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A STUDY OF VARIATION OF NORMAL OF POLYGONS CREATED BY POINT CLOUD DATA FOR ARCHITECTURAL RENOVATION FIELD

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Abstract. Acquiring current 3D space data of cities, buildings, and rooms rapidly and in detail has become indispensable. When the point cloud data of an object or space scanned by a 3D laser scanner is converted into polygons, it is an accumulation of small polygons. When object or space is a closed flat plane, it is necessary to merge small polygons to reduce the volume of data, and to convert them into one polygon. When an object or space is a closed flat plane, each normal vector of small polygons theoretically has the same angle. However, in practise, these angles are not the same. Therefore, the purpose of this study is to clarify the variation of the angle of a small polygon group that should become one polygon based on actual data. As a result of experimentation, no small polygons are converted by the point cloud data scanned with the 3D laser scanner even if the group of small polygons is a closed flat plane lying in the same plane. When the standard deviation of the extracted number of polygons is assumed to be less than 100, the variation of the angle of the normal vector is roughly 7 degrees.

Keywords. Point cloud; 3D laser scanner; physical space; virtual reality; polygon optimization.

1. Introduction

In the architectural renovation field and the urban design field, acquiring current 3D (3-Dimensional) space information of cities, buildings, and rooms rapidly and in detail has become indispensable. The following problems exist although this acquisition work has been done up to now with TS (Total Station) and digital cameras, etc.

1. There is a limit in the range, the measurement precision, and the volume of data that can be acquired.
2. Huge work is necessary for the acquisition of detailed 3D data.
3. Even if a PC is used, this work still requires much manual labour.

The 3D space acquisition technique with a 3D laser scanner (3DLS) has been developed as a solution to these problems. Recently, research using 3DLS has increased in the architecture, engineering, and construction fields. For instance, a 3D digital archive of historical buildings or urban scenes has been made by using 3DLS (H. Cheng, et al, 2009; N. Shih, et al, 2009). By using mobile mapping technology, a texture-mapped 3D city model has been automatically constructed by image data captured by using a CCD camera and building shape data measured using 3DLS (Konno, et al 2000). Moreover, there has been research into image-based modelling as a method of digitizing objects without 3DLS (Q. Pan, et al, 2009).

3DLS can provide accurate and complete details, but is expensive and not portable. Additionally, it is not efficient for scanning large objects. On the other hand, image-based modelling can be applied in various environments, but is not good at scanning objects with unmarked surfaces, nor is it suited for modelling automatically (S.F. El-Hakim, et al 2003). 3DLS has been used because of the necessity of high accuracy in this study.

It is necessary to convert the point cloud data into the polygon to use the point cloud data acquired with 3DLS to design in 3DCAD (3-Dimensional Computer Aided Design), BIM (Building Information Modelling) and VR (Virtual Reality). Using polygons is more advantageous for texture mapping and shadow-casting than using point cloud data. When the point cloud data of an object or space scanned by 3DLS is converted into polygons, it is an accumulation of small polygons. When an object or space is a closed flat plane, it is necessary to merge the small polygons to reduce the volume of data, and to convert them into one polygon. When an object or space is a closed flat plane, each normal vector of small polygons theoretically has the same angle. However, if the angles are not the same, it is necessary to clarify the variation of the angle of small polygons that should become one polygon. The purpose of this study is to clarify the variation of the angle of a small polygon group that should become one polygon based on actual data.

2. 3D data modelling flow by 3DLS and this study

The authors have presented a 3D data modelling flow from objects such as

SCMOD (physical scale model) to digital data by using 3DLS. VIVID910 (Konica Minolta Sensing, Inc.) is used as 3DLS. In the previous research, three problems in the current flow were pointed out (Kitagawa, et al 2010). First, there were far more polygons and vertexes than needed. Therefore, it was difficult to draw shapes and to influence the rendering speed of 3DCAD, BIM and VR. Secondarily, scanned data was output as mesh data, and the shape of the edge of the SCMOD resembled a staircase. Therefore, there was a problem that the edge of the SCMOD was not expressed accurately. Thirdly, part of the scanned data was lacking. This was because it is impossible to scan parts where the laser could not penetrate or where the CCD (Charge Coupled Device) was invisible. Moreover, even for parts where the laser could penetrate and where the CCD was visible, scanned data was sometimes lacking, for example in the macula. Figure 1 shows the result of surface rendering and wireframe rendering of the scanned data generated from SCMOD. The scanning interval is 0.203mm in this case. Thus, a software system for resolving these problems, "Poly-Opt" was developed.

