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# Data Reduction by Applying an Image-Based Modeling and Rendering Technique to CG Models

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***Abstract*** : We applied an image-based modeling and rendering technique to reduce the data size of a CG model to be obtained as a visualization result. To date, this technique has been applied to the reconstruction of 3D graphical models from real objects; the size of the models can be reduced effectively because both color information and geometric information can be reduced. We applied a silhouette-and-voxel method that does not require design data for geometric simplification. Using our system, we simplified two models, one of which, involving medical data, was reduced by about 85% in file size. An accompanying subjective quality test showed that our approach maintains approximately the same visual quality as the geometric simplification method traditionally used.

***Keywords*** : Visualization, Data reduction, Image-based modeling and rendering.

## 1. Introduction

The Internet provides new opportunities to promote research results on web pages. Using modern technology, it is now possible to publish not only text, but also images, movies and 3D models on such pages. However, because of limitations in communication line capacity, large-sized data must be compressed or simplified for web pages. Although a number of methods exist in the field of geometric simplification (Hechbert and Garland, 1997), they cannot effectively simplify a model with color-coded information. Recently, methods in which color or detailed structural information is presented as textures have enabled good quality and effective data reduction (e.g., Cignoni et al., 1998). However, such methods require all of the digital data that comprise the model. Meanwhile, image-based modeling and rendering techniques (IBMRs) have been advancing rapidly (Jagersand et al., 2003).

We propose a new data reduction approach combining the above two methods, that is, using a texture mapping technique to represent color information and an IBMR to generate a simplified model without the design. This approach allows for a loose coupling between the modeling or visualization system and the data reduction system. Hence, it can be attached to existing commercial software. Additionally, the present approach can produce a model of arbitrary accuracy regardless of the complexity of the geometric object. For example, to teach how an airplane flies, we would use a real model of the airplane but would not need to replicate its sophistication. In such a situation, our approach would be particularly useful in creating a "skeleton" model. In this paper, we first explain our silhouette-and-voxel method. Then, we discuss its potential, applying it to a simple visualization model in the field of computational fluid dynamics and to a complicated medical brain model made from CT images. Finally, we present the results of the subjective quality test using the medical model and comparing it with the same model reduced by a geometric simplification method.

## 2. Image-Based Modeling and Rendering

IBMR is a technique for the reconstruction of 3D graphical models from real objects. A typical system configuration is shown in Fig. 1.

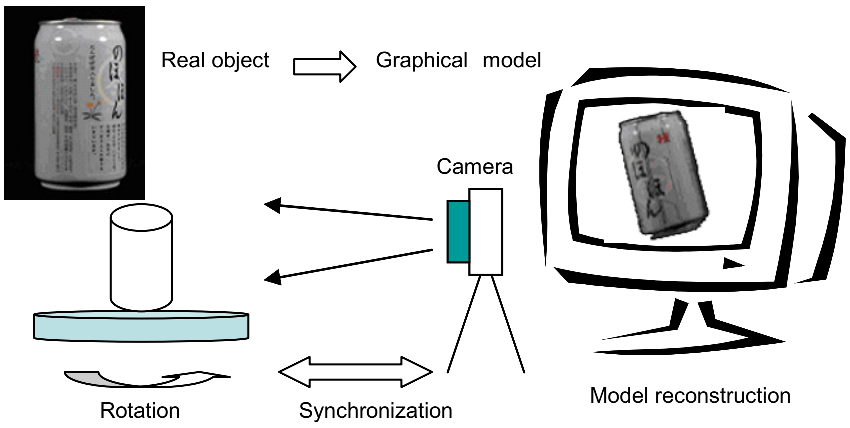


Fig. 1. System configuration of IBMR.

Generally, IBMR consists of three stages: image capturing, image modeling and rendering. First, in the image capturing stage, photographs are taken of all sides of an object as it moves on a rotating table. As the timing of the camera shutter is synchronized with the table rotation, the system can record information such as the relative positions of the camera and the object for each image. In real applications, the information obtained in this way includes errors due to inconsistencies in mechanical accuracy or lens distortion, and calibration, by which the appropriate compensation is applied to the measurements after numerous trials, is generally troublesome. Many studies on how to avoid these difficulties are underway even now.

