Journal of Visualization, Vol. 11, No. 1 (2008)79-86

Regular Paper

Anaglyph Stereo Visualization by the Use of a Single Image and Depth Information

Matsuura, F.*[1] and Fujisawa, N.*[2]

*1 Graduate School of Science and Technology, Niigata University, 8050 Ikarashi-2, Nish, Niigata, 950-2181, Japan. E-mail: mat@xfer.in
*2 Visualization Research Center, Department of Mechanical Engineering, Niigata University.

Received 7 July 2007
Revised 31 August 2007

Abstract : In this paper, an anaglyph stereo visualization is studied by the use of a single image and depth information. The present technique allows the stereo visualization of the target image without binocular camera, which has been used for generating the standard anaglyphs. Three test cases are shown in this work, which covers the generation of monochrome anaglyph from given geometrical information, and that of monochrome and color anaglyph from depth information evaluated from other imaging devises, which are placed in parallel. The experimental depth information of the target image is evaluated from the correlation-based template matching analysis of the random dot patterns optically projected on the target objects. Examples of anaglyph stereo visualization are shown for scientific art, such as the monochrome cube, monochrome plaster figure and the color artificial flowers. These results indicate that the present technique of anaglyph stereo visualization through the depth information is very useful and widely applicable to the general three-dimensional visualization.

Keywords : Three-dimensional visualization, Anaglyph, Depth information, Shape measurement, Scientific art.

1. Introduction

Three-dimensional visualization is well known and becoming popular in recent years to understand the target object and the related physical phenomena. The progress of three-dimensional visualization is greatly accelerated in recent years by the development of new multi-media devices, such as three-dimensional projector, monitor and so on. Such visualization technique is known useful for expressing the depth information on the two-dimensional image, so that there is a wide range of application in the field of scientific visualization (Bruno et al., 2006). Now, there is variety of method, which can provide the three-dimensional information of images, such as stereogram (Radvanyi, 1999), anaglyph (Glen, 1985; Smith et al., 1999; Sakashita et al., 2005), polarization glasses (Matsushita et al., 1998), stereo projector and monitor (Hernandez et al., 1998) and so on. For conducting such stereo visualization, images are normally taken from binocular camera, which consists of two parallel imaging devices with a certain distance equivalent to that of human eyes (= 60-65 mm). However, the necessity of such special imaging devices keeps away from popularization of the three-dimensional visualization in the present conditions. It would be very helpful to generate the three-dimensional images from a standard single camera, which is available in general market.

In principle, the information from image pair from binocular imaging system is equivalent to the one of images and the depth information (Ideses and Yaroslavsky, 2005). Therefore, the three-dimensional image can be generated from a single imaging device, once depth information is available from other methods. This means that the stereo visualization can be carried out using a single image in combination with the depth information.

Anaglyph is one of the most economical methods for expressing the depth information and is also the most popular method among many three-dimensional visualization techniques. However, there are fewer studies to improve the visual quality of anaglyphs in literature (Ideses and Yaroslavsky, 2005; Yaroslavsky et al., 2005). This method uses red-cyan (or red-blue) glasses in three-dimensional visualization of stereo images. The depth information can be observed by the parallax of the red-filtered images on the left and the cyan-filtered image on the right. Therefore, the anaglyph can reproduces the three-dimensional information, but the color of the target may not be reproduced correctly due to the loss of red and cyan information, which have already been used for getting the parallax information. In spite of such drawback, the anaglyphs are accepted as a simple method of three-dimensional visualization (Matsuura et al., 2006) and applicable to the visualization of scientific art (Nakayama et al., 2004; Hertzberg and Sweetman, 2005; Fujisawa et al., 2007; Burge, 2007).

In the present paper, the experimental techniques are studied for stereo imaging and three-dimensional visualization based on a single image and the depth information from other methods. An attention is placed on the generation of monochrome and color anaglyphs for application to scientific art.

