Paper

Projection-Based Assistance for Ultrasonic Diagnosis

Yoshihiro Yasumuro* Non-member
Agus Prayitono* Non-member
Kazuhiro Kohyama* Non-member
Masataka Imura* Non-member
Yoshitsugu Manabe* Non-member
Osamu Oshiro** Member
Kunihiro Chihara* Non-member

This research focuses on developing visual assistance for ultrasound echographic measurement. Proposed system performs a direct projection of the intersectional imagery onto the patient's body by an optical projector. The surface shape of the patient is taken into consideration for image projection. Optical shape measurement and graphical synthesis techniques are combined for producing distortion-free images so that the physician can intuitively manipulate the ultrasonic probe and observe the echography in the identical physical space.

Keywords: Ultrasonic Diagnosis, Echography, Projector, Mixed Reality, 3D Measurement

1. Introduction

The success of computer graphics technology in recent years has led to the creation of spectacular effects in movies, interactive computer games, and Virtual Reality(VR) environments. This very success gives new challenges to enrich the real world where we live and work with computer-generated imagery and information as it already is in movies and games today. To answer this challenge, many researchers have tried to explore the possibility of mixing the real world and the computer-generated virtual world; this new research area is widely referred to as Mixed Reality(MR) [1][2].

This research investigates the possibility of applying MR representation display in medical fields, especially for developing new visual assistance in ultrasonography diagnosis. Comparing to other measurement such as X-ray and MRI(Magnetic Resonance Imaging), ultrasonic imaging is pervasive technique and has advantages in realtime, noninvasive interactive examination. However, aligning the acquired cross-sectional images and 3-dimensional(3D) reconstruction are only done in the experienced doctor's head. Systematically fitting echographic images to their corresponding measured positions allows not only 3D reconstruction but also extending the use of echography to the pre-operation processes such as marking and scheduling for paracentesis.

* Grad School of Information Science, Nara institute of Science and Technology
8916-5, Takayama, Ikoma, Nara, 630-0101 JAPAN
** Graduate School of Engineering Science, Osaka University
4-5-6 Machikaneyama, Toyonaka, Osaka, 565-0456 Japan

2. Related work

For merging real and graphics sceneries, two approaches have been developed. The first approach uses a head-mounted display (HMD) to augment the real scene captured by a camera. The second type uses a projector to attach a virtual object to a real scene by directly projecting graphical contents onto the physical objects. The most similar work to our research had been conducted by Ohbuchi [8] and State [9], taking the first approach using HMDs for merging ultrasonic medical images with the real scene with see-through manner. Our method follows the second approach, for enhancing the real environment with useful information. Interestingly, the use of projectors to change and augment reality has a long history, as seen in the theater and cinema. Recently, radical applications have been proposed by Morishima [3], to enhance the face of an actor, and by Raskar [4][5], to change the color and texture of real objects. Pinhaez [6] proposed a device consisting of a mirror, a projector and a CCD camera as a display for future ubiquitous computing, and Kjeldsen [7] added new functionality to this device as an interactive display by enabling it to any movement or gesture around the projected surface.

We focus on practical use of interactive see-through examination with echography for not only image diagnosis but also pre-operational procedures that require geometrical consistency between the patient's body and the imagery data. Spinal anesthesia, for example, physicians search proper position and direction for centesis operation by examination with X-ray images and examination by palpation. However, X-ray images are usually taken in different situation beforehand and per-

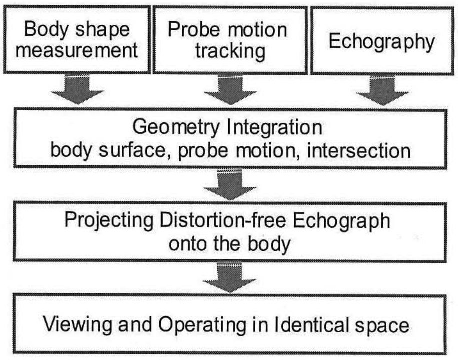


Fig. 1. Overview of the system functions

formance is technically based on the physician's experience. Therefore, we introduce projection-based visual assistance to directly support physicians undertaking ultrasonography diagnosis of a patient located in the same site.