Secondly, a geometric model is created by synthesizing the captured images and the camera information. There are various methods involved in this process, which are classified into two categories: the geometric and voxel methods. In the geometric method, the positions of the vertices are acquired from the images by one of many methods. For example, in the shape-from-shading method, the depth is determined based on differences in shade intensity caused by the position of the object in relation to the light and the camera (e.g., Okatani and Deguchi, 1996). There are also methods based on triangulation by stereo vision and on Particle Imaging Velocimetry (PIV) (Someya et al., 2003). In the voxel method, the object is mapped into the voxel block, again using one of several methods (e.g., He et al., 1995); in the present study, for example, we have chosen the silhouette method (e.g., Mulayim et al., 2003), which is described detail in Section 3 below.

Finally, the captured images are mapped back onto the model without colors. Through these three stages, a real object, such as the real can of tea on the left side of Fig. 1, is converted into a graphical model, such as that on the right side of Fig. 1.

# 3. Applying IBMR to a CG Model

## *3.1 CG Camera Versus Real Camera*

We applied the IBMR described in the previous section to computer graphics (CG) models. For the purpose of image capturing, instead of a standard camera, we used a CG camera, whose principal benefit is that is no need for calibration. The position of a CG camera can be established without error, and there is no distortion. Furthermore, CG cameras are able to capture an image from any direction, even from the bottom or the inside of the object. All procedures for image capturing in our method were the same as those for ordinary IBMR.

The present technique can be used to determine the complexity of rendering, by which we mean not the complexity of the model in the object-space but that in the image-space (Bartz, 2003). Compared with other existing techniques, the present method does not require geometric information in the object-space at all, while the voxelizing polygon and point rendering techniques sample it in the geometry.

## *3.2 Modeling*

For the purpose of the second stage, we chose the silhouette and voxel method. Though this method is quite simple, it is able to treat an object with a concave surface and was deemed to be sufficient for demonstrating our approach.

In the first step, all images captured by the CG camera are converted to silhouette images. Next, a volume block consisting of $N^3$ voxels and encompassing the extent of the reconstructed object is prepared. Here, N is a parameter controllable by an operator that indicates the resolution of the reconstructed model. Using the set of silhouette images, a voxel model is reconstructed by a method similar to sculpturing. Assuming a spherical object, we could use the same circular image over and over because the outline of a sphere is always a circle. Once the cube is sculptured by the first silhouette image, we obtain a cylinder. Repeating this process by applying the images from all directions gives a sphere which consists of voxels, as shown in Fig. 2.

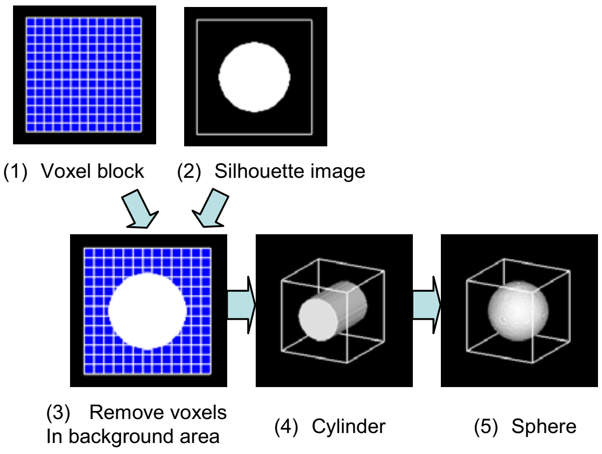


Fig. 2. Concept of “sculpturing”.

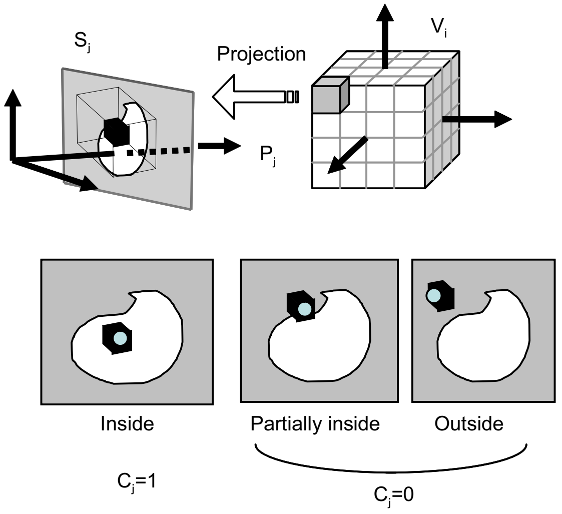


Fig. 3. Calculation method of “sculpturing”.

