A COMPARATIVE ANALYSIS OF PHOTOGRAMMETRIC POINT CLOUD AND MESH MODEL OF 3D OBJECT REPRESENTATION

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ABSTRACT: The representation of 3D objects is a fundamental aspect of various industries and mapping tasks, including computer graphics, computer-aided design, virtual reality, 3D printing, topographic mapping, 3D building, and 3D urban modeling, etc. Point clouds and mesh models are prevalent techniques for capturing and reconstructing 3D object shapes and their attributes. This research presents a comparative analysis of point clouds and mesh models, exploring their integrity, accuracy, processing time, storage requirements, and applicability in 3D object representation.
Image acquisition of two cases comprising 3D object samples of varying complexities and structures was conducted and the point clouds and mesh models were generated through photogrammetric software. An evaluation framework was developed to assess the 3D representation capability of different targets and different data models. The study shows that dense points clouds exhibited satisfactory integrity and geometric quality in representing scene objects. On the other hand, mesh models, demanding larger storage space and longer processing time, tended to result in texture distortion and surface deformation, The findings of this study have significant implications for 3D object representation and would help utilize 3D point cloud or mesh models in an optimal way.

1. INTRODUCTION

The utilization of photogrammetric techniques for 3D reconstruction has expanded significantly due to the rapid development of digital cameras, computer vision algorithms, and data processing capabilities(Braun et al., 1995; Ham et al., 2019). This evolution has led to the generation of highly detailed and accurate photogrammetric point clouds, making photogrammetry an attractive choice for various applications, including surveying, cultural heritage documentation, virtual reality, and industrial design(Eisenbeiss and Sauerbier, 2011). On the other hand, mesh models, which consist of interconnected triangles or other polygonal elements, have been widely adopted in computer graphics for their efficiency in rendering and manipulation. Mesh models provide a simplified representation of complex objects while maintaining a visually pleasing appearance. Additionally, mesh models have applications in fields such as computer-aided design(Ham et al., 2019).

However, the choice of representing 3D objects between photogrammetric point clouds or mesh models depends on user requirements and is often subject to trade-offs between accuracy, storage requirements, processing speed, and application-specific needs(Braun et al., 2015). Understanding the strengths and weaknesses of each representation is crucial for successfully supporting decision-making in various fields.

This research aims to bridge the gap in understanding the essential characteristics that point clouds and mesh models represent by conducting a systematic comparison of both types of data. Through assessing the reconstruction capabilities, data acquisition methods, accuracy performance and processing time, the findings concluded may shed light on better treatment of photogrammetric products and offer insight into further improvement in data processing and model formations toward 3D object representation.

2. PAPER REVIEW

Photogrammetric point clouds are 3D datasets of a vast collection of individual points in space, each representing a specific feature or surface point from a real-world object or scene. Point cloud is a large amount of 3D point data generated through photogrammetric orientation, image matching and intersection computation procedures (Li et al., 2021). Photogrammetric point clouds have obvious advantages in scene reconstruction and 3D visualization and can provide comprehensive, accurate, and realistic scene information, taking an important role in the feature extraction and representation of interested objects for many applications(Ruan and Liu, 2020; Wang and Kim, 2019). In addition to 3D coordinates, photogrammetric point clouds can integrate color or intensity information, which provides a more realistic scene presentation and description of object characteristics, receiving high application flexibility.

Mesh models, on the other hand, are surface models composed of triangular meshes, which can be used to describe the geometric shapes and appearance of objects(Kalfarisi et al., 2020). Unlike photogrammetric point clouds, the mesh model contains the topological relationships of the edges and faces of entities and benefits in rendering the data closer to the real geometric shape of the object(Gao et al., 2022). As the 3D mesh model is produced based on the dense point cloud, the accuracy of it certainly inherits and often worsens the one from point cloud(Park and Lee, 2019). Compared with point cloud, the mesh model requires more computing resources and storage space. Besides, during the production process of mesh models, some points are subtracted from the equalization surface to improve model production efficiency. Consequently, it may be difficult to capture complex geometric shapes and details in mesh models.

