Optimization of 3D Shape Sharpening Filter Based on Geometric Statistical Values

Masanari Yokomizo, Daisuke Miyazaki, Masashi Baba, Ryo Furukawa,
Masahito Aoyama, Shinsaku Hiura, and Naoki Asada
Hiroshima City University
Hiroshima, JAPAN
http://ime.info.hiroshima-cu.ac.jp/

Abstract

A plaster statue is an object created from a mold made from a stone statue, for example, and into which plaster is poured and hardened. The delicate shape is lost, however, during the molding process, and an issue arises in that the plaster statue has a smoother shape than does the original statue. Consequently in this research, by applying a sharpening filter to the 3D shape data of a plaster statue, highlighted contours comparable to those of the original stone statue are reconstructed for the 3D shape data. The objective is to prepare a stone statue that is used as a reference and to sharpen the input data to match the histogram of the edges of the 3D shape of the stone statue.

1 Introduction

Throughout the world, there are various historical cultural assets that have existed for hundreds and thousands of years. Since such cultural assets have existed for a long period of time, defects and damage caused by natural disasters and human factors, and gradual disintegration over time have altered their current shape from the original shape. In addition, research in recent years has attempted to preserve these cultural assets as 3D data.

The preserved shape, however, provides the current shape of the cultural asset, and some differences compared to the original shape are recognized because of the abovementioned damage and disintegration. In addition, plaster statues characteristically tend to be smoother than the original in the case of Buddha statues made of stone or other materials.

The purpose of our research is to reconstruct the shapes of cultural assets such as Buddha statues made of stone or other materials that have disintegrated and smoothened, and also plaster statues that have smoothened from their original shapes due to the molding process. The reconstruction is performed by using a sharpening filter to sharpen the 3D shape. To perform optimum sharpening, parameters of the sharpening filter are set by geometric statistical values.

2 Related Work

3D data processing is widely investigated. For example, feature-preserving smoothing techniques [1, 2, 3, 4, 5, 6] are widely used for de-noising the 3D geometrical data. On the other hand, a few number of algorithm is proposed for sharpening the 3D geometrical shapes. Chuang et al. [7] proposed a method that performs smoothing and sharpening of 3D shapes by solving the Poisson equation. Zhang et al. [8] proposed an exaggeration method of 3D shape which can interactively change the parameter of local area of its shape. Unlike these methods, we use 3D LoG filter for sharpening due to its simpler implementation.

This paper introduces an application of 3D LoG filter for analyzing cultural assets. The problem we tackle is to estimate the best appropriate parameters of 3D LoG filter using the statistical invariant of geometry. We employ example-based approach for solving the problem. Bhattacharyya distance of the 3D edge histogram between the source 3D data and the target 3D data is used as a criteria for estimating the parameters of 3D LoG filter, which has not been performed in existing papers. At the end of this paper, we show the result using the actual cultural assets in order to emphasize the applicability of our method in the field of archaeology.

3 3D Shape Sharpening Based on Geometric Statistical Values

Our research uses a Laplacian of Gaussian (LoG) filter for performing optimal sharpening and a differential filter for performing calculations of edges.

3.1 Sharpening of 3D Data by 3D LoG Filter

The Laplacian calculation of the 3D Gaussian distribution becomes Equation (1):

$$h_{\log}(x,y,z) = \frac{(x_m-x)^2+(y_m-y)^2+(z_m-z)^2-3\sigma_1^2}{(\sqrt{2\pi})^3\sigma_1^7} \cdot \exp\left(-\frac{(x_m-x)^2+(y_m-y)^2+(z_m-z)^2}{2\sigma_1^2}\right). \quad (1)$$

Here, the interest point is set as (x, y, z), and a neighboring point within a distance $4\sigma_1$ from the interest point is set as (x_m, y_m, z_m). Note that the effect of points beyond $4\sigma_1$ can be ignored due to its small value.