The above explanation is purely conceptual; the actual calculation is carried out inversely. Each voxel $V_{i\,(i=1,2,3,\ldots,N^3)}$ is projected onto every silhouette image, as shown in Fig. 3. The status of the voxel location on the image is then determined: either inside, outside or partially inside. Here, we evaluate the status of the voxel location by using only the center of gravity of the voxel. This is based on the assumption that we set the parameter N indicating voxel resolution for an appropriately small value compared with the pixel size on the screen on which the object will be displayed. The projection matrix $P_{j\ (j=1,\,2,\,3,\,\ldots,\,t)}$ was obtained previously during the image capturing stage. Here, t is the number of images captured. Using matrix $P_j$, the center of gravity of the voxel is projected onto the silhouette images $S_{j\ (j=1,\,2,\,3,\,\ldots,\,t)}$. If the point is inside the silhouette, the status is set $C_{j\ (j=1,\,2,\,3,\,\ldots,\,t)}$ for 1. When all statuses equal 1, i.e., $\Sigma C_j = t$, we define the voxel is inside the object. When the evaluation of all voxels has been carried out, the modeling is completed. Once a voxel model is obtained, it is converted to a surface model by means of an isosurface method with a marching cube algorithm. The surface model is then simplified by a geometrical simplification method using mesh reduction with error control (Klein et al, 1996).

### *3.3 Texture Selection*

We chose the maximal front face concept to select the texture for each simplified triangle. Each triangle has a normal vector and each image has a camera orientation vector which is included in the projection matrix $P_j$. We selected the image having the smallest value for the product of these vectors. The texture for the voxel became the image trimmed in the area in which it was projected. We selected this simple method to demonstrate our approach even though it is not applicable in the case of an image of a complex object, a translucent object or the volume rendering.

### *3.4 Implementation and Computer Environment for Tests*

We used Windows PC for the computer experiment. The sample system was implemented on AVS/Express, an application package for visualization. All functions for IBMR were implemented by us. For the image capturing stage, we developed a new macro program in AVS/Express to capture images automatically from all surrounding directions and developed some new programs written in C to acquire the projection matrix P. For the modeling stage, we developed the whole silhouette-and-voxel procedure as a new program in C language. For conversion from the vexel model to the surface model, we used AVS/Express standard functions like isosurface, geometric surface reduction and VRML output features. The images captured were compressed in JPEG files using the default parameters of the system. The geometric data generated by our system was stored in a file in VRML ver. 1 format.

There were two reasons for implementing the present system on a commercial software package. The first was our goal to develop a system that could cooperate with existing systems in a loose coupling environment. The second was expediency: our immediate purpose was to demonstrate our approach, rather than to obtain the best speed or the highest possible quality.

## 4. Experiments

### *4.1 Separation of Physical Data*

We first tried to separate physical data from its geometry as textures. The original model was a fluid dynamics simulation shown in Fig. 4. The colors indicate the pressure distribution on the external surface of the block; the green band indicates a shock wave. By applying our approach to this model, we separated the color information as textural images. The output is shown in Fig. 5. Here, we did not apply the silhouette-and-voxel method to reconstruct the geometric model. Our purpose was to see whether IBMR using a CG camera could work well. The model shown in Fig. 5(a) is the original surface model; Fig. 5(b) shows the textural images to map back onto the surface; and Fig. 5(c) shows the restored model, which should be identical to the model shown in Fig. 4.

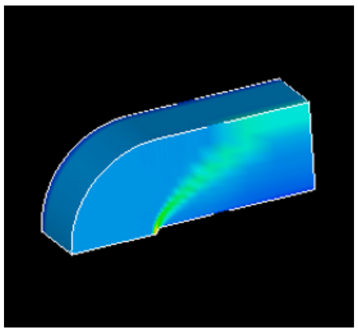


Fig. 4. Test model (fluid dynamics simulation).