2. Experimental Method

2.1 Experimental Setup

An illustration of the experimental setup is shown in Fig. 1, which consists of imaging device, LCD projector and frame grabber installed to a personal computer. As a basic imaging device, monochrome CCD camera (648 x 494 pixels, 8 bit) or digital color CCD camera (3008 x 2000 pixels, 8 bit) is used for imaging the target object. The position of such base camera is placed in front of the target object. In this study, the distance between the base camera and the target object is set to 1.2 m. A LCD projector is placed just behind the camera to project a random dot pattern on the target object. Each dot is 3 mm in diameter and is white on the black background. It should be mentioned that the monochrome CCD camera is used for generating the monochrome anaglyph and the color CCD camera is for the color anaglyph. In order to obtain the depth information of the target object, other monochrome CCD cameras are located in parallel to the base camera with a certain distance.

2.2 Camera Calibration

The camera calibration is carried out using a calibration plate to eliminate the effect of lens distortion and minor misalignment of the camera positions. The calibration plate is a planar white plate having an area of 600 mm x 800 mm, where many black markers of 3 mm in diameter are located in an array with an interval of every 20 mm. The plate is fixed on an electric traversing device to move in the depth direction (*z* direction, see Fig. 1). The calibration plate is set at five different positions in the depth direction, which is at every 70 mm intervals. Note that the relationship between image and physical coordinates is approximated by third-order polynomials;

$$x' = \sum_{j=0}^{3}\sum_{i=0}^{3}\alpha_{ij}x^i y^j, \quad y' = \sum_{j=0}^{3}\sum_{i=0}^{3}\beta_{ij}x^i y^j \quad (i + j \le 3) \tag{1}$$

where x, y are image coordinates, x', y' are physical coordinates, and α, β are coefficients of matrix determined by least-square method using the calibration plate (Soloff et al., 1997).

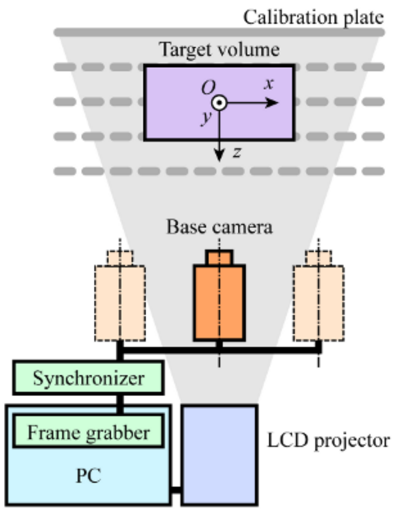


Fig. 1. Experimental setup for three-dimensional visualization.

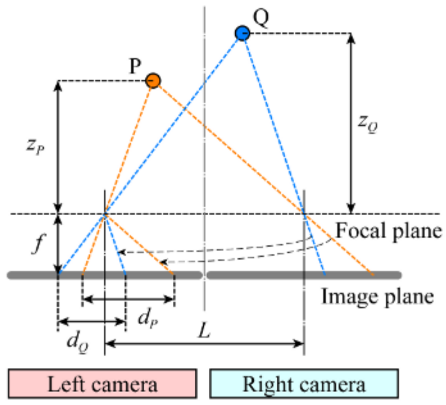


Fig. 2. Depth information and parallax displacement.

2.3 Depth Information

The depth information of the target object can be obtained from two parallel cameras placed side by side. Assuming that two cameras are parallel, the depth information z of the target object can be expressed by the following simple equation:

$$z = \frac{fL}{d} \tag{2}$$

where d is a parallax displacement on the image plane, f is a focal length of the camera lens and L is a distance between two parallel cameras (Fig. 2). Since z is inversely proportional to d, parallax displacements of the points P and Q, which are denoted by d_P and d_Q, respectively, are found to be $d_P > d_Q$. Note that the parallax displacement d between two images is evaluated from the correlation-based template matching analysis with sub-pixel interpolation (Kiuchi et al., 2005; Fujisawa et al., 2006). The correlation window size is set to 23 x 23 pixels. Then, the depth information z can be obtained from Eq. (2), which results in $z_P < z_Q$ in Fig. 2. On the other hand, Eq. (2) is used for evaluating the parallax displacement from the depth information z to generate the displacement image of the anaglyph.

