Window Shape Determination based on Stone Texture for Stereo Matching

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ABSTRACT

In recent years, it has become very important in fields of archaeology, ethnology and cultural anthropology to measure 3-D shapes of cultural assets, such as stone statues. Many of them are in fields, and the stereo method is better to measure them than active ranging methods, because the stereo method needs no special equipment. In the region-based stereo method, a large search window will spoil the resolution, whereas a small window will cause a wrong correspondence.
In this paper, we describe a stereo matching method to measure 3D shapes of stone statues using adaptive shapes of search windows for stone texture. There are granitic textures on stone surfaces, which are mixture of bright ground and many dark small grains. We inspect the feasibility of stereo matching based on this texture. Search windows which include both bright and dark areas of the texture can determine the reliable correspondence. We use triangular windows that include the dark grains on each apex as search windows. All triangular windows are generated by the Delaunay triangulation. Each apex is a representative point of dark areas of the granitic texture.
Experimental results indicate that this method works effectively for real stone statues.

1. Introduction

The various stone statue cultures which exist around the world have mach value as a cultural heritage of mankind commonness. In recent years, it has been required to generate a database of 3D shapes of stone statues to keep information of their shapes against weathering and to provide for quantitative analytic methods (Sato, 1986). More efficient 3D shape measuring methods are being sought.

There are some active ranging methods which can provide high precision by non-contact (Inokuchi, 1984)(Sato, 1994). They have been developed mainly in the industrial field, and they need special equipment and measuring environments. These active methods are not suitable for measuring stone statues because most of them are in temples or fields and they can't be moved easily.

On the other hand, there is a passive ranging method called stereo-vision. Stereo-vision is more suitable than active methods for the field scene because they need no special equipment. But there is a significant problem of finding corresponding points. There is a region-based method to solve this correspondence problem. This method determines the correspondence of regions (= search windows) on both images by the correlation of their brightness (Okutomi, 1993). A central problem in this method lies in selecting the shape of the window (Christian, 1997). Whereas a large window will spoil the resolution and increase the computation cost, a small window will cause a multiple correspondence problem because it contains only a small number of data points (Kanade, 1995).

In this paper, we propose a region-based stereo method using search windows which are adaptive to a stone texture.

First, the dark areas of the texture on the stone surface are extracted with the Laplacian-Gaussian filter. Then a triangular mesh is generated by the Delaunay triangulation. Each triangle has the extracted dark areas at the apex and is used as a search window. A change graph of the correlation value of the brightness is made in each left-right window pair, and its form is evaluated. Trustworthy corresponding based on the evaluation value is done.

In the following chapter, we explain about the texture of stone statues and its influence on stereo matching. Chapter 3 describes about a window shape determination adapted to the texture, and chapter 4 shows a stereo matching algorithm. Experimental results are described in chapter 5. Finally we give a brief summary.

2. Stone Texture

2.1 Characteristics on the stone surface

A granitic texture can be seen in images of stone statues. This texture of many dark small grains scattered on a bright ground is caused by elements of the stone. It is often seen on the stone statues manufactured in comparatively recent years. Many such statues are made of granite (Fig.1) which is a mixture of quartz (gray), black mica (black) and feldspar (white). Weathering is another reason that causes this texture. It is observed on the old statues (Fig.2) whatever stone they are made of. Their surfaces are rough due to weathering, thus ununiformity of light and shade occurs when they are illuminated.

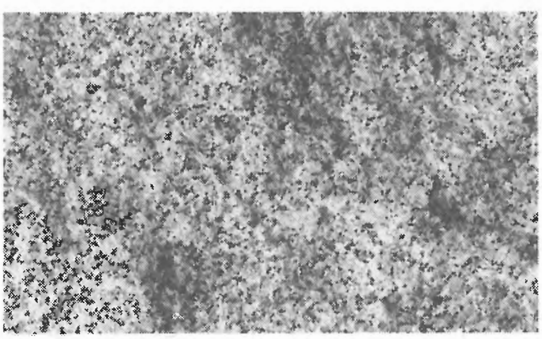


Figure 1. Surface of granite.

Figure 2. Weatherd stone statue.