3. Proposed Method

Our approach is based on integration of heterogeneous measurement and synthesis of intersectional image to project onto the body surface (Fig.1). Projection-based display has two significant points that must be taken into consideration for preparing the visual contents to display. One is that the area of the object surface to be illuminated from a projector is limited. In other word, occluded surface from the projector is not available for display use. Depending on the viewer's position, some part of the imagery may be calculated as the one to show up on the surface in the "backside" from the projector. The other point is that displayed graphics has distortion because of the surface shape and the position difference between the projector and the viewer. To cope with these problems, we use the same projector for both displaying and shape measurement for avoiding complexity. The number of devices require the same number of local coordinate systems, calibration and computational error for integration.

This research brings together several fundamental components to implement three major functionalities: a 3D shape measurement system, a 6 degrees of freedom (DOFs) position tracking system, and an ultrasound echographic measurement system (Fig.2). Each component has a different local coordinate system. Therefore, synchronisation of these three components also means that a global coordinate system can be defined and each local coordinate system related to this global coordinate system. Each component and its underlying methods are described in more detail in the following sections.

The proposed display system will work as follows: as each echography image is acquired by an ultrasound scanner, its position and orientation in 3D world space are tracked with 6 DOF. Simultaneously, the position and orientation of a viewer are also tracked with 6 DOF. Using this geometry, an image-generation system produces 3D renderings of 2D ultrasound images that satisfy the viewer's perspective. These images are then projected onto the real world by a projector. To produce

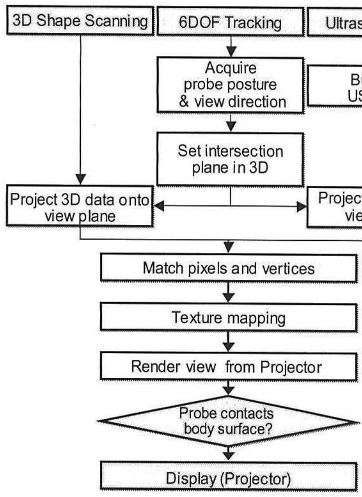


Fig. 2. Process flow

distortion-free images, knowledge of the object' s surface is required. Therefore, 3D measurement of the real scene is conducted beforehand, using a CCD camera and a projector. The result is a see-through perspective 2D ultrasound image registered in its true 3D location.

4. Distortion-free Projection

Interpreting 3D intersectional data and understanding spatial relation ships within the patient's body is intrinsic performance to achieve the image diagnosis. However, such mental 3D fusion may not sufficient for scheduling of operation in which the exact quantitative geometry relation ships between the skin surface and the inner information is crucial. Therefore, ideally a physician would like to see the image data directly inside the patient's body. Furthermore, ultrasound echographic images need to be not only displayed at the correct position pointed by ultrasound probe but also displayed to match a user field of view.

To generate see-through images, first it is necessary to make registration of ultrasound echographic images to the position directed by the ultrasound transducer. Measurement reports from tracking device are used to determine the ultrasound probe's location. Next a user's viewing plane is defined to estimate the shape of the echographic images observed from user's viewpoint. Fig.3 describes an algorithm for creating see-through images. A see-through view of intersection is approximately produced by parallel projecting every image pixel of an echographic image to the previously defined viewing plane. To give enough space for the projected image, the viewing plane is assumed to have two times bigger size than the original echographic image. This image is then utilized to form an array of texture image which is mapped onto reconstructed measured surface later. Fig.4 depicts the situation. The figure also shows a procedure for determining projection surfaces for every texture image pixel. Here, the 3D model of the computer-reconstructed patient's body is used to estimate the projection surfaces. A parallel projection is also used in this procedure to determine corresponding

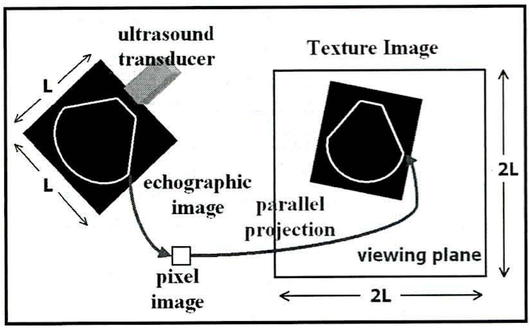


Fig. 3. Composing a texture image and calculating its corresponding projection surface by implementing parallel projection