3. Generation of Anaglyph Images

3.1 Monochrome Anaglyph from Given Geometrical Information (Case 1)

Usually, anaglyph stereo images are generated by simply synthesize the image pair taken from the binocular camera having a lens distance of human eyes. Thus, the depth information is automatically supplied through the parallax of stereo image pair. On the other hand, the anaglyph stereo images can be generated from a single image in combination with the depth information taken from the other information, such as the geometry of the target object and the experimentally measured depth information. The procedure of anaglyph image generation in these cases is described as case 1 in Fig. 3.

When a single image is taken from a CCD camera, the image can be used as the base image of the stereo image pair and the other image can be generated from the base image and the depth information. An example of anaglyph image generated through the known geometry of the target

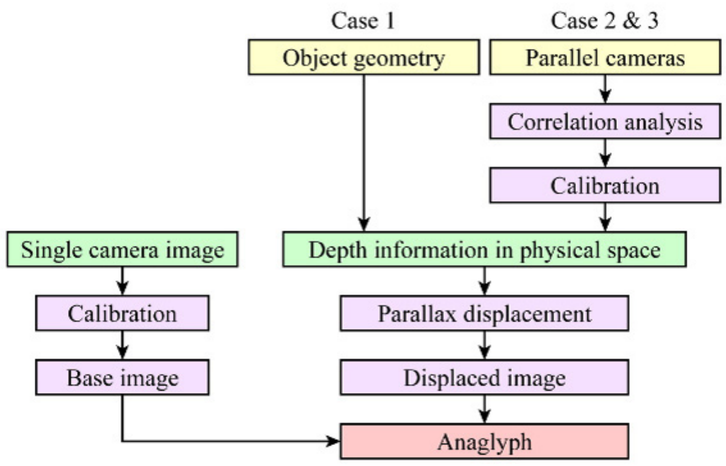


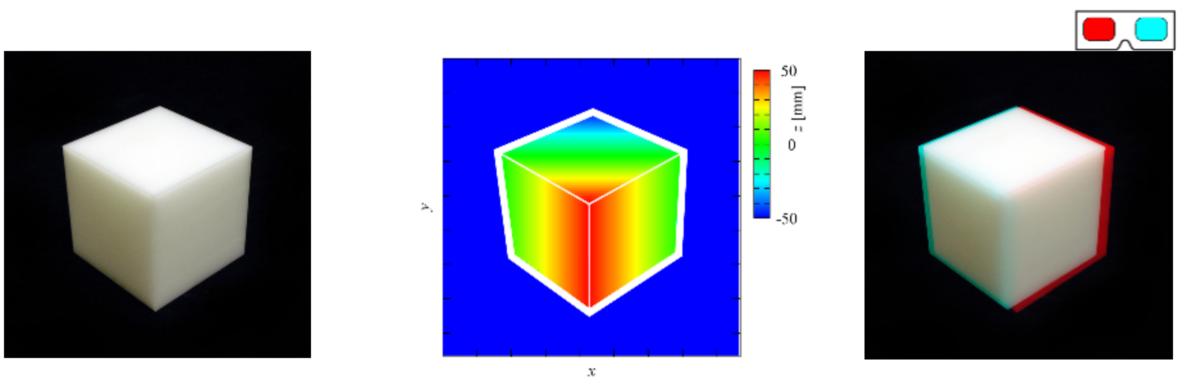
Fig. 3. Flow chart of anaglyph generation.

object is shown in Fig. 4. In this case, the depth information can be easily evaluated from a single image (Fig. 4(a)) by detecting the characteristic points, such as the corners of the target and the geometrical information of the cube (Fig. 4(b)). Then, the parallax displacement is calculated pixel by pixel from Eq. (2), and the displacement image is generated from the base image taken from the monochrome CCD camera. Note that the base image should be calibrated to remove the influence of lens distortion and misalignment of the camera. Figure 4(c) shows an example of anaglyph image of the cube, which has a 70 x 70 x 70 mm^3 in physical space. The three-dimensional information can be seen by the observation with red and cyan filtered glasses.