2.2 Influence of the texture on stereo matching

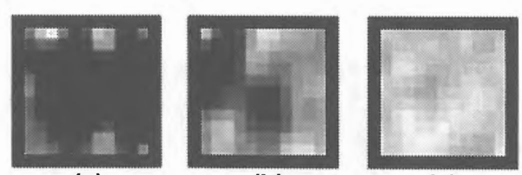
Brightness distributions inside a search window have an influence on the reliability of correspondence because this process is based on the correlation of the brightness. Some examples of the search windows whose brightness distributions are different from each other are shown in Fig.3. Fig.4 illustrates the relations between their size and the evaluation value of correspondence. The evaluation value is obtained by evaluating the form of the correlation value change graph. (That is mentioned later in chapter 4.) As the evaluation value is larger, the reliability of correspondence is higher (Yamaguchi, 1996). We can say that the window which includes both bright and dark areas gives more reliable correspondence than the window which is mostly bright or dark, even if it is small.

3. Adaptive Window Shape Determination

We make the window shape adapted to the granitic texture of the stone statue in order to determine the smallest size of search window without losing the reliability of correspondence. The shape is determined so as to include both bright and dark areas of the texture.

3.1 Texture extraction

We extract dark areas of the granitic texture by applying the Laplacian-Gaussian filter on the left image which is the reference image in stereo matching. A dark area of the texture becomes the mountain in the second differential value shown as Fig.5. We consider the peak of the differential value as the feature point of each dark area. 50% of the upper peaks are selected to use only information of the



(a) **(b)** **(c)**

Figure 3. Brightness distributions: (a) Almost dark; (b) Bright and dark; (c) Almost Bright

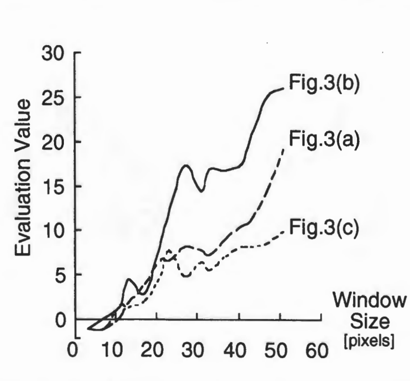


Figure 4. Evaluation values of corresponding.

clearly dark areas. The disturbance of random noise is reduced by a effect of the smoothing filter σ =1.5 pixels. Incidentally, we use a monochrome 8bit image.

3.2 Window shape determination

We make a triangular mesh by the Delaunay triangulation that has the extracted feature point on each node. The Delaunay triangulation is a typical technique which connects each point of the random point group and forms a triangular mesh (Yamamoto, 1994). We use each triangle of the mesh as the search window for stereo matching. The search window made by this algorithm has the following advantage.

Windows can be small while retaining reliability: Each triangular window includes both dark and bright areas of the stone texture. It has the dark areas at vertices and its interior is filled up with the bright ones. Also this window can use the information of positional relation of dark areas by reflecting on the window shape. Therefore the reliability of correspondence becomes high.

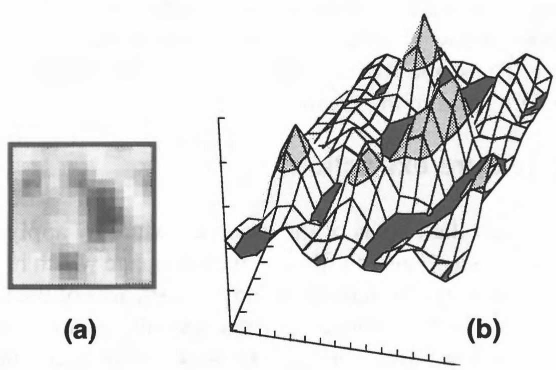


Figure 5. Filtering result of the texture: (a)Granitic texture ; (b)Its differential value graph.

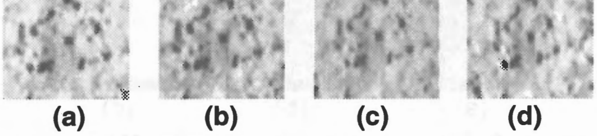


Figure 6. Texture on slanted surfaces: (a) 0 deg.; (b) 15 deg.; (c) 30 deg.; (d) 45 deg.

