Highlighting Feature Regions Combined with See-Through Visualization of Laser-Scanned Cultural Heritage

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***Abstract*—We propose a method for precise point-based see-through visualization in which feature regions are highlighted. And by using this method we can recognize the 3D structures of the cultural heritage clearly. The recent rapid development of laser scanners has enabled the precise measurement of real cultural heritage objects. In the measurement, we acquire a point cloud consisting of a large scale of 3D points. The point cloud records complex outer and inner 3D structures of the measured object. See-through visualization is an effective method for recognizing inner 3D structures. To recognize the entire 3D structures based on the point cloud, we need a method for extracting and visualizing feature regions recorded in the point cloud. Therefore we combined these two methods to obtain the highly visible 3D structures of cultural heritage objects.**

Keywords—laser-scanned point cloud; cultural heritage; principal component analysis; see-through visualization

I. Introduction

In recent years, countries around the world have digitized cultural heritages in an effort to preserve cultural heritages for future generations [1, 2]. It is useful not only for preserving cultural heritage but also for publishing to the world through the network and research on humanities. For example, in Kyoto, the Yamaboko of the Gion Festival has been digitized and used for research.

The 3D point cloud of cultural heritage has begun to be used as a record form for digital archives because of the recent rapid development of laser scanning technology. This technology enables us to independently measure both the inside and the outside of a cultural heritage and merge both sets of data. However, conventional opaque rendering [11, 12, 13] cannot simulate the internal structure of a cultural heritage. Therefore, a method to quickly and reliably visualize large-scale and complex laser scanned point clouds by see-through imaging, or transparent visualization, was developed [3, 4, 5]. Using this method, it is easy to see the structure of the cultural heritage, including the inner structure.

However, this method has a problem; the overall shape becomes unclear if the opacity is lowered. In this paper, we visualize the shape more clearly by highlighting the feature regions representing the edge of the 3D structure of the measurement point cloud of the cultural heritage. Combined with the see-through visualization method, the visibility of the 3D structure is improved. As target data, we use the 3D point clouds obtained by laser measurement of Hachiman-Yama float of the Kyoto Gion Festival and Nakajima-ke residence.

To extract the feature regions, a method based on the relative gradient method [6] and principal component analysis [7, 8, 9] is proposed. The relative gradient method is a method of evaluation by obtaining the inner product of the normal vectors existing in arbitrary neighborhoods from the point of interest. However, accurate normal vectors cannot be obtained by laser measurement. Therefore, we use principal component analysis to extract feature regions. In this method, principal component analysis is performed on the coordinates of a point group located inside a local sphere centered on each point, and the eigenvalue of the obtained third principal component is evaluated as a pseudo curvature It is a method suitable for acquiring three-dimensional structural information such as dihedral angle, plane, etc. from the 3D shape expressed by a point cloud. The structure of this paper is as follows.

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Fig.1. The Hachiman-Yama float used in the Gion Festival.

In Section 2, we describe the see-through visualization method. In Section 3, we describe our proposed method. In Section 4, we demonstrate our method by applying it to point cloud of cultural heritages. Section 5 presents the conclusion.

II. SEE-THROUGH VISUALIZATION METHOD

The precise see-through imaging of colliding point clouds can be executed with a correct depth feel with interactive speed by using the stochastic point based transparent rendering [3], which was proposed for dealing with large-scale laser-scanned point clouds recently. The abovementioned collision area opacity and the high collision risk area opacity can also be realized within the framework of the rendering. When applying the rendering to a given laser-scanned point cloud, first, we randomly divide it to statistically independent subgroups. Then, under the assumption that the point density is uniform in a small local surface segment with an area size *S,* the opacity of the segment, α, obeys the formula

$$\alpha = 1 - \left(1 - \frac{s}{S}\right)^{n} \quad , \qquad (1)$$

where n is the number of points in S for each point subgroup, and s is the size of the area whose image just overlaps one pixel in the image space. Formula (1) indicates that the opacity α is controllable through n. We can realize a higher opacity by increasing n and lower it by decreasing n. The increase of n is easily realized by simply creating a proper number of copies of randomly selected points in the original point cloud. Similarly, the decrease of n is realized by randomly eliminating points in

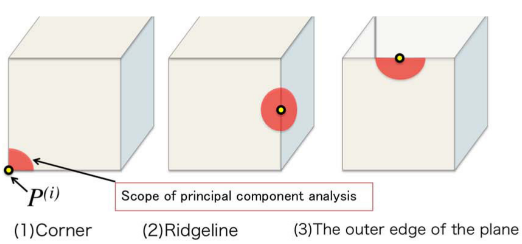

Fig. 3. Three kinds of feature regions to be extracted

Fig. 2. See-through imaging of a laser-scanned point cloud of the Hachiman-Yama float.

the original point cloud. By tuning the number of points n in S, that is, by tuning the point density in S, the probability that the local surface segment is visible is controlled, which means that the opacity α is tuned.