3.2 Monochrome Anaglyph from Experimental Depth Information (Case 2)

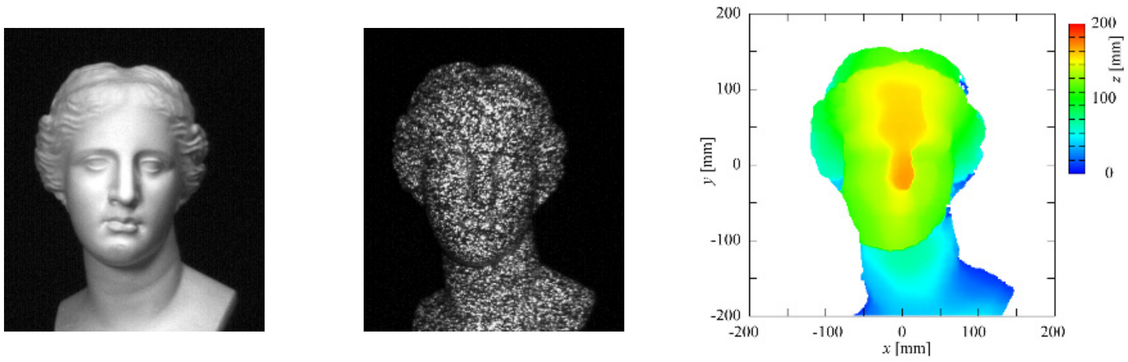
When the depth information is not given, it has to be evaluated by experimental observation. In this case, the depth information can be evaluated from the image from the base camera and the CCD camera placed in parallel. Note that a monochrome CCD camera (648 x 494 pixels) similar to the base camera is used for getting the depth information in the present study. The depth information is evaluated from the correlation-based template matching analysis of the pair of images. Then, the depth information is transformed into the parallax displacement at each pixel of the image at the base camera position using Eq. (2). Note that the image information is transformed into the physical coordinates by the calibration to remove the influence of lens distortion and minor misalignment of the camera positions. Then, the anaglyph stereo images are generated by the use of the displacement image and the base image after the image calibration.

The procedure of stereo imaging and the generation of anaglyphs for three-dimensional visualization are described in Fig. 5, which shows a target object of plaster figure under white light



(a) base image (b) depth information (c) monochrome anaglyph

Fig. 4. Monochrome anaglyph of cube from given geometrical information.



(a) base image (b) random dot pattern (c) depth information

(d) monochrome anaglyph

Fig. 5. Monochrome anaglyph of plaster figure from experimental depth information.

illumination (Fig. 5(a)), that in a random dot pattern (Fig. 5(b)), the depth information of the plaster figure obtained from the stereo imaging (Fig. 5(c)) and the anaglyph image of plaster figure generated by the present method (Fig. 5(d)). Note that the anaglyph image generated by the present method is obtained from the two parallel cameras with a distance L = 128 mm. The successful generation of the anaglyph is found from the observation with red-cyan filtered glasses.

It is expected that the inaccuracy of depth information is influential on the visual quality of the anaglyph. Figure 6 shows the side views of the plaster figure at various camera distances L, which are taken by a CCD camera in front of the plaster figure. The result indicates some errors in the depth information, which are dependent on the distance between the cameras and that between the cameras and the target object. It is found that errors appear in the depth information at larger parallax displacement, which is due to the error in the correlation-based template matching analysis near the boundary of the plaster figure. However, the smaller parallax displacement produces an inaccuracy in the depth information due to the sub-pixel error, which can be seen around the nose of the plaster figure. Thus, the present result indicates that the optimum camera distance L is considered as L = 64-128 mm. It should be mentioned that the RMS error in the present experiment is found to be about 3 mm in L = 64-128 mm, which is obtained from the calibration study.

Examples of anaglyphs with erroneous depth information are shown in Fig. 7(a) and (b). It is found that three-dimensional visual quality of the anaglyph is partly lost due to the error in the depth information at the narrower camera distance, though it is not clearly seen (Fig. 7(a)). On the other hand, an example of anaglyph at wider camera distance is shown in Fig. 7(b), which shows the influence of artifacts on the left shoulder and on the rugged hair of the plaster figure, which is marked by yellow circles. Thus, the error in the depth information is influential on generated anaglyphs.

