article publication.

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