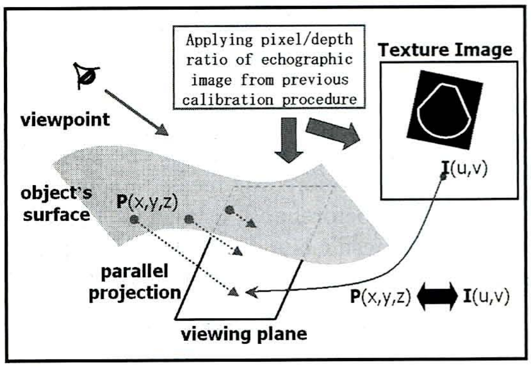


Fig. 4. Composing a texture image and calculating its corresponding projection surface by implementing parallel projection

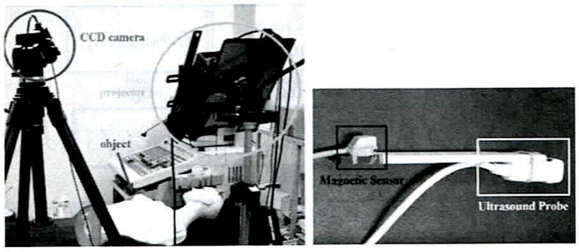


Fig. 5. System Setup

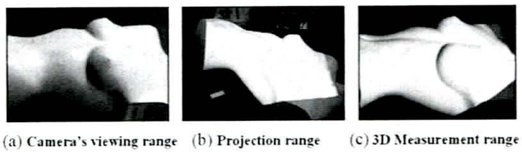


Fig. 6. Covered range of the 3D measurement system

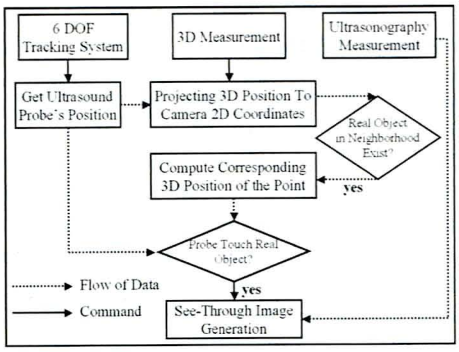


Fig. 7. Flow diagram of algorithm to determine physical contact moment between ultrasound transducer and body's surface

projection surfaces of every texture image pixel.

To calculate the true position of projection surface, it is necessary to determine the real dimension of the echographic image pixel. Therefore, ultrasound probe calibration was conducted beforehand. In this calibration procedure, an object whose height was known by manual measurement was put in the front of the probe. By observing the result of echographic image, pixel/length ratio of the echographic image can be determined. This ratio is then employed for determining corresponding projection surface for every echographic image pixel.

By rendering graphics of reconstructed 3D model of the body shape on which the texture of the intersection image is mapped, see-through intersection is visualized. The key of proposed method is concentrated into setting up the viewpoint as focal point of the projector when rendering the graphics. This rendering achieves hidden surface removal using depth cueing from the projector position [12], which is equivalent to getting rid of backside surface from the projector. The projection matrix for the rendering is same as the one which is calibrated and used for the shape measurement. This projection works so that the texture images are created to match with the user's field of view. Finally, the geometric relationship between the projector and the real scene coordinates is used to calculate transformation matrix that relate positions of those texture image system coordinates to their corresponding positions in the real 3D world. As well a camera model used for 3D measurement, this transformation is obtained from initial calibration procedure using similar technique. This transformation is thus acquired from Euclidean transformation that relates defined world coordinate system to projector-centered coordinate system.

5. System Implementation

5.1 System Configuration In this research common optical hardware such as an Epson projector ELP500 and a Watec CCD NTSC camera WAT-202D are used for the measuring devices; a Polhemus Fastrack magnetic tracking system including a transmitter and receivers is also employed; and a Linux workstation equipped with 868 MHz Intel Celeron Processor, 252 MB memory is used to control overall system. Camera images are acquired by a capture card, I-O DATA GV-VCP with VGA(640x480) resolution. The configuration of proposed system is shown in Fig.5. The baseline distance between the camera and the projector is 50cm and measurement area is located at 70cm from the baseline. Echography system is HITACHI EUB-565A, which provides echography output as NTSC video signal.

Fig. 7 shows the process flow diagram of the whole system components. First it is necessary to determine the time when ultrasound echographic measurement is being conducted. An algorithm to detect ultrasound transducer movement continuously and to determine the time when the probe touches the patient's body can solve this problem. A measuring report from the tracking device is employed to provide the probe location in real time, while CCD camera parameters and the reconstructed 3D model of the patient's body are then used to determine the physical contact moment between the transducer and the body surface.