Hence, the filtering calculation of the 3D LoG filter is expressed by Equation (2), where $y_{\log}$ and $z_{\log}$ can be expressed similarly, when the input point is set as (x, y, z) and the output point is set as $(x_{\log}, y_{\log}, z_{\log})$.

$$x_{\log} = \frac{\sum_{m=0}^{n-1} x_m h_{\log}(x_m,y_m,z_m)}{\sum_{m=0}^{n-1} h_{\log}(x_m,y_m,z_m)}. \quad (2)$$

Finally, subtracting the LoG applied point with a constant weight k from the input point renders a point

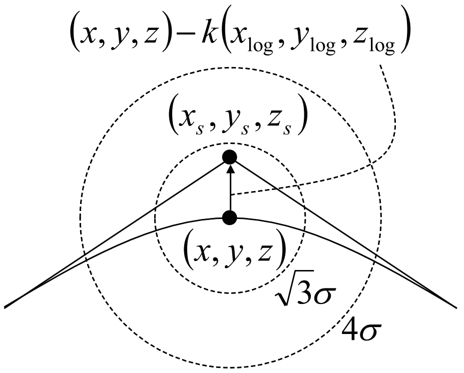


Figure 1. Transformation of sharpening

of the sharpened shape $(x_\mathrm{s}, y_\mathrm{s}, z_\mathrm{s})$. (Here, y_s and z_s can be expressed similarly.)

$$x_\mathrm{s} = x - kx_\mathrm{log}. \tag{3}$$

Equation (1) is not applied as is. The set of positively weighted points and the set of negatively weighted points are independently calculated to obtain weighted averages, which are summed at the end.

In addition, weighting by the normal, inspired by the bilateral filter [1], was performed in the sharpening of this research (parameter σ_2). This weighting is shown below.

$$h_\mathrm{n}(x_m, y_m, z_m) = \frac{1}{(\sqrt{2\pi})^3\sigma_2^3} \cdot \exp\left(-\frac{(n_\mathrm{x}(x_m - x) + n_\mathrm{y}(y_m - y) + n_\mathrm{z}(z_m - z))^2}{2\sigma_2^2}\right). \tag{4}$$

Here, $(n_\mathrm{x}, n_\mathrm{y}, n_\mathrm{z})$ is the surface normal of point (x, y, z). Thus, Equation (5) results by multiplying Equation (2) with Equation (4). (The same is true for y_log and z_log.)

$$x_\mathrm{log} = \frac{\sum_{m=0}^{n-1} x_m h_\mathrm{log}(x_m, y_m, z_m) h_\mathrm{n}(x_m, y_m, z_m)}{\sum_{m=0}^{n-1} h_\mathrm{log}(x_m, y_m, z_m) h_\mathrm{n}(x_m, y_m, z_m)}. \tag{5}$$

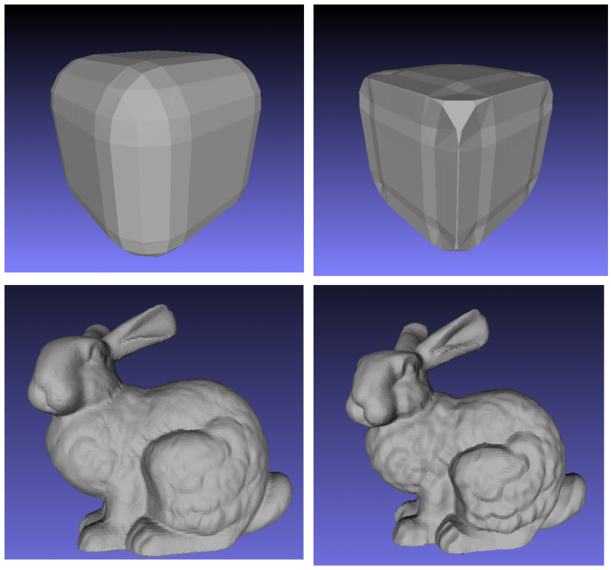
Figure 2 shows some results of 3D LoG filter.

3.2 Edge Calculation of 3D Shape by the Differential Filter

Our purpose is to deform the deteriorated objects' shape so that they become closer to their original shape. We deform the object so that the edge magnitude histogram of the input shape becomes similar to that of the reference shape.