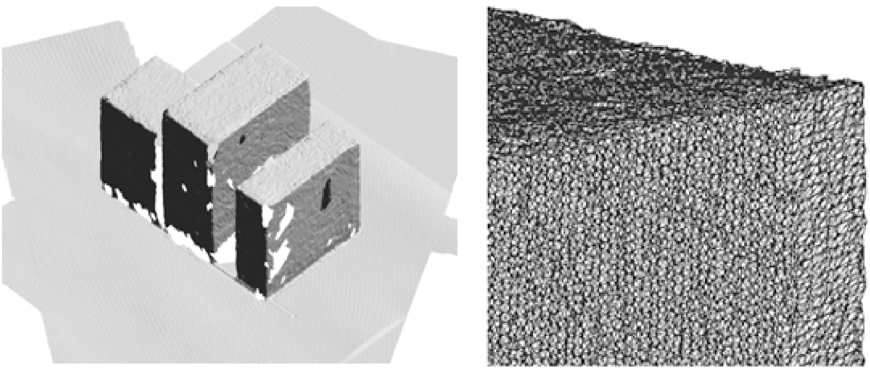

Figure 1. Scanned data generated from a SCMOD: Surface rendering (left) and wireframe rendering at the edge (right)

2.1. 3D DATA MODELLING FLOW BY USING POLY-OPT

This section describes the general current 3D data modelling flow. First of all, the object is scanned by using 3DLS. 3DLS cannot scan a hidden surface. Therefore, the object must be rotated in steps and must be scanned from 360 degrees. Next, a set of the scanned data is merged on “Polygon Editing Tool

Ver.2.3" which is the software accompanying VIVID910. Then, the merged scanned data is converted into optimal scanned data by using Poly-Opt which is a polygon optimization system. This data is output by a general VRML97 (Virtual Reality Modelling Language) format and optimal scanned data is created.

The processing flow of Poly-Opt consists of four steps: transforming coordinate axis step, calculating planes step, calculating new vertexes step, and generating a polygon step (Figure 2 and 3). First of all, in the transforming coordinate axis step, to carry out the VR authoring easily, the rotation transformation is done from the original coordinate axis of scanned data to the horizontal and vertical coordinate axis. Next, in the calculating planes step, the planes including each surface of scanned data are generated. Then, in the calculating new vertexes step, the vertex that becomes the edge of the object is calculated by making a simultaneous equation for each generated plane and obtaining the solution. Finally, in the generating a polygon step, the polygon is generated by uniting the obtained vertex groups by the Delaunay triangulation method. The argument when Poly-Opt is executed is described as follows: *k*: Index of arbitrary vector; θ (degree): Permissible angle of extracted normal vector; *L1* (mm): Distance in the perpendicular direction between planes that are separated; *L2* (mm): Distance in the horizontal direction between planes that are separated; *R* (mm): Composure given to co-domain obtained by the plane equation.