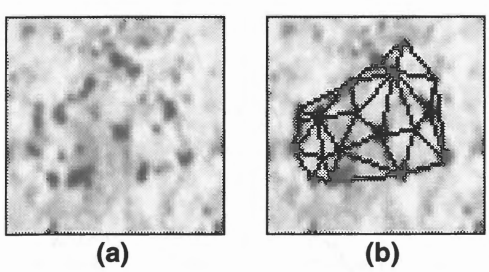


Figure 7. Result of window shape determination: (a)Original texture; (b)Determined windows.

Depth range a window contains isn't wide: When an object surface slants against the image plane, its texture is compressed towards the inclination direction as shown in Fig.6. A search window shaped by this method is compressed in the same way. The depth range which the window contains becomes small, and matching with this window can keep resolution.

The result of this algorithm applied to the texture in Fig.7(a) is shown in Fig.7(b).

4. Matching Algorithm

In the parallel stereo model, we can limit the search area of matching; i.e., the epipolar line becomes the image scanning line. The correspondence is decided based on the correlation value of the brightness between left and right windows. The correlation function is as follows;

$$C = \frac{1}{S}\frac{\sum_{j\in W_R}\sum_{i\in W_L}\left(I_L(i)-\mu_L\right)\left(I_R(j)-\mu_R\right)}{\sqrt{\sigma_L^2\sigma_R^2}} = \frac{\sigma_{LR}^2}{\sqrt{\sigma_L^2\sigma_R^2}} \quad \textbf{(1)}$$

$I_L(i)$ and $I_R(j)$ are brightness intensities, and μ_L, μ_R, σ_L^2, σ_R^2 are the mean and variance of windows, respectively. S is the area of the window and σ_{LR}^2 is the covariance.

To make a certain correspondence and to increase the number of corresponding windows, we use two algorithms described in following sections.

4.1 Evaluation of correlation graph

Correlation values C are calculated by moving the right window around the corresponcence-possible area, and we make a correlation value change graph (from now on, correlation graph, simply) shown in Fig.8. This graph explains the relation between disparity and C . The position of the peak indicates the corresponding point. The disparity is the distance from the left window to the right one in x-coordinate value.

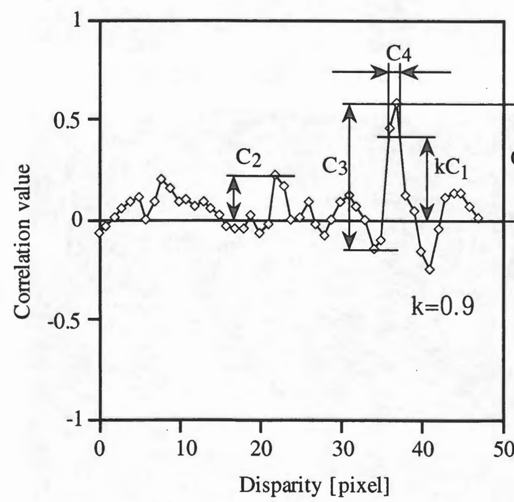


Figure 8. Concept of the correlation graph evaluation.

In case where there are some peaks of similar height or the maximum height is low, the correspondence has low reliability. We evaluate the correlation graph to make the correspondence certain by using the following function;

$$P_1=\begin{cases} C_1-\gamma_1 & (C_1>\gamma_1) \\ -1 & (C_1\le\gamma_1) \end{cases},\quad P_2=\begin{cases} C_2-\gamma_2 & (C_2>\gamma_2) \\ -1 & (C_2\le\gamma_2) \end{cases}$$
$$P_3=\begin{cases} C_3-\gamma_3 & (C_3>\gamma_3) \\ -1 & (C_3\le\gamma_3) \end{cases},\quad P_4=\begin{cases} \gamma_4-C_4 & (\gamma_4>C_4) \\ -1 & (\gamma_4\le C_4) \end{cases} \qquad \textbf{(2)}$$

and

$$\begin{aligned} P &= (P_1+P_3)\times P_2\times P_4 && (\textit{if all } P_i>0) \\ &= -1 && (\textit{if any } P_i<0) \end{aligned} \qquad \textbf{(3)}$$

