Advances in Engineering Research, volume 208
Proceedings of the International Conference on Innovation in Science and Technology (ICIST 2020)

Effects of Radius Threshold on Delaunay and Alpha-Shapes Mesh Generation

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***Abstract*—Three-dimensional (3D) scanning has been used widely for prototyping. However, sometimes the object is not successfully reconstructed into a 3D model. One of the important parameters in the mesh generation is the radius threshold. This study aimed to investigate the effects of the radius threshold on the mesh generation in terms of mesh quality, percentage of generated faces, and the processing time. Two methods, i.e., Delaunay and Alpha-shapes, were implemented for the comparison. A Kinect sensor was utilized for the 3D scanning. Skanect and Matlab were employed for point cloud capturing and data processing, respectively. As a result, the mesh quality and percentage of the generated faces were influenced by the radius threshold even though the two methods have different trends. The effect of the radius threshold on the processing time can be neglected. Generally, Delaunay resulted in lesser processing time compared to Alpha-shapes.**

Keywords—mesh, kinect, skanect, 3D reconstruction, 3D scanning

I. INTRODUCTION

Three-dimensional (3D) scanning has been used widely for prototyping [1–4]. One of the low-cost techniques for this is scanning using a Kinect sensor [5–8]. The sensor has been utilized to produce a point cloud. A number of meshes were then generated from this cloud to reconstruct a 3D model. However, sometimes the model is not successfully reconstructed into a 3D model. Many holes were found, as the algorithm failed to generate faces. Additionally, unnecessary vertices sometimes still exist, whereas they should be removed. The generated triangular faces sometimes have a poor quality, i.e., not equilateral. Furthermore, the processing time for the reconstruction time is also a concern, especially for rapid reconstruction.

One of the important parameters in the mesh generation is the radius threshold. This study aimed to investigate the effects of the radius threshold on the mesh generation in terms of mesh quality, percentage of generated faces, and the processing time. Two existing methods, called Delaunay and Alpha-shapes, were employed for comparison.

II. METHODS

A. 3D Scanning

The purpose of the 3D scanning is to obtain a point cloud which will be used to reconstruct the 3D object. In this study, four types of 3D objects were employed: cube, cone, pyramid, and cylinder. Each object was scanned three times; the best result was taken for further process. An XBox 360 Kinect Sensor (Microsoft, Redmond, United States) was employed for obtaining point cloud, i.e., vertices to be processed. The Kinect sensor works by capturing the depth information of the object. Skanect (Occipital, San Francisco, USA) was utilized for scanning together with the Kinect. Matlab (Mathworks, Natick, USA) was employed for data processing. All these software were installed on a laptop with Intel® Core™ i3-3110M CPU @2.4GHz and 6144MB RAM.

The scanning setup is shown in Fig. 1. The Kinect sensor was placed in 90 cm of height. Its angle can be adjusted from -27° to 27°. The distance of the Kinect sensor to the object (d) was adjusted from 74 cm to 85 cm to obtain the optimum capture. This adjustment is necessary to ensure the object remains inside the Skanect bounding box. Table I shows the effect of d on the scanning result. The red circles indicate the error (as part of the object was outside the bounding box).