3. METHODOLOGY

3.1. Data Acquisition

3.1.1. Targets

Two different kinds, in terms of complexities and structures, of targets were chosen in this study. Target1(Figure 1(left)) is a relief of civil engineering with 131cm in length, 111cm in width, and 10cm in depth(Figure 2); Target2(Figure 1(right)) is a sculpture with 55cm in length, 55cm in width, and 75cm in height.

Figure 1. Target1(left) and Target2(right).

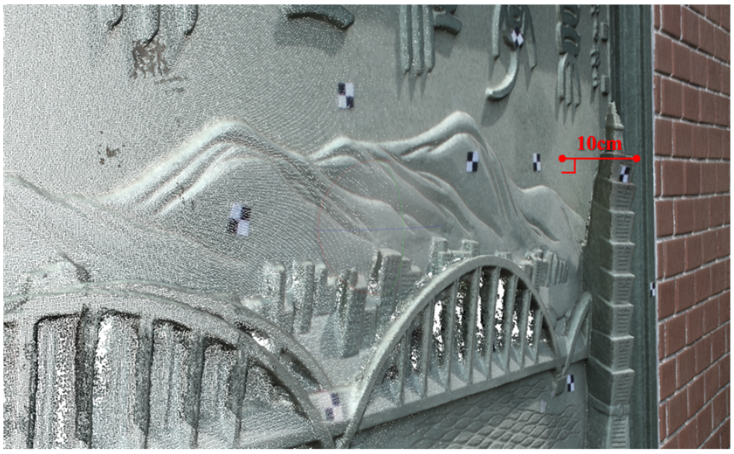


Figure 2. Depth of Target1

3.1.2. Image Acquisition and Instrument Configuration

The instruments used in this research include camera(Canon EOS 600D) and LiDAR(PENTAX S-3180). To reconstruct 3D models, here gives the information related to photogrammetric configuration and software: object distance: 3.0m; GSD: 1mm; overlap rate: 80%; image strip: 3strips; the number of images of Target1: 54; the number of images of Target2: 155; software for alignment and generating point cloud and mesh model: Metashape.

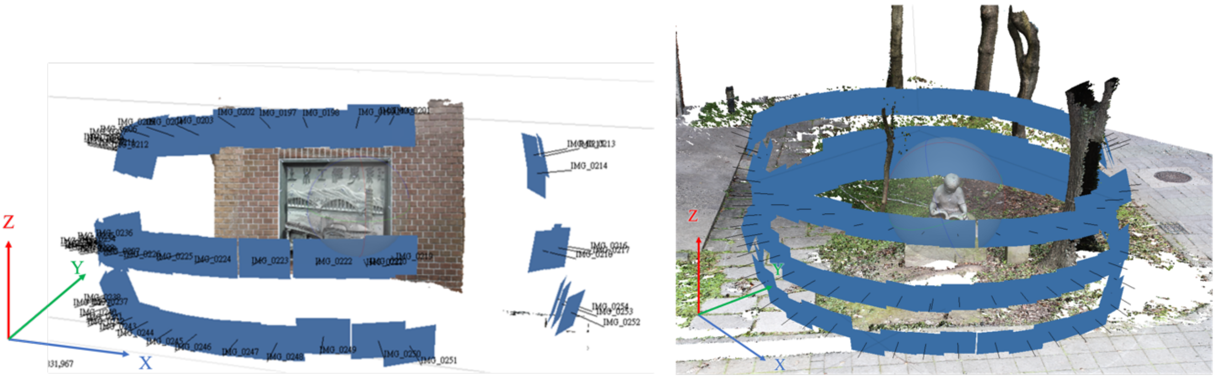


Figure 3. Image acquisitions of Target1(left) and Target2 (right).

3.1.3. Reference point clouds

Point clouds of Target1 and Target2 were scanned by PENTAX S-3180 with 0.0002° in horizontal and 0.0004° in vertical point interval under controlled conditions. The dense and highly precise point clouds were used as reference data for quality assessment. The coordinates of control points and feature points (check points) for both Target1 and Target2 were extracted from LiDAR point clouds.