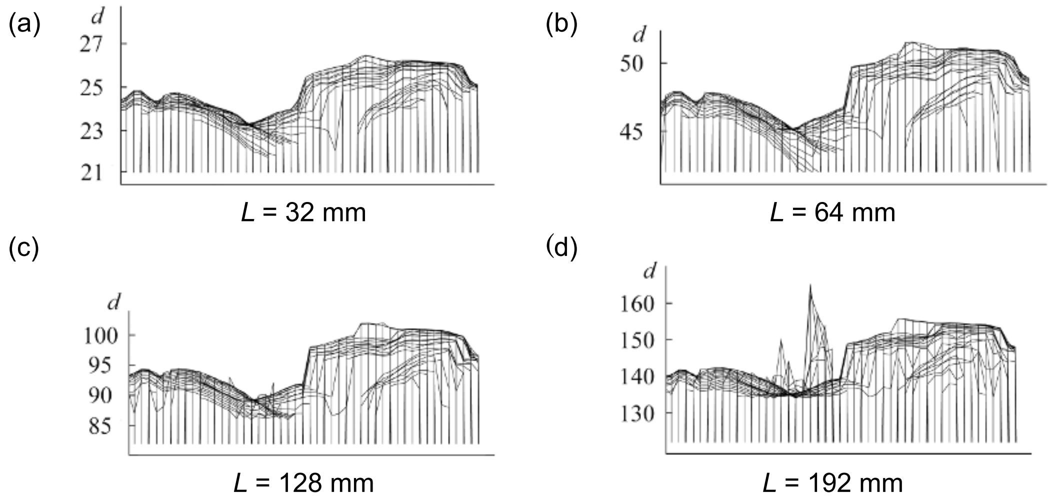


Fig. 6. Depth information of plaster figure taken from various camera distances.

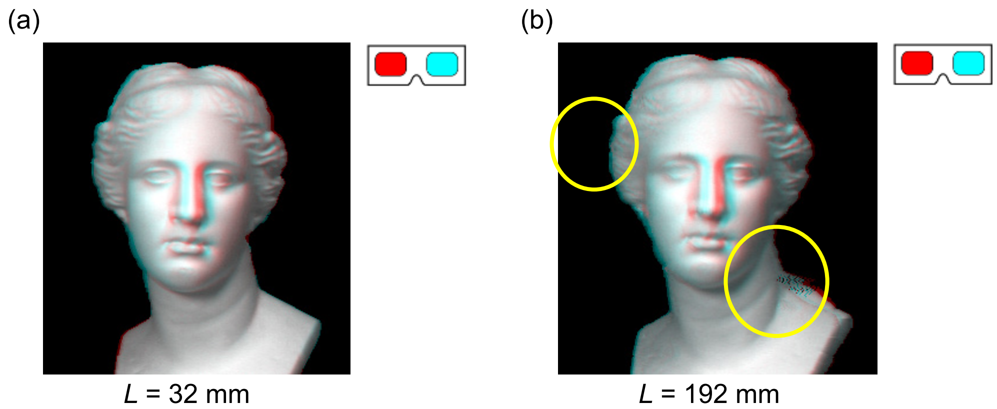


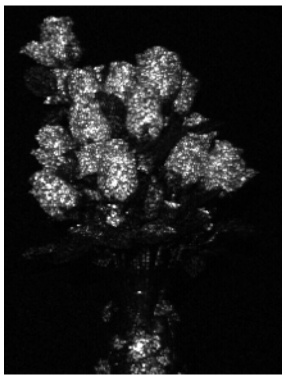
Fig. 7. Anaglyphs generated from erroneous depth information.