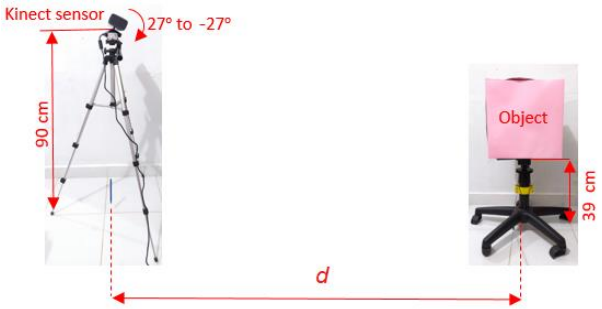
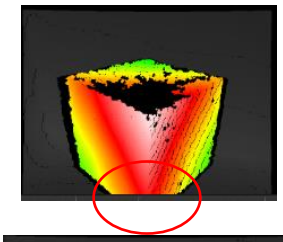
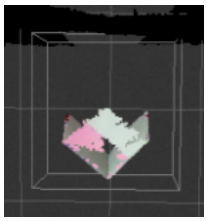
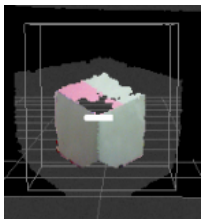
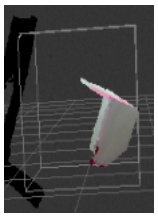
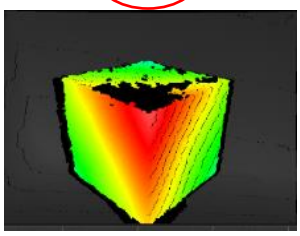
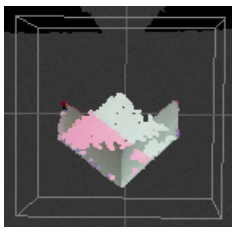
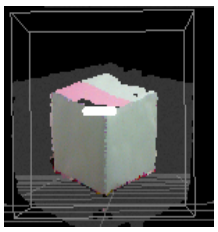
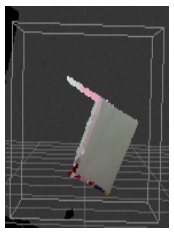
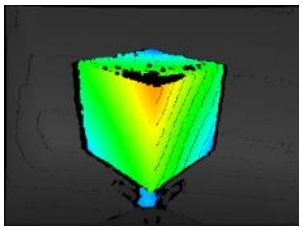
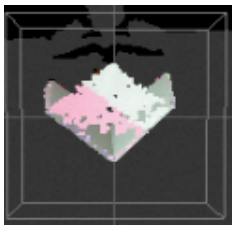
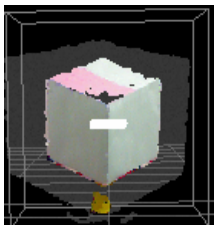
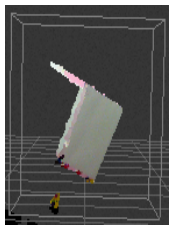
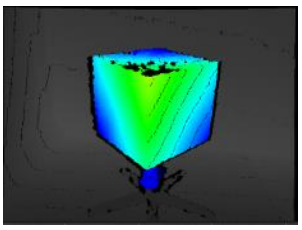
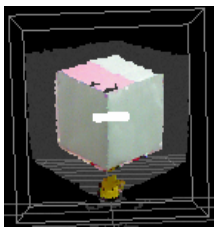
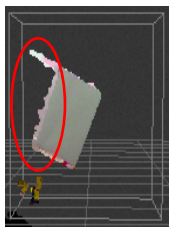


Fig. 1. The scanning setup.

TABLE I. EFFECT OF THE SENSOR-OBJECT DISTANCE ON THE RESULTED SCANNING PROCESS

d	Raw Depth Feed	Top view	Front view	Side view
64 cm				
74 cm				
84 cm				
94 cm				

B. *Mesh Generation*

Each point in the point cloud obtained from the scanning process is called a vertex. These vertices were processed to generate meshes by connecting them to form faces. There are two types of mesh*:* structured mesh and unstructured mesh. Structured mesh has regular element connectivity; each nodal has the same pattern to mark the surrounding nodal. On the other hand, the unstructured *mesh* has an irregular pattern. In this study, we generated meshes in both types.

A 3D object is reconstructed from a number of vertices. A vertex consists of three parameters (i.e., the coordinate): $\{x, y, z\} \in \mathbb{R}^3$. At least three vertices are connected to make a triangular face, which is the simplest 3D component. Triangle is the basis of almost all shapes; the other shapes can be built from triangles. Several faces build a 3D surface that matches the shape of the original object.

This study compares Delaunay and Alpha-shapes methods for mesh generation. The effects of the radius threshold on both methods were investigated. Performances of these methods with varied radius thresholds were compared in terms of the mesh quality, percentage of the generated faces, and the processing time.

C. *Delaunay Triangulation and Alpha-Shapes*

Delaunay triangulation [9,10], which was introduced by Delaunay in 1934, is very useful for work related to mesh generation. To be categorized into Delaunay triangulation, a triangle must meet the Delaunay criteria as depicted by the circles in Fig. 2. This study investigates the effects of variation of the radius threshold of those circles. In the experiment, the thresholds of 1 to 25 were applied. This threshold had no unit. Vertices within the range of this threshold will be eliminated to minimize the unnecessary vertices.