3.2. Data Processing

Once the data for both relief(Target1) and sculpture(Target2) were acquired, the following steps were taken for data processing and 3D reconstruction:

Alignment: The orientation parameters of images were estimated and sparse point clouds generated.

Point Cloud Generation: Dense point clouds were generated.

Mesh Model Creation: Mesh models were created by connecting the points to form triangles. The mesh models provided a structured and efficient representation of the objects.

Quality Assessment: Completeness, accuracy, storage and processing time were assessed for both point clouds and mesh models.

3.3. Comparative Analysis

With the generated photogrammetric point clouds and mesh models of both the relief and sculpture, comparative analysis on assessing the impact of object type and 3D representation method on the reconstruction capability considering feature preservation, accuracy, data storage space, and processing time was followed.

3.3.1. Root Mean Square Difference

To compare the spatial geometric accuracy of different 3D models, well distributed feature points as check points were selected to this end. Coordinates of them were measured and compared with those in LiDAR data to come up with RMSD (Root Mean Square Difference), as shown in Eq.(1).

$$RMSD = \sqrt{\frac{\sum_1^i (x_i - X_i)^2}{n}} \tag{1}$$

where x_i = Coordinate of feature point in photogrammetric point cloud or mesh model, *i*=1…*n*;
X_i = Coordinate of feature point in LiDAR point cloud;
n = Number of feature points.

3.3.2. Data Storage Space and Processing Time

In investigating the reconstruction capability of different objects and the 3D representation models, this research considered two crucial elements: data storage space and processing time. These elements are pivotal for practical applications, as they directly impact the efficiency and feasibility of 3D modeling tasks.

4. RESULTS AND ANALYSIS

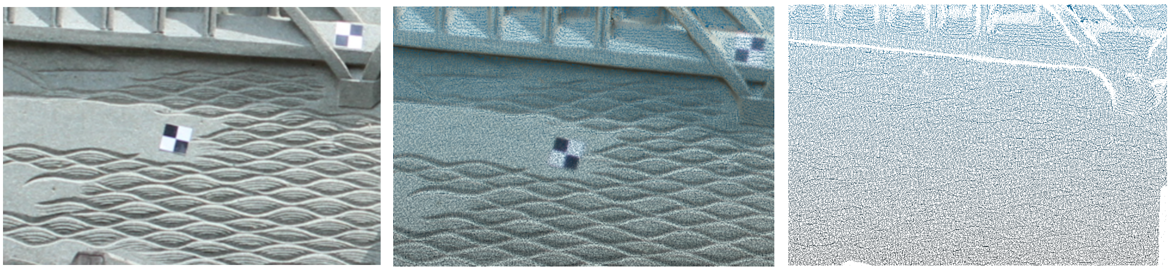
4.1. Completeness

Point clouds rendered high integrity in terms of geometric shape and spatial information(Figures 4~7(c)). Mesh models exhibited variations in both geometric presentation and texture mapping that resulted in distortion and smoothed details(Figures 4~7(d)).

Another noticeable observation was the influence of color information on feature recognition. Before adding color information to the 3D models, both point clouds and mesh models, the capability to recognize and identify features in the objects was limited((c) and (e) in Figures 4~7). The lack of color data hindered the differentiation of specific surface points, particularly in regions with subtle variations in depth and shading effect.

A critical discovery pertained to the alignment of point clouds and vertices was that the algorithmic issues led to point cloud pruning and subsequent feature loss. This effect was observed when comparing point clouds from the same locations to the vertices of the mesh models(Figures 4(d) and 7(d)). This loss of feature points had a cascading effect on object feature recognition, impacting the overall completeness and accuracy of the reconstructions.