C_1 is a height of the maximum peak, C_2 is a ratio of the maximum and the second peak, C_3 is a smaller difference of the maximum peak and valleys of both sides, and C_4 is the width of the maximum peak. γ_1- γ_4 are threshold values of C_1- C_4, and where $\gamma_1 = 0.6$, $\gamma_2 = 1.3$, $\gamma_3 = 0.2$, $\gamma_4 = 7.0$ this time. If any evaluation value P_i is lower than its threshold, P becomes -1, and matching is rejected. When P is positive, the correlation graph is complemented by the spline interpolation around the maximum peak, and the disparity is obtained in sub-pixel order.

4.2 Disparity propagation

Stone statues with a smooth surface have seldom large differences of disparity among adjoining windows except for the neighborhood of the edge. After the correlation based matching, we propagate the disparity from the corresponding windows to one which is not corresponding. This disparity propagation is applied when two or three windows which touch its sides are corresponding. This algorithm calculates the weighted average of each valid disparity and contributes it to the disparity of the invalid window. The weight follows the distance between the centers of gravity.

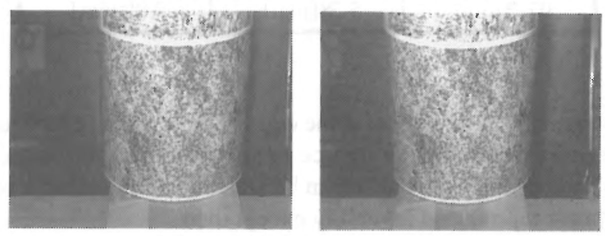
5. Experimental Results

We applied our stereo method to real stereophonic images. A cylinder on which printed granitic texture has been applied was used as the object for the purpose of quantitative examination of measurement. A stone statue of Hotei (one of the Seven Deities of Fortune) was measured to compare with the conventional stereo method. All computations were run on an SGI-O2 Workstation.

5.1 A cylinder-shaped object

The diameter of the cylinder was 200mm, and printed texture was applied to it. The stereo pair is shown in Fig.9 which are 1280x1024 pixels taken with a digital still camera. Information of the red channel was taken out from the 24bit color data, and used as a 8bit monochrome image.

Fig.10 shows the triangular mesh. The total number of windows and the maximum, minimum and mean values of their area are shown in Table 1. Results of measured 3D coordinate values are projected on the X-Y plane by removing height information. This is shown in Fig.11. The correct cylinder side is projected to a circle whose center is in (100,100) and its radius is 100 mm. The errors of the projection of each triangular window are calculated in the radius direction from the correct circle, and the maximum, mean, and standard deviation of errors and the mismatch ratio are shown in Table 2. The mismatch ratio is the number of the window whose error from the correct circle is more than 7mm to whole. This depends on the fact that 0.5 pixels deviation of disparity equals about 7mm according to the camera parameter.



(a) (b)

Figure 9. Stereo pair of cylinder. : (a)Left image; (b)Right image.

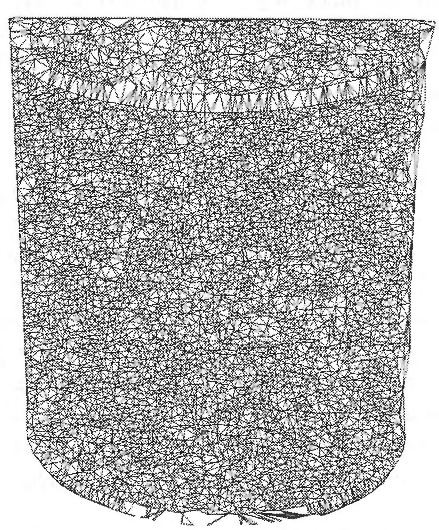


Figure 10. Generated Delaunay triangular mesh of Fig.9(a).

Table 1. Statistic values of search windows.