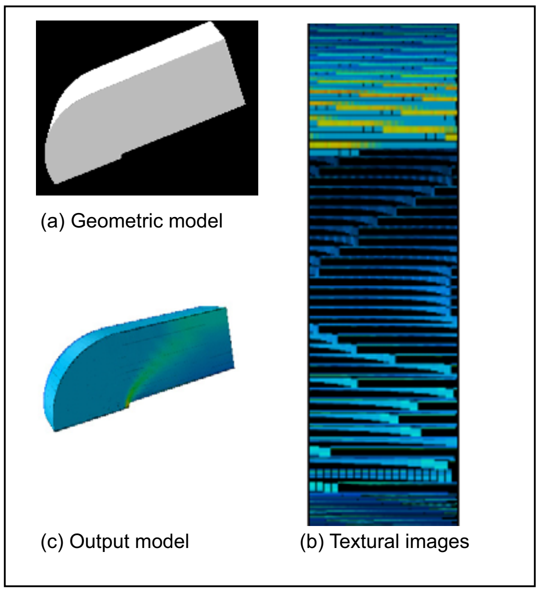


Fig. 5. Separation of physical data from geometry.

### 4.2 Data Reduction

We used the brain data shown in Fig. 6 as our second experimental model. The model was generated using the isosurface of medical CT images (e.g., Toriwaki and Mori, 1998), which included 74,176 vertices and 148,460 triangles. The data size was 29 MB in VRML ver. 1 format. Although the model does not include any physical data on the surface, many fine structures (sulcuses) exist on it. We believe that our approach could be applied to illustrate sulcuses in textural images.

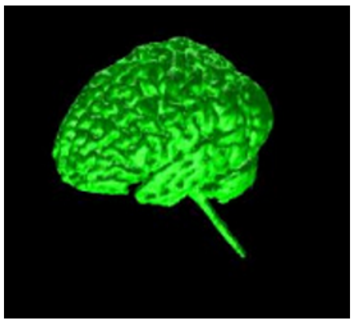
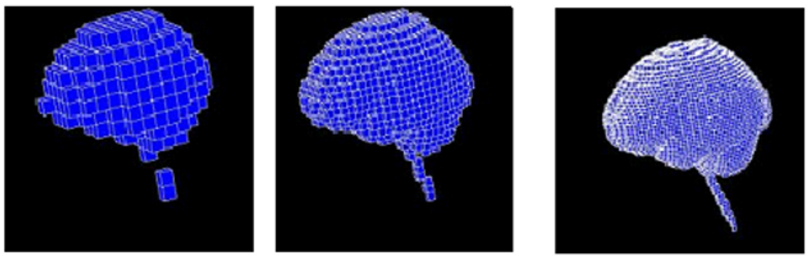


Fig. 6. Test model (brain from CT images).



(a) N = 4 (b) N = 5 (c) N = 6

Fig. 7. Voxel models after “sculpturing”.

We captured the images with a CG camera while rotating the brain around the X and Y axes. Capturing every 10 degrees gave us a total of 72 images. The resolution of the image was 500 × 500. During voxel block preparation, we tested parameter N from 3 to 9. Three candidate models, N = 4, 5 and 6, are shown in Fig. 7. We identified N = 6 as the minimum size model having the appearance of the original brain. The number of voxels was 265,093. After generating the voxel model, we converted it to a surface model by using an isosurface. The number of surfaces was then reduced by geometric surface simplification. The simplified surface model shown in Fig. 8 included 818 vertices and 4,422 triangles. The reduction ratio was 93.5% for the number of vertices and 97% for the number of triangles. The model was exported in VRML format with a file size of 2.42 MB. Finally, textural images were mapped back onto the model. The final result is shown in Fig. 9. The size of the textural images in the JPEG file was 1.82 MB; hence, the total data for the result was 4.24 MB (2.42 MB + 1.82 MB). As the original was 29 MB, the reduction ratio was 85.4%.