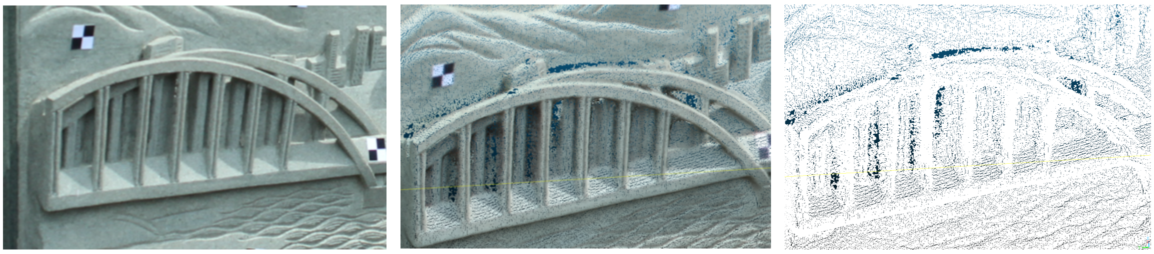
Target1 represents the kind of object that could not be photographed in a full panorama. Consequently, it exhibited limitations regarding feature coverage due to restrictions in capturing angles(Figure 5. (b)). Target2, on the other hand, allowing for nearly full scene coverage, had fewer limitations related to shooting angles and thus yielded more complete and comprehensive 3D reconstruction results.



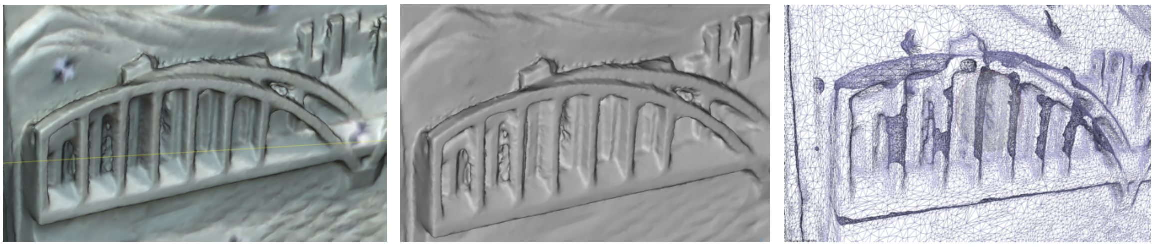
(a)Original image (b)Point cloud with colors (c)Point cloud without colors