Number of windows	Maximum area	Minimum area	Mean area
13466	574 [pixels]	6[pixels]	56.4 [pixels]

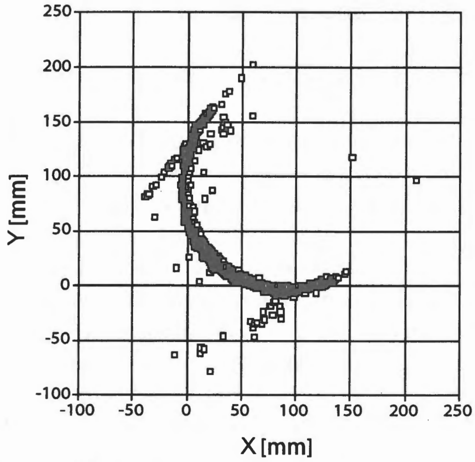


Figure 11. X-Y prots of corresponding results.

Table 2. Statistic values of error.

Whole Windows	Error > 7mm	Mismatch Ratio
13466	1215	9.0[%]
Maximum	Mean	Standard Dev.
97.2[mm]	5.38[mm]	7.81[mm]

Some large errors occur at the edge of the cylinder because the angle between the surface of the object and the image plane becomes too big. It can be stated that the cylinder is almost reproduced favorably except there.

5.2 The statue of Hotei

This statue was made of granite with a H320xW400xD220 mm shape. The stereo pair is shown in Fig.12 which are 640x480 pixels taken with the digital video camera. Similarly, information of the red channel was used as a 8bit monochrome image.

Results of proposed method are shown in Fig.13, Fig.14 and Table 3. Also results with the conventional stereo method using fixed rectangular windows of 7x7 and 15x15 are shown in Fig.15 for comparison. The higher intensity, the larger disparity in these images. The corresponding score and the mismatch ratio are shown in Table 4. The proposed method can lower the mismatch ratio without reducing its correspondence score in comparison with the conventional method. The correct disparity is obtained from an active measurement system, the Liquid Crystal Range Finder.

Fig.16 is result of the 3D model calculated from the disparity. We can mention that the outline shape of the statue is restored well.

(a) (b)

Figure 12. Stereo pair of Hotei. : (a)Left image; (b)Right image.

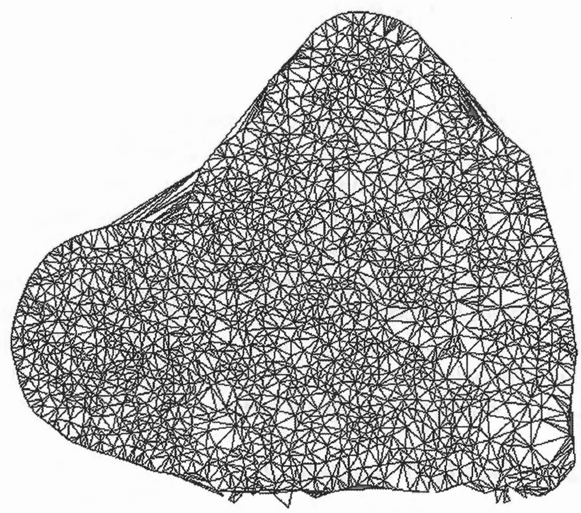


Figure 13. Generated Delaunay triangular mesh of Fig.12(a).