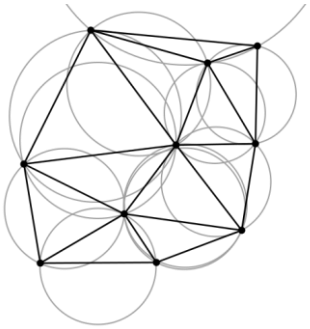


Fig. 2. Delaunay triangulation (License: CC BY-SA 3.0).

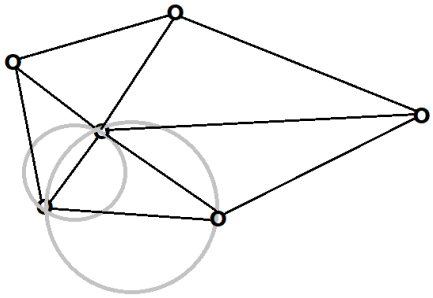


Fig. 3. Alpha-shapes and the radius threshold.

Alpha-shapes or α-shapes [11,12] is a method in which a set of vertices will be extracted so that the boundary shape is obtained (see Fig. 3). In the Alpha-shapes method, it is necessary to determine the radius threshold for the circle that will move to detect vertices in order to find a set of points where a circle is touching three vertices simultaneously. At the time of the extraction process, the size of the circle (called α–ball) will increase, but the vertex that has been detected by the α–ball must remain on the side of the ball until one of two conditions is reached: the radius of the ball reaches a maximum or three vertices have been detected. In case there are more than three vertices, the unnecessary vertices will be eliminated and not used to build a triangular face.

D. Parameters of the Performance Test

By varying the radius threshold, performances of Delaunay and Alpha-shapes methods were compared in terms of the mesh quality, percentage of the generated faces, and the processing time. The procedure is depicted in Fig. 4. Matlab was employed for this process.

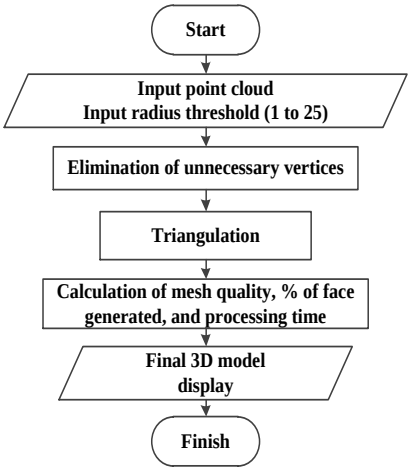


Fig. 4. Procedure to obtain the final 3D model from the point cloud.

Mesh quality ($\bar{q}$) measures how close the generated meshes to the ideal shape, i.e., equilateral triangle. In this study, the mesh quality is calculated by averaging the quality of the faces ($q \in [0,1]$). Face quality = 1 means the triangle has equal sides length (an equilateral triangle). Face quality = 0 means the three vertices have the same coordinate. Eq (1) and (2) calculate q and $\bar{q}$, respectively. In those equations A indicates the area of the face and N indicates the number of faces in the 3D model.

$$q = \frac{4A\sqrt{3}}{a^2 + b^2 + c^2} \tag{1}$$

$$\bar{q} = \frac{1}{N}\sum_{i=1}^{N} q_i \tag{2}$$

The percentage of the generated faces was also calculated to evaluate Delaunay and Alpha-shapes performances. Failure in this parameter causes holes in the final 3D model. Besides mesh quality and percentage of the generated faces, processing time was also calculated and compared, as this parameter is crucial for massive and real-time 3D reconstruction.

III. Results and Discussions

Fig. 5. depicts an example of the point cloud obtained from the 3D scanning (left) and the generated 3D model (right). In this example, the Alpha-shape radius threshold was 2. In that Mesh Generator Analyzer, blue and red dots indicate good faces (quality ≥ 0.6) and not good faces (quality < 0.6), respectively. The radius threshold of 2 yielded the mesh quality of 0.6, 87.25% of generated faces (the rest 12.75% causes holes), and 1.3 s of the processing time.