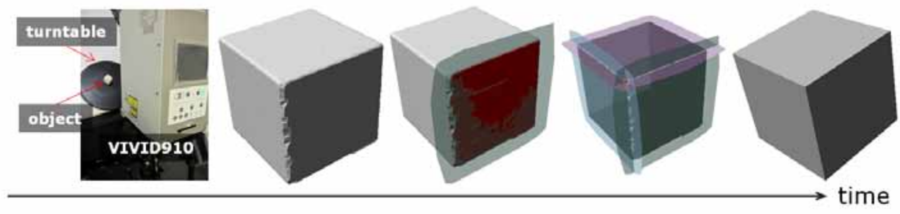

Figure 2. Images of the Poly-Opt flow

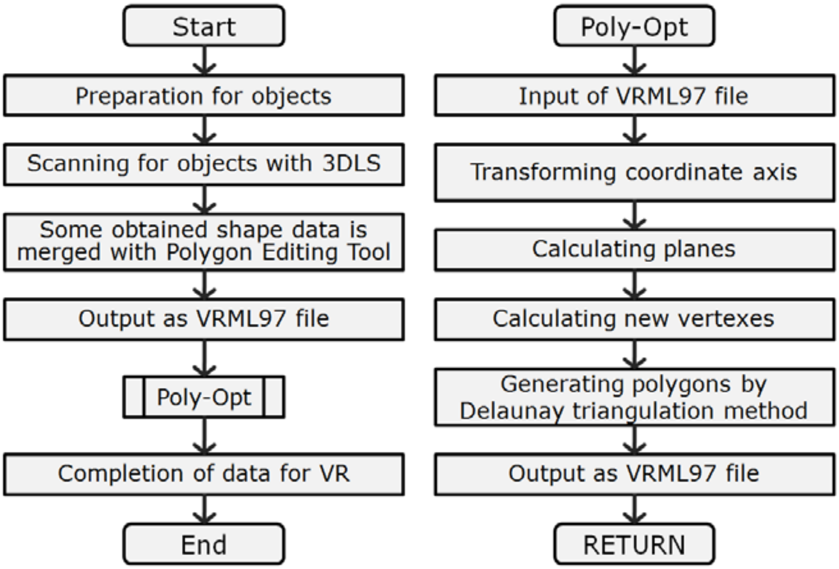

Figure 3. The entire VR modelling flow (left) and the entire Poly-Opt flow (right)

2.2. USE OF POLY-OPT IN THIS STUDY

In this study, a closed flat plane from the small polygons converted from the point cloud data scanned by 3DLS is generated, and the variation of the angle of small polygons is investigated. Therefore, the normal vector extraction function which belongs to the calculating planes step of Poly-Opt is used. Chapter 3 shows the content of the experiment.

3. Experimentation

3.1. EXPERIMENTAL METHODOLOGY

The experiment object is a hexahedron made of polystyrene, which has closed planes. One ridge line of the hexahedron is about 49mm, the number of polygons is 22,217, and the number of vertexes is 11,111 scanned by using 3DLS. The scanning interval is 0.053mm. The procedure of the experiment is shown below.

1. Thirty polygons (*PolygonMn*. *M* is surface ID, *M*=0-5. *n* is the number of polygon, n=30) which should be on the same plane of each surface (*surfaceM*) are selected on the interface of Poly-Opt randomly.

2. The extracted permissible angle θ is set on the interface of Poly-Opt. The number of polygons extracted within the assigned θ angle is counted (*PolygonMnθ*). θ are 17 patterns: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25, 30, 35, and 40-degrees.
3. The average value (*PolygonMaveθ*) and the standard deviation (*PolygonMstdevθ*) of *PolygonMnθ* are calculated by formula (1) and (2) below. In this experiment, *PolygonMaveθ* and *PolygonMstdevθ* of thirty polygons (n=30) for each θ of *surfaceM* are calculated in a statistical approach.

$$PolygonMave\theta = \frac{1}{n}\sum_{i=0}^{n} PolygonMi\theta \tag{1}$$

$$PolygonMstdev\theta = \frac{1}{n}\sum_{i=0}^{n} \sqrt{(PolygonMi\theta - PolygonMave\theta)^2} \tag{2}$$

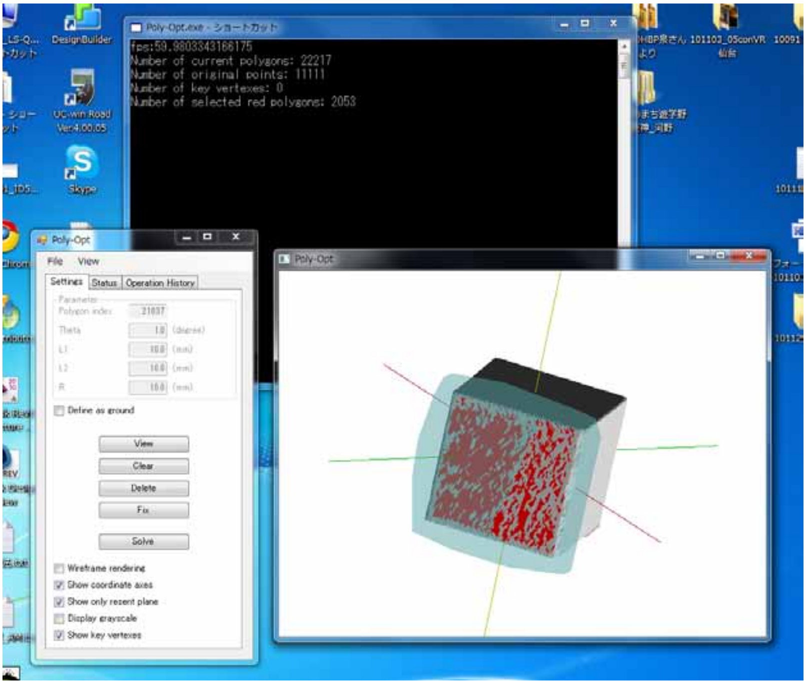

Figure 4. Experimental screen shot using Poly-Opt

3.2. RESULT AND DISCUSSION

The results of *PolygonMaveθ* and *PolygonMstdevθ* for each assigned θ of *surfaceM* are shown in Figure 5, 6 and 7. The tendencies in the scatter charts of each *SurfaceM* are similar.