Partial differentiation of the 3D Gaussian distribution for the x axis results in Equation (6). (The same is true for $h_{\nabla\mathrm{y}}$ and $h_{\nabla\mathrm{z}}$.)

$$h_{\nabla\mathrm{x}}(x, y, z) = -\frac{x_m - x}{(\sqrt{2\pi})^3\sigma_3^5} \cdot \exp\left(-\frac{(x_m - x)^2 + (y_m - y)^2 + (z_m - z)^2}{2\sigma_3^2}\right). \tag{6}$$



(a) (b)

Figure 2. Example of 3D LoG filtering: (a) Shape before sharpening. (b) Shape after sharpening.

Here, (x, y, z) is the interest point, and (x_m, y_m, z_m) is the neighboring point within the distance of $3\sigma_3$ from the interest point.

Given the components of the unit normal for the neighboring point as $(n_{\mathrm{x}m}, n_{\mathrm{y}m}, n_{\mathrm{z}m})$, then the positive total component $(n_\mathrm{px}, n_\mathrm{py}, n_\mathrm{pz})$ and the negative total component $(n_\mathrm{mx}, n_\mathrm{my}, n_\mathrm{mz})$ are determined by Equations (7) and (8). Calculation for N_p points where $x_m - x \geq 0$:

$$n_\mathrm{px} = \sum_{m=0}^{N_\mathrm{p}-1} n_{\mathrm{x}m} h_{\nabla\mathrm{x}}(x_m, y_m, z_m). \tag{7}$$

Calculation for N_m points where $x_m - x \leq 0$:

$$n_\mathrm{mx} = \sum_{m=0}^{N_\mathrm{m}-1} n_{\mathrm{x}m} h_{\nabla\mathrm{x}}(x_m, y_m, z_m). \tag{8}$$

The normalized vector of the positive and negative total component are expressed as $(\hat{n}_\mathrm{px}, \hat{n}_\mathrm{py}, \hat{n}_\mathrm{pz})$ and $(n_\mathrm{mx}, n_\mathrm{my}, n_\mathrm{mz})$,respectively. Gradient of x axis x_edge is calculated from Equation (9) using the positive average vector component and the negative average vector component.

$$x_\mathrm{edge} = \sqrt{(\hat{n}_\mathrm{px} + \hat{n}_\mathrm{mx})^2 + (\hat{n}_\mathrm{py} + \hat{n}_\mathrm{my})^2 + (\hat{n}_\mathrm{pz} + \hat{n}_\mathrm{mz})^2}. \tag{9}$$

The same is done also for y_edge and z_edge.

The edge magnitude e for the point (x, y, z) is calculated by Equation (10).

$$e = \sqrt{x_\mathrm{edge}^2 + y_\mathrm{edge}^2 + z_\mathrm{edge}^2}. \tag{10}$$

3.3 Calculation of Edge Magnitude Histogram and Parameter Estimation

The constant for the edge parameter σ_3 is decided a priori, because all values of the edge intensity change

(a) (b)

Figure 3. Input query data: (a) Plaster statue. (b) 3D data of the plaster statue.

(a) (b)

Figure 4. Input reference data: (a) Hercules' head. (b) 3D data of Hercules' head.

if this σ_3 value is changed.

Estimating the parameters σ_1, σ_2, and k is accomplished by comparing histograms for the edges from two shapes. One is the cultural asset subject to reconstruction (the plaster statue in this research). The other one is a stone or wooden statue (preferably with less disintegration and damage) made in the same era as the cultural asset subject to reconstruction. The assumption here is that by making the sharpened shape of the cultural asset subject to reconstruction close to the histogram of the edges for a stone or wooden statue of the same era, a shape similar to the edges of the cultural asset in the same period can be reproduced.

The Bhattacharyya distance was used as a comparison metric. The smaller the value is, the more similar the two histograms are. A perfect matching is 0, and a perfect mismatch is 1.

4 Experiment

The purpose of our research is to re-produce the original shape of a plaster statue by sharpening the 3D data of the plaster statue. Thus, the 3D data of the plaster statue is initially required. The 3D data used in this experiment was acquired by measuring the real plaster statue (Figure 3 (a)) by a laser sensor (Figure 3 (b)).