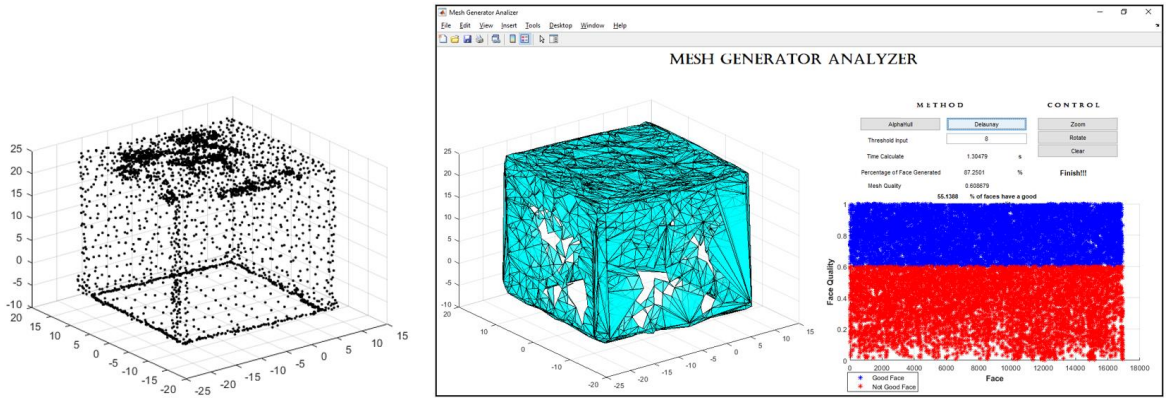


Fig. 5. Example of the point cloud obtained from the 3D scanning (left) and the generated mesh (right).

In the Mesh Generator Analyzer, blue and red dots indicate good faces (quality ≥ 0.6) and not good faces (quality < 0.6), respectively. In this example, the Alpha-shape radius threshold = 2. This threshold yielded 87.25% of generated faces (the rest 12.75% causes holes).

A. *Mesh Quality*

The mesh quality vs. radius threshold for Delaunay and Alpha-shapes is depicted in Fig. 6. The mesh quality was inversely proportional to the radius threshold; it applied to both methods and all types of the 3D objects (cube, cone, pyramid, and cylinder). Additionally, based on the experiment, sometimes, Delaunay resulted in a better result (e.g., cylinder), and sometimes Alpha-shapes was better (e.g., cube). However, the effect of the radius threshold on mesh quality resulted from Delaunay and Alpha-shapes was similar.

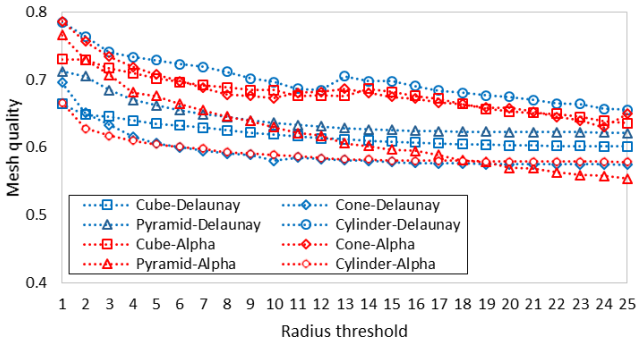


Fig. 6. Mesh quality vs. radius threshold.

B. *Percentage of Generated Faces*

The percentage of generated faces vs. radius threshold is depicted in Fig. 7. Generally, the percentage of generated faces increased exponentially with the radius threshold. However, some problems were found for some objects, e.g., cylinder. Some faces were failed to be built. Generally, the effect of the radius threshold on the percentage of generated faces resulted from Delaunay and Alpha-shapes was similar.

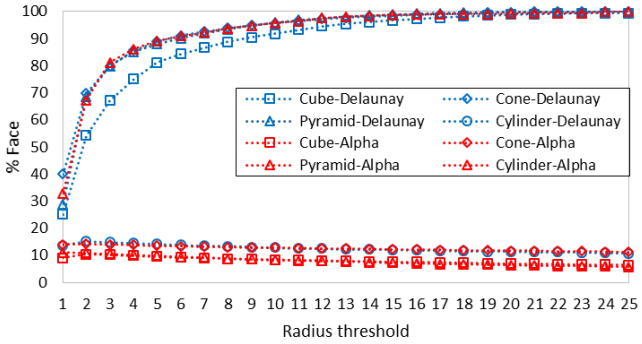


Fig. 7. Percentage of generated faces vs. radius threshold.