5.2 Surface Acquisition Using Gray Encoded Structured Light So-called gray-code-generated structured lights (gray code patterns) are employed for 3D shape measurement of the body surface (13)(14). As shown in Fig.8 (right), n numbers of gray code patterns divide the real scene or space into 2^n light planes. These light planes can be seen as unique addresses for the space(Fig.8 (left)), and also correspond to unique pixel coordinates (x, y) of the camera (15). This unique correspondence between the camera and the projector enables triangulation for pixel by pixel. Projection of 9 gray encoded patterns is used for producing dense measurement data in less than 10 seconds. Compared to measurement using 512 slits of lighting that can give the same dense data for the measurement space shown in Fig.6, employed 3D measurement system can benefit from a short measuring period.

It is almost impossible, however, to obtain measurement data which is free of noise, and so it is necessary to remove noise before using the data for further steps. For this purpose, a shape reconstruction algorithm including a simple noise-removing procedure is applied (Fig.9). First, an effective volumetric space in a real 3D scene is defined. Any points on the depth map image corresponding to real 3D points outside the defined space are then removed. Next, maximum length or distance between spatially consecutive image points is defined. Similarly, any consecutive image points separated by a distance greater than the defined maximum length are also removed. Finally, the remaining image points and their corresponding 3D coordinates are used for surface reconstruction of the real scene.

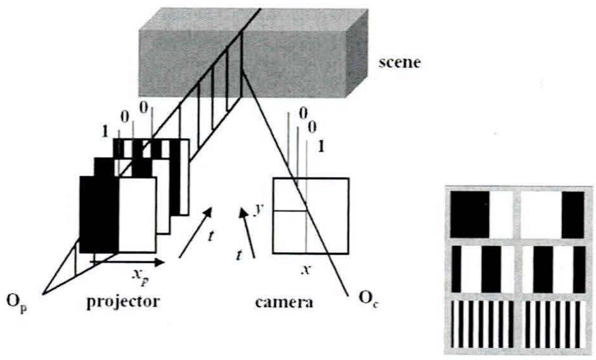


Fig. 8. Graycode

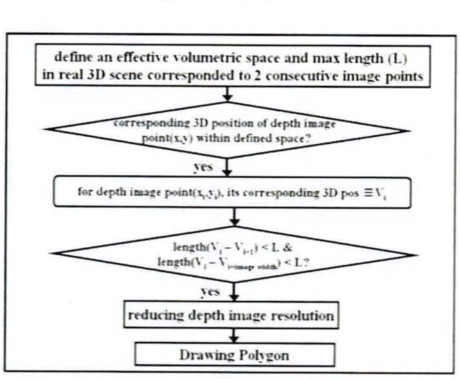


Fig. 9. Shape reconstruction algorithm for building 3D model of a real scene

5.3 Evaluation of Display System A cube-shaped target was used as calibration object for implicit and explicit parameters of both the camera and the projector. The cube has 120 mm length of edges. It was placed on the examination bed within the 3D measurement covered area. The position of each point in the previously defined world coordinates is known by manual measurement. The maximum error for shape measurement is less than 4 mm.

The scheme to evaluate the accuracy for displaying echography images cannot be straightforward, because it is difficult to prepare an object whose inner geometry is precisely known and is able to be observed by see-through manner without optical refraction and scattering, besides its surface is supposed to be opaque enough to show projected graphics. In this experiment, a checker-board image was used instead of ultrasound echographic images, assuming that the checker-board indicates the section plane. Then we put an opaque object in front of the checker-board as a visible surface, whose

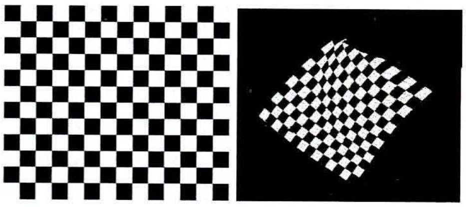


Fig. 10. Texture image distortion due to irregular shape of projection surfaces

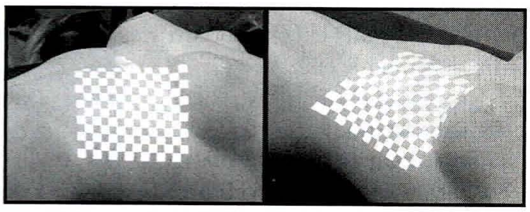


Fig. 11. Projection results from the viewer(left) and different viewpoint(right)