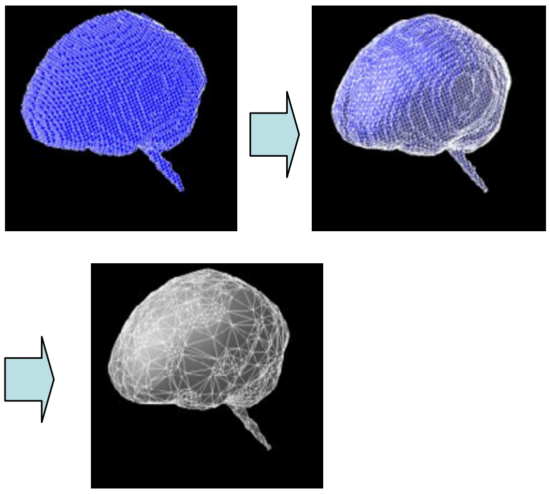


Fig. 8. Triangulation and geometric surface simplification.

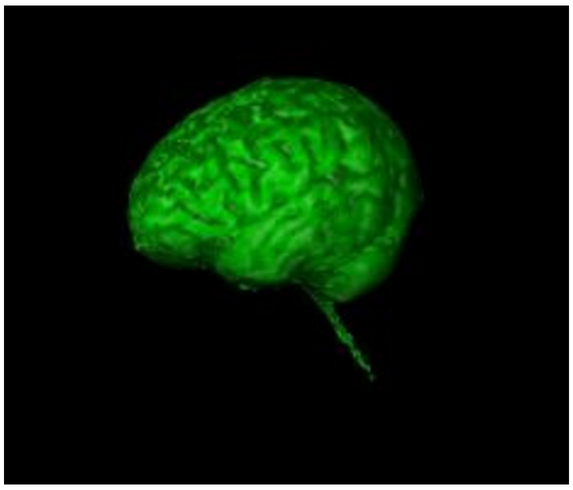


Fig. 9. The final result.

### 4.3 Subjective Test about the Quality

In order to confirm the advisability of our approach, we evaluated the quality of the resultant images by human subjective test with the brain model shown above, comparing the images produced by the present method with those produced by geometric simplification. As there is no standard method of evaluation for 3D models, we implemented an image quality test in which the 3D models were rendered from a typical viewpoint.

Fig. 10. The 91% reduction model by geometric simplification.

Using the same geometric simplification as the method we used as a part of our modeling process and which is implemented in an AVS system, the original brain model was converted to reduction models at reduction ratios of 50%, 60%, 80%, 85%, 90%, 91%, 93% and 95% and the models were then rendered to images. Figure 10 shows the 91% reduction image, whose VRML file size was 3.83 MB. Our subjects were asked to compare the 91% reduction image with the image shown in Fig. 9. We selected the 91% reduction data because reduction of near 90% is sensitive for humans, according to Enjoji et al. (2004) who used images with the same geometric simplification image together with other images.

The test system was implemented as a web page which our subjects could access from their desktop computers. In the test, two images are presented in the web browser within a second. One of the images was always the 91% reduction image and the other image was selected from a set of 9 images: images with 8 levels of reduction and the image as reduced by our method, i.e., that shown in Fig. 9. The order of their presentation was automatically randomized. The subject was asked to select the better quality image and was given unlimited time to answer. The subject's selection of an image automatically advanced the screen to the next pair of images. The test continued until the subject explicitly pushed a stop button.

The results of the test are shown in Table. 1. Eight subjects (A to H) participated in the test. The total number of the answers was 464. The percentages in the table indicate the ratios at which each subject answered that the 91% reduction image had a lower quality than the other image presented. The row for 91% in Table 1 shows a score of almost 50%, indicating that the two images were considered equally good. All of the subjects correctly distinguished the reduction ratio.

Table 1. The result of subjective quality test.

| | Subject [ % ] | | | | | | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Compression ratio | A | B | C | D | E | F | G | H | Number of questions | Number of selections | % |
| 50% | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 45 | 45 | 100.0% |
| 60% | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 56 | 56 | 100.0% |
| 80% | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 60 | 60 | 100.0% |
| 85% | 100 | 100 | 100 | 100 | | 100 | 100 | 100 | 40 | 40 | 100.0% |
| 90% | 82 | 100 | 86 | 50 | 100 | 71 | 100 | 80 | 50 | 43 | 86.0% |
| 91% | 60 | 38 | 33 | 75 | 67 | 0 | 100 | 0 | 41 | 20 | 48.8% |
| 93% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 57 | 0 | 0.0% |
| 95% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 56 | 0 | 0.0% |
| Our method | 0 | 38 | 17 | 33 | 100 | 38 | 0 | 0 | 59 | 15 | 25.4% |

The bottom row of Table 1 shows the scores of the comparison of our method with the 91% reduction image. The score shows a scattered result, suggesting that the quality of our method cannot be evaluated in the same way as that of the geometric simplification method or that subjects of a certain type preferred the image produced by our method to the 91% reduction image. Subject E, for example, who preferred our method, was a medical doctor.