It should be remarked that additional new points need not be added to the raw point cloud data, even when we increase n. All we have to do is simply copy points in the original data. When stochastically calculating the pixel intensities of images based on the abovementioned visible probability, the point

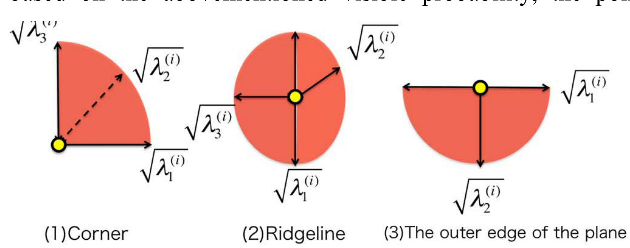

Fig. 4. Point distribution of feature regions

clouds are divided into statistically independent subgroups. Therefore, the copied points are treated as independent rendering primitives. For details, see [3]. The feature that only raw point clouds are used for visualization is advantageous for reliable validation of the simulation based on data acquired by directly measuring the real world.

Fig. 1(left) is the cultural heritage of Hachiman-Yama float before decoration and Fig. 1(right) is after decorated. Fig. 2 show an example of the application of the method to laser-scanned point clouds of Hachiman-Yama. By controlling the opacity α, it is possible to see the internal structure. The overall α is 0.3.

III. PROPOSED METHOD

In this section, we explain our visualization method. First, we extract the feature regions by principal component analysis. Second, we emphasize by controlling the opacity according to extracted feature regions. Below, we explane each procedure.

A. Feature regions extraction method

There are three feature regions defined in this research is three parts as shown in Fig. 3. The corners and edges represent 3D edges. In addition, since some surfaces may not be obtained when laser measurement is performed, it is necessary to extract the outer edge portion of the plane.

Many methods for extracting feature regions from point clouds have been proposed [6, 7, 8, 9, 10] . In this research, extract three types of feature regions in Fig 3 by using principal component analysis, which is said to be relatively resistant to

Fig. 5. Laser-scanned point cloud of the Hachiman-yama float.

noise. The method will be described below. First, the

eigenvalues ($\lambda_3 < \lambda_2 < \lambda_1$) and the eigenvectors ($v_0$, v_1, v_2) are obtained by calculating the covariance matrix S from the coordinates of the point cloud inside the sphere of the radius r

Fig 6. Rainbow color map. The largest value is assigned red color, the middle value is assigned green color, and the smallest value is assigned blue color.

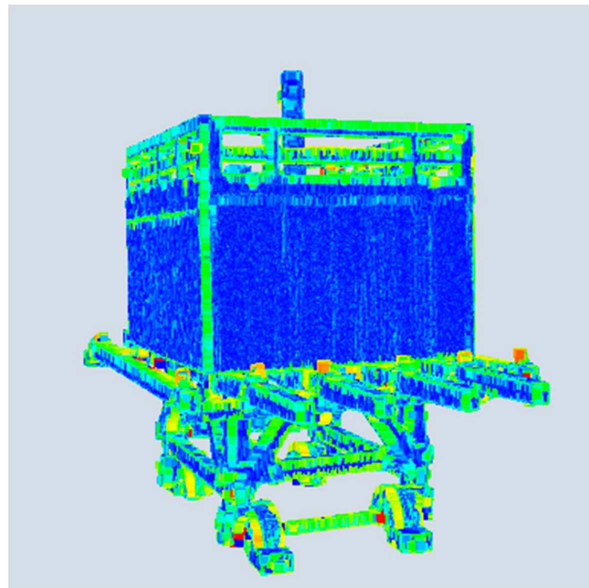

Fig. 7. Color assignment of laser-scanned point cloud of the Hachiman-Yama float according to feature values.