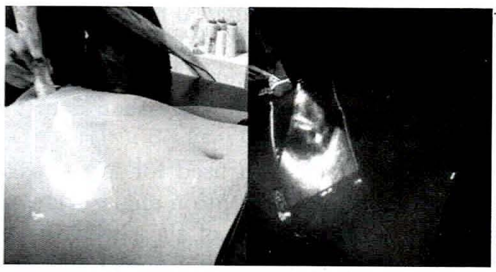


Fig. 12. See-through echography result

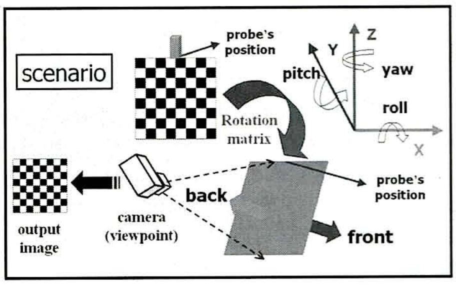


Fig. 13. The scenario of an experiment to evaluate the displaying system

shape is measured and distortion-free checker pattern is synthesized and projected to show see-through intersection. The checker-board's length and width is 16 cm. Furthermore, it is assumed to have pixel/cm ratio of 16 (it has the density of 16 image pixels in one cm length). This ratio plays an important role for determining projection surface of every echographic image pixel. This ratio was also used to calculate projection errors of the displaying system below.

The process of conducted experiment is described through the following paragraph:

(1) First, a digital camera is placed to the position of a designed user's viewpoint. The viewpoint's location was measured manually by a ruler.

(2) A checker-board is set up to a known position within 3D measurement space. The checker-board was also set up to face the same direction with the digital camera as if a user is observed the back of the checker-board. The checker-board also needed to be placed to have the same tilt and slant angle with the digital camera. (Fig.13)

(3) An image of the same checker-board is then placed to the same location within computer-generated virtual 3D measurement space. To do so, a measurement report from tracking device needed to be alternated by the designed location.

(4) The designed scenario's scene was measured using the 3D measurement system.

(5) The (virtual) checker-board was projected onto the designed scene.

(6) Projected image was then captured using the digital camera.

(7) Next a paper box was placed to the area covered by 3D measurement system.

(8) Using the same way, the (virtual) checker-board was then projected onto the scene.

(9) See-through image projected onto the box was also captured by the digital camera.

(10) Projection errors was calculated by comparing image pixel of the captured image and image pixel of previously captured image that shown the initial scenario's scene.

Three scenarios had been used for the experiments, in each of which, different rotation angles were specified to give different orientations of the checker-board and the digital camera. The rotation angles were specified as combination of yaw, pitch, and roll angles (Fig.13).

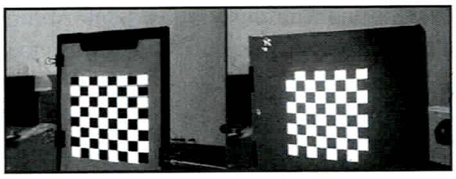


Fig. 14. A result of the experiments for evaluating the displaying system

Displaying errors Δx and Δy are then introduced, while Δx refers to the displaying error parallel to horizontal axis and Δy refers to the displaying error parallel to vertical axis.

Fig.14 shows one of the results of conducted experiments in three different scenarios. The left picture shows experiment displaying the (virtual) checker-board image onto surface of the real checker-board that had been set up beforehand, while the right picture shows experiment displaying the same (virtual) checker-board image onto a white paper box. The displaying error was calculated by observing the position of each corner of the small rectangles of the checker-board image.