3.3 Color Anaglyph from Experimental Depth Information (Case 3)

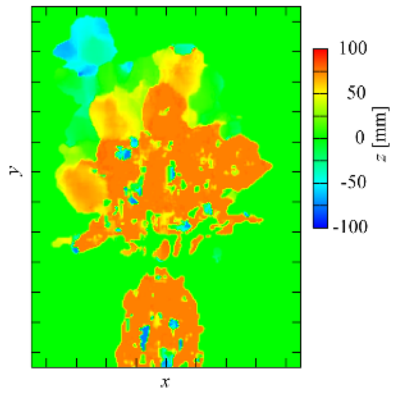
In case of color anaglyph, the procedure of image generation is similar to the case of monochrome anaglyphs. Only the difference is that the parallax displacement obtained from the correlation-based template matching analysis has to be added to the color image, where the HSI color format (H: hue, S: saturation, I: intensity) is preferred to minimize the error in the image generation. It should be mentioned that bilinear interpolation of image is introduced into the generation of anaglyph to match the image size of the depth information with the base color image, because the image size of the color CCD camera is generally different from that of the monochrome CCD camera, which is the case in this study. In the present study, the two monochrome CCD cameras (648 x 494 pixels) are placed on both sides of the color CCD camera (3008 x 2000 pixels) to evaluate the depth information of the target object. Note that the distance between the monochrome CCD camera is set to L = 100 mm in the present experiment.

Figure 8 shows a target object of artificial flowers under white light illumination (Fig. 8(a)), that in a random dot pattern (Fig. 8(b)), the depth information (Fig. 8(c)) and the color anaglyph of the artificial flower (Fig. 8(d)). Several points seem to have erroneous depth information in Fig. 8(c), which is due to the darkness of the random dot pattern on the target surface, as observed on the leafs and the flower vase. However, these errors may not deteriorate so much the visual quality of anaglyph, because they are dark enough to be detected. For generating the color anaglyph, the RGB color information of the base image is transformed into HSI color space to reduce the unexpected noise in the image processing, which occurs near the color boundaries. Then, the parallax displacement from the depth information is added to each color. The successful generation of the color anaglyph can be observed through the red-cyan filtered glasses. It is noted that red or cyan color should be avoided from the target image for generating color anaglyph, because each color has already used for getting the parallax information. The preferred color for color anaglyph is purple, yellow and white.

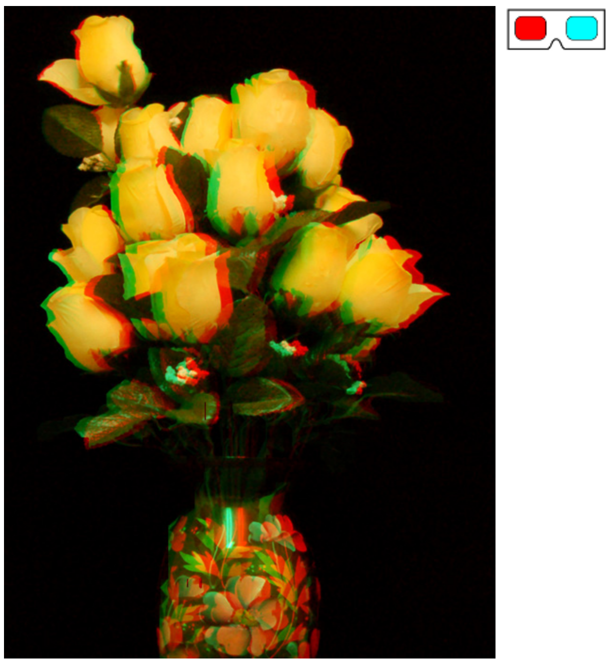
(a) base image



(b) random dot pattern



(c) depth information



(d) color anaglyph

Fig. 8. Color anaglyph of artificial flowers from experimental depth information.

4. Conclusion

The three-dimensional visualization by anaglyph stereo image is studied by the use of a single image and the depth information of the target object. This technique allows the generation of anaglyph stereo images without the standard binocular camera. Three cases are considered in the present paper, which cover the monochrome anaglyph generated from target geometry, the monochrome and the color anaglyph generated from experimental depth information, which are obtained from other CCD cameras with an illumination using random dot pattern and the correlation-based pattern-matching analysis. These results indicate that anaglyph stereo images are successfully generated by the single image and the depth information, which indicates the validity of this technique. The visual quality of the anaglyph is greatly influenced by the inaccuracy in the depth information, but it depends on the darkness of the images. The successful examples of anaglyph stereo images are shown as the scientific art, such as the cube, the plaster figure and the artificial flowers, which are successfully observed through the red-cyan filtered glasses.