(d)Mesh model with colors (e) Mesh model without colors (f) Mesh model vertices

Figure 4. 3D representation of Target1

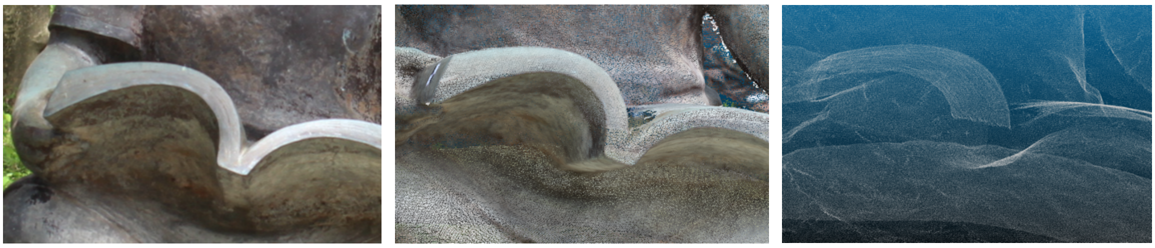


(a)Original image (b)Point cloud with colors (c)Point cloud without colors

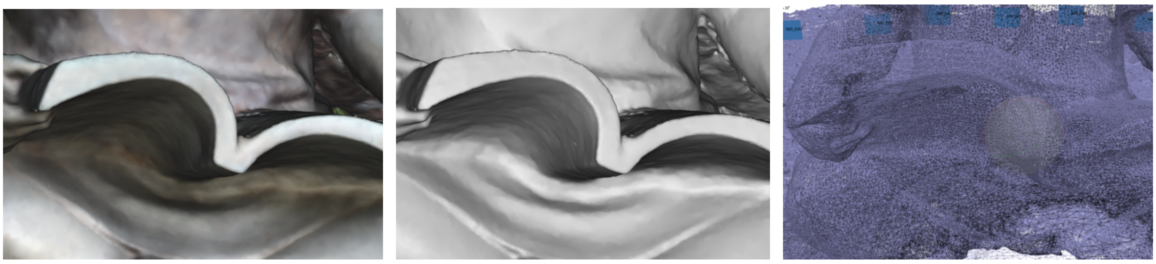


(d)Mesh model with colors (e) Mesh model without colors (f) Mesh model vertices

Figure 5. 3D representation of Target1



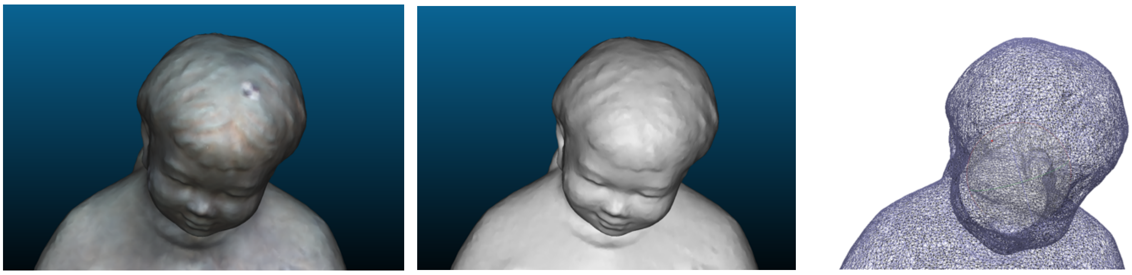
(a)Original image (b)Point cloud with colors (c)Point cloud without colors



(d)Mesh model with colors (e) Mesh model without colors (f) Mesh model vertices

Figure 6. 3D representation of Target2

(a)Original image (b)Point cloud with colors (c)Point cloud without colors



(d)Mesh model with colors (e) Mesh model without colors (f) Mesh model vertices

Figure 7. 3D representation of Target2

4.2. Accuracy of Feature Points

The accuracy analysis is bifurcated into two target segments. Target1 was deployed with a total of 9 control points and 25 feature points (check points), while Target2 12 control points and 18 feature points. The control points and feature points for both targets are depicted in Figure 8. Table 1 shows about 4mm and 7mm RMSD, a degraded positioning quality, of mesh models as compared to the point clouds in Target1 and Target, respectively. The RMSD in Target2 is larger than that in Target1, the implication of less precise positioning quality when confronted with surround imaging geometry. Besides, the quality degradation of mesh models grows up to 7mm, namely 7 GSD, would considerably affect the 3D representation of object in geometric aspect, demanding further investigation.

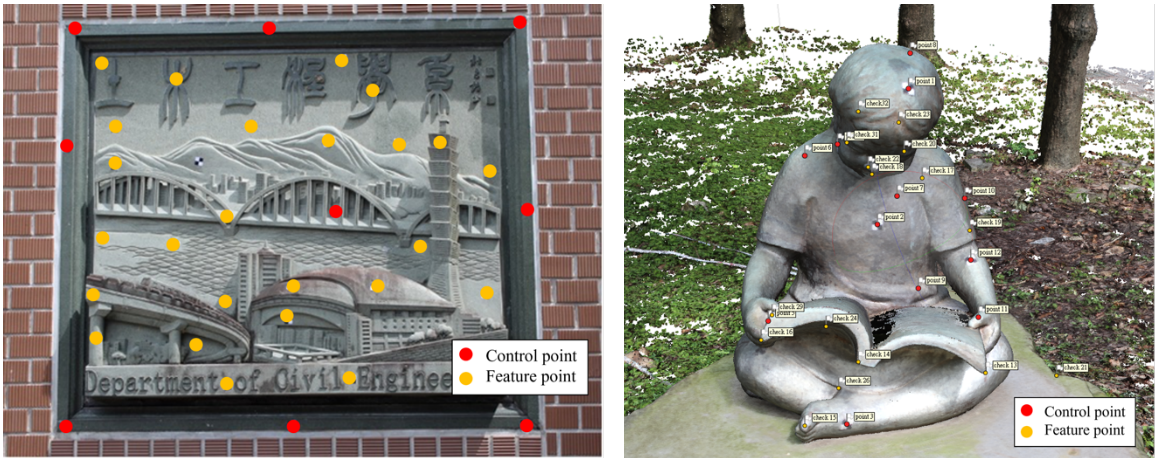


Figure 8. Distribution of Control points and Feature points on Target1(left) and Target2(right).