This research requires the edge data of the stone statue that was made in the same era or by the same creator as the original statue in order to sharpen the plaster statue. The plaster statue measured for this experiment is a stone statue made between the 9th and 13th centuries from among the Dazu Rock Carvings. A stone statue from the closest possible period is thus required. The one readied for this experiment is the stone statue of Figure 4. The stone statue of Hercules' head was made in approximately the 3rd century, a period much older than when the Dazu Rock Carvings were made. Nonetheless, this experiment performed optimization of the parameters for sharpening by using the edges of this stone statue, since it has remained in a good state of preservation.

As explained in Section 3.3.4 for parameter estimation, we performed sharpening by the LoG filter and estimated the optimum parameters by comparing the

Table 1. Calculation of LoG filter parameters and Bhattacharyya distances

	σ_1			
σ_2-k	3.0	3.5	4.0	4.5
1.0-0.1	0.207854	0.207761	0.207059	0.205900
1.0-0.2	0.195334	0.191273	0.188261	0.186328
1.0-0.4	0.183967	0.209668	0.227754	0.247339
1.0-0.5	0.200292	0.237523	0.271486	0.296913
2.0-0.1	0.205575	0.206050	0.207488	0.207044
2.0-0.2	0.175135	0.193815	0.194742	0.196443
2.0-0.4	0.175135	0.185074	0.207555	0.190036
2.0-0.5	0.176057	0.202760	0.236762	0.207739
3.0-0.1	0.204027	0.205042	0.205958	0.207739
3.0-0.2	0.191076	0.191076	0.195003	0.196830
3.0-0.4	0.169433	0.175655	0.180057	0.207719
3.0-0.5	0.163139	0.177653	0.205669	0.234963
4.0-0.1	0.203387	0.204185	0.762450	0.208648
4.0-0.2	0.189578	0.190714	0.193456	0.196417
4.0-0.4	0.166219	0.170434	0.178309	0.229074
4.0-0.5	0.157188	0.165362	0.180809	0.261547

sharpened edge data and the edge data of the stone statue. The smallest values for the Bhattacharyya distance between the histogram of the edges of the sharpened 3D shape and the histogram of the edges of the 3D shape of the stone statue would be considered optimum in the determination of whether the data was optimum. The results of the 3D shape comparison between the plaster statue of the Dazu Rock Carvings (Figure 3) and the stone statue of Hercules' head (Figure 4) are shown in Table 1. The results showed that the optimal parameter values were 3.0 for σ_1, 4.0 for σ_2, and 0.5 for k, since these values rendered the smallest Bhattacharyya distance. Figure 5 shows the 3D shape of the plaster statue sharpened with the above optimal parameter values.

The results of the experiment conducted in this research show that the mesostructure is heightened in definition after sharpening compared to that before sharpening, as can be seen in Figure 5 (b) relative to Figure 5 (a). Consequently, it is thought that the shape after sharpening is closer to the original shape than the shape before sharpening. However, the head

Figure 5. Result: (a) 3D shape of the plaster statue profile before sharpening. (b) 3D shape of the plaster statue profile after sharpening.

of Hercules was made during a much earlier period than the period of the Dazu Rock Carvings, and the creators were different. We believe that closer sharpening to the original can be accomplished by testing with a stone statue made closer in period or by the same creator.

5 Conclusion

This research was conducted with the aim of optimization of a 3D shape sharpening filter. As a result, optimum sharpening was achieved by transforming the parameters for sharpening, by calculating edge intensities, and by comparing the Bhattacharyya distances. As a future subject for study, enabling automatic estimation in lieu of manual estimation will be considered as a means to perform parameter estimating over a wider range.

In addition, as a future application of the technology used this time, contribution to a 3D digital archive of historical, cultural assets can be accomplished by archiving the 3D shape data of original stone statues and Buddha statues in good condition in a database by period or by the creator, and by employing this technology whenever stone statues or Buddha statues in bad condition are excavated.

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