When θ is 0, most numbers of extracted polygons are 0. That is, when θ is 0, other polygons are hardly extracted. Therefore, each normal vector of small polygons which lie in the same plane is not actually the same angle.

When θ is 30, the standard deviation of the extracted number of polygons is very small, from 1.2 to 3.0. Therefore, all polygons which lie in the same plane are extracted. Some *surfaceM* to which the standard deviation is smaller exist when θ is larger than 30. However, polygons which do not obviously lie in the same plane, such as the area of stair-like edges, are extracted as a result of the observation. Then, average values of the number of polygons extracted when θ is 30 are used to decide the standard number of polygons (*PolygonMave30*).

The variation of the value of *PolygonMn*θ (*M* is a fixed value.) is large when the value of *PolygonMstdev*θ is large. Moreover, the standard deviation does not have a true threshold that becomes a criterion. It is a relative value. When the threshold of standard deviation is assumed to be 100, the θ that becomes *PolygonMstdev*θ < 100 becomes *surface0* = 7, *surface1* = 6, *surface2* = 4, *surface3* = 5, *surface4* = 3, and *surface5* = 5(degrees). That is, it is sure to become *PolygonMstdev*θ < 100 at $\theta \geqq 7$. Moreover, the polygon extraction rate to *PolygonMave30* is as follows at $\theta = 7$ (*PolygonMave7*): *Polygon0ave*θ*7* / *Polygon0ave*θ*30* * 100 = 93.9%; *Polygon1ave*θ*7* / *Polygon1ave*θ*30* * 100 = 94.7%; *Polygon2ave*θ*7* / *Polygon2ave*θ*30* * 100 = 93.4%; *Polygon3ave*θ*7* / *Polygon3ave*θ*30* * 100 = 96.4%; *Polygon4ave*θ*7* / *Polygon4ave*θ*30* * 100 = 93.1%; *Polygon5ave*θ*7* / *Polygon5ave*θ*30* * 100 = 93.8%. That is, it becomes a high sampling fraction of 90% or more for *PolygonMave*θ*30* about all *SurfaceM*.