Acknowledgements

The authors would like to thank Prof. N. Asada and his colleagues from University of Aizu and Mr. Y. Takeda from Niigata University for their help during the course of this study.

References

Bruno, F., Caruso, F., De Napoli, L. and Muzzpappa, M., Visualization of industrial engineering data in augmented reality, Journal of Visualization, 9-3 (2006), 319-329.
Burge, P., Hidden pattern, Journal of Visualization, 10-2 (2007), 171-178.
Fujisawa, N., Verhoeckx, M., Dabiri, D., Gharib, M. and Hertzberg, J., Recent progress in flow visualization techniques toward the generation of fluid art, Journal of Visualization, 10-2 (2007), 163-170.
Fujisawa, N., Nakamura, Y., Matsuura, F. and Sato, Y., Pressure field evaluation of microchannel junction flows through μ PIV measurement, Microfluidics and Nanofluidics, 3 (2006), 447-453.
Glen, R. C., Influence of background color on the chirality of anaglyph (red/green) stereo diagrams, Journal of Molecular Graphics, 3 (1985), 135.
Hernandez, A., Basset, O., Bremond, A. and Magnin, I. E., Stereoscopic visualization of three-dimensional ultrasonic data applied to breast tumours, European Journal of Ultrasound, 8-1 (1998), 51-65.
Hertzberg, J. and Sweetman, A., Images of fluid flow: Art and physics by students, Journal of Visualization, 8-2 (2005), 145-152.
Ideses, I. and Yaroslavsky, L., Three methods that improve the visual quality of color anaglyphs, Journal of Optics A.: Pure and Applied Optics, 7 (2005), 755-762.
Kiuchi, M., Fujisawa, N. and Tomimatsu, S., Performance of a PIV system for combusting flow and its application to a spray combustor model, Journal of Visualization, 8-3 (2005), 269-276.
Matsushita, T., Nakamura, K., Ohe, T., Nakagawa, K. and Kurokawa, T., Portable-type stereo fluoroscope for surgery, European Journal of Radiology, 26-3 (1998), 312-315.
Matsuura, F., Fujisawa, N. and Takizawa, K., Stereo visualization and three-dimensional motion analysis of rhythmical movement, 12th International Symposium on Flow Visualization, ISFV12-17.2-139 (2006).
Nakayama, Y., Oki, M., Aoki, K. and Takayama, S., Jomon pottery observed from the point of view of fluid mechanics: Did jomon people discover twin and Karman vortices?, Journal of Visualization, 7-4 (2004), 349-356.
Radvanyi, A. G., The difference-stereogram, Journal of Mathematical Imaging and Vision, 11-3 (1999), 255-275.
Sakashita, R., Fujisawa, N., Matsuura, F., Takizawa, K., Anaglyph stereo visualization of rhythmical movements, Journal of Visualization, 10-4(2007), 345-346.
Smith, J., Connell, S. and Swift, J., Stereoscopic display of atomic force microscope images using anaglyph techniques, Journal of Microscopy, 196-3 (1999), 347-351.
Soloff, S., Adrian R. and Liu, Z -C., Distortion compensation for generalized stereoscopic particle image velocimetry, Measurement Science and Technology, 8 (1997), 1441-1454.
Yaroslavsky, L., Campos, J., Espinola, M. and Ideses, I., Redundancy of stereoscopic images: experimental evaluation, Optics Express, 13-26 (2005), 10895-10907.

Author Profile

Fuminori Matsuura: He received his M.Sc. (Eng) in Mechanical Engineering in 2004 from Niigata University. He is now studying at Graduate School of Science and Technology of Niigata University as a PhD candidate and continuing the research on the measurement of micro flow phenomena and three-dimensional visualization.

Nobuyuki Fujisawa: After he was educated at Tohoku University (M.E. 1979, D.E. 1983), he joined Gunma University in 1983 and worked as a research associate in the field of turbo machinery and turbulence measurement. He was promoted to associate professor in 1991 and extended his research field to flow visualization, measurement and control of turbulent flow. Since 1997, he has been a professor of Niigata University and is continuing research in the simultaneous measurement of scalar and vector fields of thermal and combusting flows, quantitative flow visualization and passive and active control of flow-induced noise.