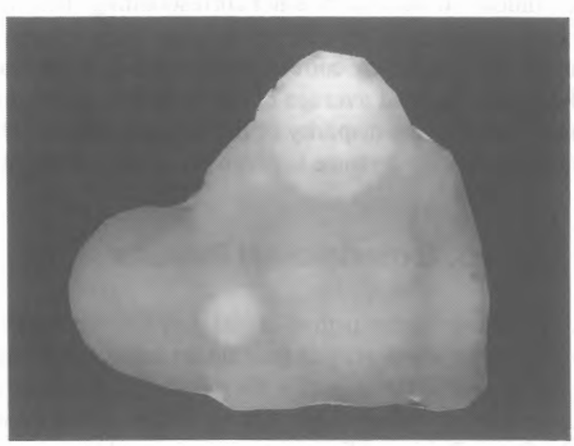
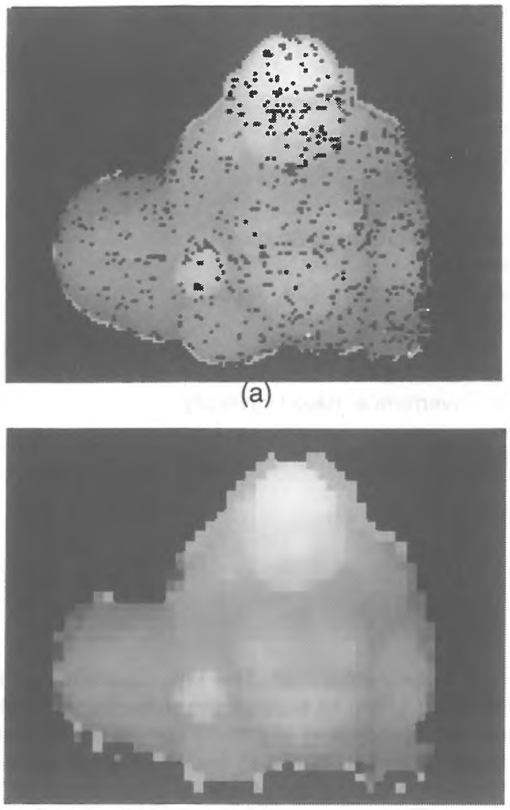


Figure 14. Result disparity image of proposed method.

Table 3. Statistic values of search windows.

Number of windows	Maximum area	Minimum area	Mean area
3988	376 [pixels]	7[pixels]	48.1 [pixels]



(a)

(b)

Figure 15. Disparity images of conventional method; (a)with 7x7 window.; (b)with 15x15 window.

Table 4. Corresponding points and mismatch ratio.

Matching Method	Corresponding points	False points	Mismatch ratio
Proposed Method	130,664	4,365	3.3%
With 7x7 window	115,936	4,104	3.1%
With 15x15 window	129,362	8,867	6.7%
Correct Image	131,711	-	-

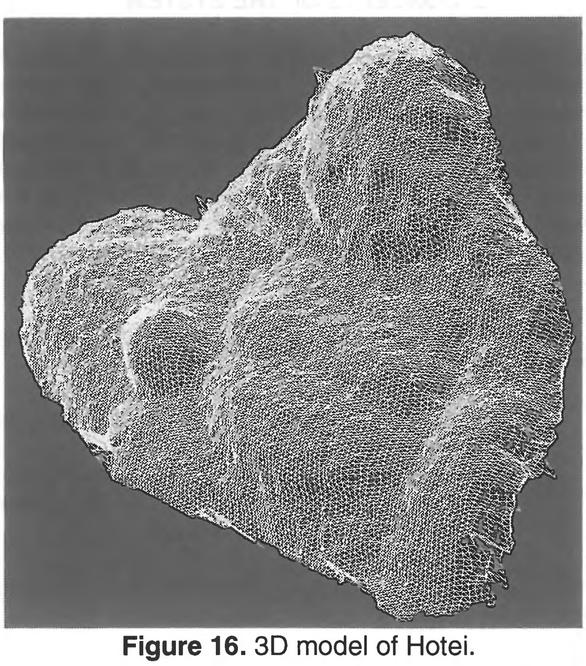


Figure 16. 3D model of Hotei.

6. Summary

In this paper, we have presented a region-based stereo method using adaptive window shapes. We have investigated the influence of the stone texture on stereo matching, and adapt the search window shape to the texture. Feature points of the granitic texture are extracted. The triangular mesh which has the feature point on each node is generated by the Delaunay triangulation. Then the correlation based stereo matching is done by using the mesh as the search windows. The correlation graph is made, and its form is evaluated for reliable correspondence. The disparity is obtained in sub-pixel order according to the correlation graph complemented by the spline interpolation. The disparitiy is propagated among the adjacent windows by supposing smoothness on the surface of the object.

We have applied this method to actual stereo images and considered the results. We find that the proposed method can get more corresponding points without increasing the wrong correspondence than the conventional stereo method. The 3D models are restored, and we confirm that the proposed method can measure approximate shapes of objects.

As our future work, we will apply this method to various real stone statues and measure more complex shapes. Also, our objective is to get the whole shape of the object by the stereo images from more than one direction.

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