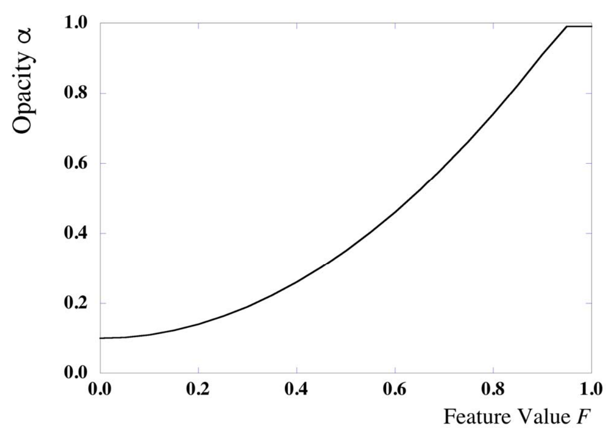

Fig. 8. Relation between opacity α and feature value F.

from the point of interest $P^{(i)}$. The eigenvalues represent the direction of component axes, and S is a real symmetric matrix, so that $\lambda > 0$ and that eigenvectors belonging to different eigenvalues are orthogonal to each other is guaranteed.

In Fig. 4, if $P^{(i)}$ is corner, $\lambda_1 = \lambda_2 = \lambda_3$ holds. If $P^{(i)}$ is ridgeline, $\lambda_1 > \lambda_2 = \lambda_3$ holds. If $P^{(i)}$ is the outer edge of plane, $\lambda_1 > \lambda_2$ and $\lambda_3 = 0$ holds. Therefore, we define the feature value

$$F^{(i)} = \frac{{\lambda_1}^{(i)} - {\lambda_2}^{(i)}}{{\lambda_1}^{(i)}}. \quad (2)$$

Fig. 5 shows the visualization of the point cloud used in experiments. Fig. 7 shows the features of Hachiman-Yama expressed in rainbow color as Fig. 6. It can be seen that F of the plane is close to 0 and that of the part representing the edge is high.

B. *Feature regions highlighting by opacity control*

We control the opacity by the calculated feature value F. To emphasize the feature regions, if the F is high, the α is set high. In Fig. 8, the correspondence between F and α is shown when the minimum α is set to 0.1 and the maximum α is set to 0.99. In that case, F is normalized with a value from 0 to 1.

IV. VISUALIZATION RESULTS

In this section, we demonstrate the effectiveness of our proposed method by reporting the results of case studies performed using real laser-scanned point clouds. Fig. 9 shows the laser-scanned point cloud of Hachiman-yama float. The actual size of (A) is length 1.41 m, width 1.70 m, and height 2.42 m, (B) is length 2.71 m, width 4.55 m, and height 2.84 m.

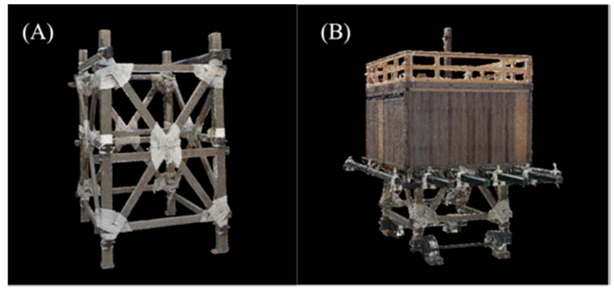

Fig. 9. Laser-scanned point cloud of the Hachiman-yama. (A): the internal structure. (B): the external structure.

Fig. 10 is a see-through visualization; the internal structure is easy to see because the α of the external structure is set low and the α of the internal structure is set high. However, there are unclear sections. Fig. 11 shows our method applied to Hachiman-yama float. The whole shape is clearly visualized because the feature region is emphasized.

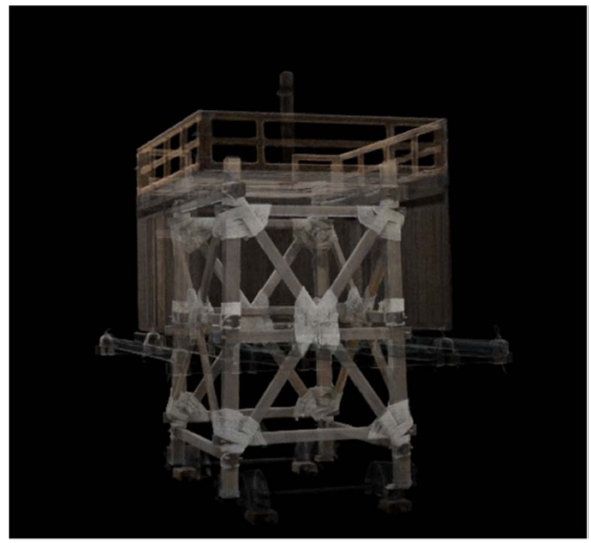

Fig. 10. See-through visualization of the Hachiman-yama float. α is 0.4 for the internal structure and 0.2 for the external structure.