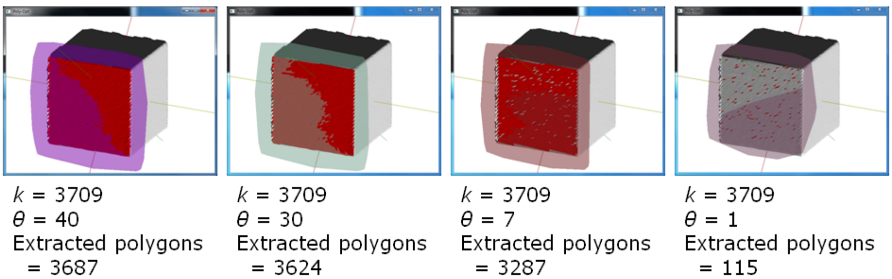

Figure 5. Example of numbers of extracted polygons per each assigned θ

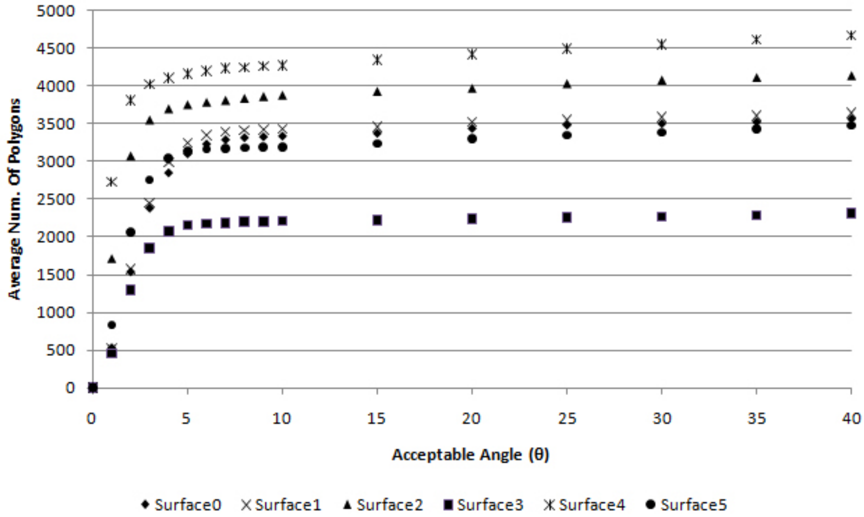

Figure 6. Average numbers of extracted polygons by each acceptable angle θ

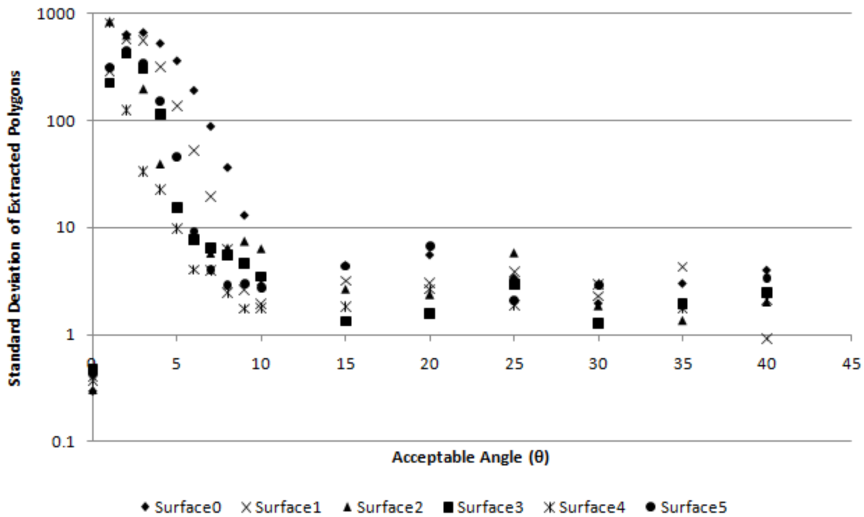

Figure 7. Standard deviation of extracted polygons by acceptable angle θ

4. Comparison measurement by using VR application

The 3D model before and after converting it with Poly-Opt is measured with the VR application, UC-Win/Road ver.4.00.05. As VR contents, 86 building models are arranged along a road which is 2km in length. Two kinds of building models for before and after conversion with Poly-Opt are prepared, the VR application is switched on, and each fps is measured. Table 1 shows the result.

Table 1. Comparison measurement by using VR application.

	VR screen shot	Buildings	Polygons	Reduction rate (%)	Average fps	Progress rate (%)
Before Poly-Opt		86	6,291,451		23.2	
After Poly-Opt		86	92,829	98.5	58.3	251.3

When the measurement results of the two kinds of 3D models are compared, the reduction rate of the polygons is 98.5%, and the improvement rate of fps is 251.3%. When the closed plane is scanned using 3DLS, a group of small polygons can be effectively generated to one closed plane by using Poly-Opt although the 3D model verified in this study is only a simple hexahedron.

5. Conclusion

The conclusion of this study is shown below.

- There are no small polygons converted by the point cloud data scanned by using 3DLS even if the group of small polygons is a closed flat plane which lies in the same plane. When the standard deviation of the extracted number of polygons is assumed to be less than 100, the variation of the angle of the normal vector is roughly 7 degrees.
- The standard deviation of the number of polygons extracted when θ is 30 is small, from 1.2 to 3, as a result of examining the average value and the standard deviation of the number of polygons extracted within the assigned θ angle by using Poly-Opt. Polygons which do not obviously lie in the same plane, such as the area of stair-like edges, are extracted when θ becomes larger than 30. That is, all polygons thought to lie in the same plane are extracted when θ is 30 degrees.

- An architect and engineer can convert a large amount of point cloud data into a polygon by inputting the parameter clarified in this study. Handling the polygon is easy in CAD, BIM and VR.

As a next step, it applies to a SCMOD of a building and city and an actual buildings though this study targets only a cube. Moreover, the variation of the normal vector of polygons is studied by using the average value and standard deviation in this study. Future work should attempt to find a better statistical technique.

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