Table 1. RMSD of Target1

Point cloud of Target1					
	X (mm)	Y (mm)	Z (mm)	XY (mm)	Total(mm)
Control point	0.158	0.470	0.169	0.496	0.523
Feature point	0.456	0.266	0.237	0.529	0.579
Mesh model of Target1					
	X (mm)	Y (mm)	Z (mm)	XY (mm)	Total(mm)
Control point	0.158	0.468	0.167	0.494	0.522
Feature point	1.643	2.557	3.026	3.039	4.288

Table 2. RMSD of Target2

Point cloud of Target2					
	X (mm)	Y (mm)	Z (mm)	XY (mm)	Total(mm)
Control point	0.248	0.585	0.752	0.636	0.984
Feature point	2.760	2.023	2.882	3.422	4.474
Mesh model of Target2					
	X (mm)	Y (mm)	Z (mm)	XY (mm)	Total(mm)
Control point	0.248	0.586	0.751	0.636	0.984
Feature point	3.992	3.694	5.001	5.439	7.389

4.3. Data Storage and Processing Time

The computation was executed using the following hardware configuration: CPU - Intel i9-13900KS, RAM - 128GB, GPU - RTX4080 16GB, SSD - 1TB/2TB, and HDD - 12TB. The results in Table 3 are concluded as follows. First of all, more images would need more time and storage space, as compared to Target2 (155 images) with Target1(54 images). Secondly, the generation of mesh models consumes more time and requires larger storage space than that of point clouds. It can be explained by realizing that mesh model generation involved the conversion of point clouds into triangle representations, leading to a longer processing time. Particularly, the intricacies of mesh construction and triangle generation contributed to the extended processing durations.

Photogrammetric point clouds exhibited relatively modest storage requirements. Compared to the mesh models, photogrammetric point clouds were denser for both the relief and sculpture, they remained manageable in terms of storage space, and even more space-efficient. In contrast, mesh models demanded more storage space than point clouds. This increase in storage space for mesh models was attributed to the interconnected triangles used to represent the surface of the object.

Table 3. Processing time and storage of 3D reconstruction

	Target1 Point clouds	Target2 Point clouds
Processing time Storage	7'28" 121,866KB	13'33" 931,156KB
	Target1 Mesh model	Target2 Mesh model
Processing time Storage	9'03" 161,276KB	28'28" 1,530,891KB

5. CONCLUSION

This research conducted a comprehensive analysis of photogrammetric 3D reconstruction of employing point clouds versus mesh models, focusing on assessing completeness, accuracy, storage space, and processing time. The results offer insights into the strengths and limitations of different approaches and suggestions for future research and improvement as follows.

(1) Dense points clouds exhibited satisfactory integrity and geometric quality, 0.5 and 4 GSD for Target1 and Target2, respectively, in representing scene objects. On the other hand, mesh models, demanding larger storage space and longer processing time, tended to result in texture distortion and surface deformation, unfavorable for the applications pursuing precise 3D mapping.
(2) Adding color information significantly improved feature recognition for both point clouds and mesh models.
(3) Objects or features that are invisible or failed in image matching would be absent from the point clouds and mesh models, remaining missing in the 3D representation stage.
(4) Dense point clouds preserve more complete and geometrically accurate scene information and are of potential for feature extraction and 3D mapping. Mesh models, though with weakened geometric quality, offer topologically interconnected point structure and support efficient data rendering.
(5) Last but not least, the loss of geometric quality and radiometric information of mesh models resulting from the algorithmic reduction may be improved by imposing feature-enhanced or feature-preserved constraints, a research topic worth trying.

6. ACKNOWLEDGEMENTS

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