Figs 12 and 13 are comparisons of the visualization results of Hachiman-yama float after amplification. The upper image uses the conventional method of determining the α, and the below image applies the proposed method. In the Fig 12(upper), the conventional method, the shape of the lattice-like platform is unclear, but Fig 12(lower), it can be seen that the proposed method is clearly visualized. In Fig 13(upper), it is difficult to visually recognize the shape of the wheel in the conventional method; in Fig 13(lower), it can be seen clearly with the proposed method.

Fig. 11. Highlighting the feature regions combined with the see-through visualization. Maximum α is 0.6 and minimum α is 0.2.

Fig.15 shows the laser-scanned point cloud of Nakajima-ke residence (Fig. 14). This residence is old Japanese-style house in Ritto-shi, Shiga, Japan. The building area is 102.58 m^2. Figs 16 and 17 are comparisons of the visualization results of Nakajima-ke residence float after amplification. For simple see-through visualization in Fig. 16, for example, the roof cannot be seen. However, if we apply our method, we can see the 3D shape as shown in Fig. 17.

V. CONCLUSION

In this research, we proposed a new method to enhance the visibility of the 3D shapes by highlighting the feature regions representing the edge of the laser-scanned point clouds of cultural heritages. We use stochastic point rendering for see-through visualization and use principal component analysis for feature regions extraction. In the conventional opacity control method, there is a problem that parts of the shape are not clear.

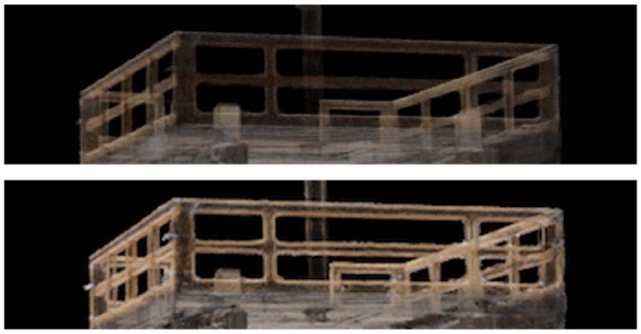

Fig. 12. Enlarged views of the upper part of the Hachiman-yama float. The top image shows the simple see-through visualization, and the bottom image shows see-through visualization combined with the feature highlighting by using our method.

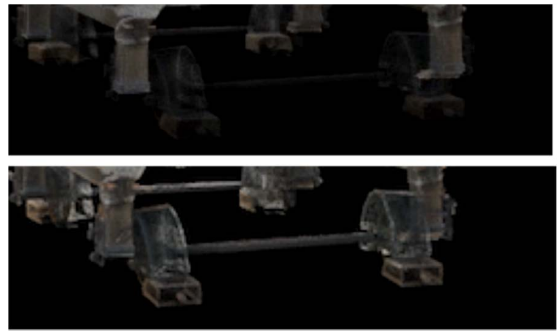

Fig. 13. Enlarged views of the under part of the Hachiman-yama float. The top image shows the simple see-through visualization, and the bottom image shows see-through visualization combined with the feature highlighting by using our method.

In our method, we control the opacity by the calculated feature value. Therefore, the feature regions, which are important in capturing the 3D shape, are emphasized, and the visibility of the shape is improved more than with conventional see-through visualization. When publishing as a digital archive, it is important to visualize unque shapes easily. Therefore, our method has contributed to preservation and succession of cultural heritages.

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Fig. 14. The photograph of Nakajima-ke residence.

Fig. 15. Laser-scanned po int cloud of the Nakajima-ke residence.

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Fig. 16. See-through visualization of the Nakajima-ke residence. Overall α is 0.3.

Fig. 17. Highlighting the feature regions combined with the see-through visualization. Maximum α is 0.9 and Minimum α is 0.3