C. *Processing Time*

The processing time vs. the radius threshold is depicted in Fig. 8. The experiment showed that the effect of the radius threshold on the processing time could be neglected. Elimination of unnecessary vertices (Fig. 4) reduced the calculating time. In general, the Delaunay method was able to generate meshes faster than Alpha-shapes; it applied to all the 3D objects (cube, cone, pyramid, and cylinder).

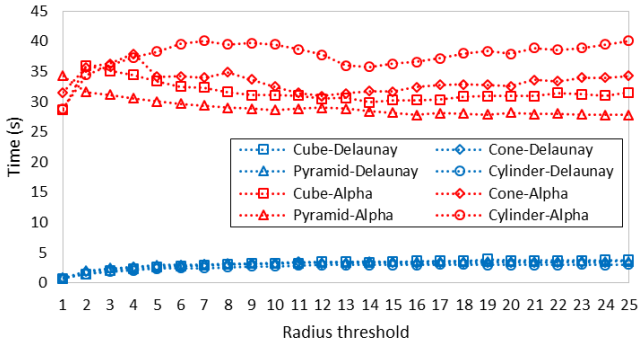


Fig. 8. Processing time vs. radius threshold.

IV. Conclusion

The mesh quality was inversely proportional to the radius threshold. The percentage of generated faces increases exponentially with the radius threshold. Generally, the effect of the radius threshold on mesh quality and percentage of generated faces resulted from Delaunay and Alpha-shapes were similar. The effect of the radius threshold on the processing time can be neglected. In general, Delaunay resulted in lesser processing time compared to Alpha-shapes.

Acknowledgment

The authors thank Politeknik Negeri Batam for the research funding and facilities.

References

[1] S. Homölle and R. Oostenveld, "Using a structured-light 3D scanner to improve EEG source modeling with more accurate electrode positions," J. Neurosci. Methods, vol. 326, p. 108378, Oct. 2019.

[2] A. Haleem, P. Gupta, S. Bahl, M. Javaid, and L. Kumar, "3D scanning of a carburetor body using COMET 3D scanner supported by COLIN 3D software: Issues and solutions," Mater. Today Proc., Aug. 2020.

[3] M. Javaid and A. Haleem, "Current status and applications of additive manufacturing in dentistry: A literature-based review," Journal of Oral Biology and Craniofacial Research, vol. 9, no. 3. Elsevier B.V., pp. 179–185, 01-Jul-2019.

[4] L. Du, "E-quality Control in Dental Metal Additive Manufacturing Inspection Using 3D Scanning and 3D Measurement," Front. Bioeng. Biotechnol., vol. 8, p. 1038, Aug. 2020.

[5] J. Smisek, M. Jancosek, and T. Pajdla, "3D with Kinect," in Consumer Depth Cameras for Computer Vision, Springer London, 2013, pp. 3–25.

[6] G. Rogati, A. Leardini, M. Ortolani, and P. Caravaggi, "Validation of a novel Kinect-based device for 3D scanning of the foot plantar surface in weight-bearing," J. Foot Ankle Res., vol. 12, no. 1, pp. 1–8, Sep. 2019.

[7] N. E. Zain and W. N. Rahman, "Three-dimensional (3D) scanning using Microsoft® Kinect® Xbox 360® scanner for fabrication of 3D printed radiotherapy head phantom," in Journal of Physics: Conference Series, 2020, vol. 1497, no. 1, p. 12005.

[8] N. T. Nhung and L. Hoang, "Applying The Kinect Sensor On Scanning 3d Human Bodies," UTEHY J. Sci. Technol., vol. 24, pp. 117–123, 2019.

[9] B. Delaunay, "Sur la sphere vide," Bull. l'Académie des Sci. l'URSS, 1934.

[10] H. Edelsbrunner, "Delaunay triangulations," in Geometry and Topology for Mesh Generation, 2009.

[11] N. Akkiraju, H. Edelsbrunner, M. Facello, P. Fu, E. P. Mücke, and C. Varela, "Alpha shapes: definition and software," Proceedings of the 1st International Computational Geometry Software Workshop. 1995.

[12] K. Fischer, "Introduction to Alpha Shapes," Dep. Inf. Comput. Sci. Fac. Sci. Utr. Univ., 2000.