## 5. Discussion

The data size after reduction was 4.24 MB. Using the latest technology, which is known as eXtremeDSL and can realize a maximum of 50 Mbps, the model can in theory be downloaded in a single second. Practical speed is likely to be much slower. Here, the key point of our approach is its independence from the complexity of the original model, except for the geometric surface simplification process. Even if the model consists of T Byte order data, we expect the data to be reduced to the same size as found in the results of the present experiment, 4-5 MB, as long as the shape is reasonably simple. Therefore, if the model is shown in a window with 500×500 pixels, it can be downloaded from a server site in a few seconds through a fast connection such as ADSL.

We cannot accurately establish the quality of our method by considering the result of only one experiment, however, a comparison of the original model (Fig. 6) with the produced image (Fig. 9) shows that, although the surface in Fig. 9 looks smoother than in the original, Fig. 9 is clearly the same brain. Additionally a comparison of Figs. 7 and 8 with Fig. 9 shows that the textural images recover the quality of the brain model. The result of our subjective test suggests that certain kinds of people simply prefer our method to the 91% reduction by geometric simplification.

## 6. Conclusion

We applied IBMR to CG models for data reduction. First, we successfully separated physical information from a colored geometric model as textures. Next, we obtained a reduction ratio of 85.4%

of the original file size. And finally, the obtained quality was judged to be acceptable by some subjects in a subjective test. The principal advantage of the present method is that the reduction ratio is controlled by parameters not related to the complexity of the original model. Hence, data of any size, even T Byte order data, is reduced to the same size. We are confident that the present approach is suitable for the publication of scientific research results on the Internet.

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## *References*

Bartz, D., Large Model Visualization Techniques and Applications, Journal of WSCG, 11-1 (2003), ISBN 80-903100-2-8.

Cignoni, P., Montani, C., Rocchini, C. and Scopigno, R., A General Method for Preserving Attribute Values on Simplified Meshes, Proceedings of IEEE Visualization 98 (1998), 59-66.

Enjoji, H., Miyachi, H. and Taniguchi, N., Polygon Reduction Quality Assessment Method based on Cognitive Characteristics, proceedings of the 17th Computational Mechanics Conference, 04-40 (2004), 439-442 (in Japanese).

He, T., Hong, L., Kaufman, A., Varshney, A. and Wang, S., Voxel Based Object Simplification, Proceedings of the 6th Conference on Visualization '95 (1995), 296-303.

Hechbert, S. P. and Garland, M., Survey of Polygonal Surface Simplification Algorithms, Technical Report CMU-CS, (1997), Carnegie Mellon University.

Jagersand, M., Burschaka, D., Cobzas, D., Dodds, Z., Hager, G. and Yerex, K., Recent Methods for Image-Based Modeling and Rendering, IEEE Virtual Reality 2003, Tutorial 1 (2003).

Klein, R., Liebich, G. and Straßer, W., Mesh Reduction with Error Control, Proceedings of Visualization, 96 (1996), 311-318.

Mulayim, Y. A., Yylmaz, U. and Atalay, V., Silhouette-Based 3D model Reconstruction from Multiple Images, IEEE Trans. on Systems, Man and Cybernetics, Part B, 33-4 (2003), 582-591.

Okatani, T. and Deguchi, K., Reconstructing Shape from Shading with a Point Light Source at the Projection Center – Shape Reconstruction from an Endoscope Image, Proceedings of the 13th International Conference on Pattern Recognition, (Vienna), 1 (1996-8), 830-834.

Someya, S., Okamoto, K. and Tanaka, G., 3D Shape Reconstruction from Synthetic Images Captured by a Rotating Periscope System with a Single Focal Direction, Journal of Visualization, 6-2 (2003), 155-164.

Toriwaki, J. and Mori, K., Visualization of the Human Body toward the Navigation Diagnosis with the Visualized Human Body, Journal of Visualization, 1-1 (1998), 111-124.

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