The first scenario was settled as yaw angle was 90°, pitch angle was also 90° and roll angle was 0°. Displaying errors were Δx: 0.1 - 0.8 [cm] and Δy: 0.0 - 1.2 [cm]. Similarly, the second scenario in which yaw angle was 90°; pitch angle was 110°; roll angle was 0°. This scenario gave displaying errors Δx: 0.0 - 0.5 [cm] and Δy: 0.0 - 1.4 [cm]. Finally, the last scenario where yaw angle was assigned to 90°, pitch angle was 90° and roll angle was assigned to 45° showed displaying errors Δx: 0.0 - 1.2 [cm] and Δy: 0.1 - 1.9 [cm]. The most influencing factor to give a large error is angular parameters of the probe posture and viewing directions. Slight error or fluctuation of the angle output from the trucking device and digital camera setup may cause large displacement in the peripheral part on the section plane. On the other hand, the central part directly beneath the probe has constantly less displaying error within 0.5 [cm], which is same level as the shape measurement error. Depending on the field angle of the projector, the baseline of the 3D measurement system is located too far from the measurement area so that the current implementation covers almost whole torso. System configuration must be tuned for closer range of local area of the patient body to achieve higher accuracy.

6. Concluding Remarks

In this research, to give a visual assistance for ultrasonographic diagnosis a systematic scheme for projection-based display was proposed. An implementation was then developed by applying and integrating proposed methods into single system. Although the current implementation is also designed to anticipate development of 6 DOF sensors that can improve its usability and accuracy, our next step is addressed to improving the system arrangement of the optical measurement setup for higher accuracy. As for the graphics rendering to be projected on the patient's body, virtually accumulating the intersectional imagery to show the inner volume for marking on the skin as preoperational investigation is within our scope, too.

Acknowlecgement
Parts of this work were supported by Japan Society for the Promotion of Science (JSPS), "Grants-in-Aid for Scientific Research" (Kiban-A(2)14208106).
(Manuscript received July 27, 2004)

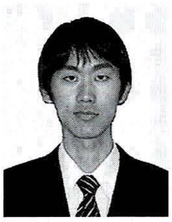
References

(1) P. Milgram, F. Kishino, A Taxonomy of Mixed Reality Visual Display, IECE Transaction Information Systems, Vol.E77-D, No.12, pp. 1321-1329, 1994
(2) R. Azuma, Y. Baillot et al.: Recent Advances in Augmented Reality, IEEE Computer Graphics and Applications, Vol.21, No.6, pp. 34-47, 2001
(3) S. Morishima, et al.: "Hyper Mask: Talking Head Projected onto Real Objects", Proceeding of Multimedia Modeling, 2000
(4) R. Raskar, et al.: "The Office of the Future: A Unified Approach to Image-Based Modeling and Spatially Immersive Displays", Proceedings of SIGGRAPH, Orlando, USA, 1998
(5) R. Raskar, et al.: "Shader Lamps: Animating Real Objects with Image-Based Illumination", Proceedings of 12th Euro graphics, Workshop on Rendering, London, England, 2001
(6) C. Pinhaez, et al.: "The Everywhere Display Projector: A Device to Create Ubiquitous Graphical Interfaces, Proceedings of Ubiquitous", Computing, Atlanta, USA, 2001
(7) R. Kjeldsen, et al.: "Interacting with Steerable Projected Displays, Proceedings of 5th International Conference on Automatic Face and Gesture Recognition", Washington DC, USA, 2002
(8) M. Bajura, H. Fuchs, and R. Ohbuchi, Merging Virtual Objects with the Real World: Seeing Ultrasound Imagery within the Patient, Proceedings of SIGGRAPH, pp. 203-210, Chicago, USA, July 1992
(9) A. State et al., Case Study: Observing a Volume Rendered Fetus within a Pregnant Patient, Proceeding of IEEE Visualization '94, pp. 364-368, Washington D.C., October 1994
(10) Matsuzaki, et al.: "Shared 3-D Environment for Ultrasound Probe in Telemedicine", Master Thesis, Graduate School of Information Science, NAIST, Nara, Japan, 2002
(11) M. Bajura, H. Fuchs, and R. Ohbuchi: "Merging Virtual Objects with the Real World", Seeing Ultrasound Imagery within the Patient, Proceedings of SIGGRAPH, pp. 203-210, Chicago, USA, July 1992
(12) M. Woo et al.: "OpenGL Programming Guide: The Official Guide to Learning OpenGL Version 1.2", Addison-Wesley, 1999
(13) S. Inokuchi, K. Sato, and F. Matsuda, "Range-imaging System for 3-D Object Recognition": Proc. of 7th ICPR Vol.2, 1984, pp. 806-808
(14) K. Sato and S. Inokuchi: "Range-Imaging System Utilizing Nematic Liquid Crystal Mask", Proc. of 1st ICCV, 1987, pp. 657-661
(15) R. Klette et al., Computer Vision: Three-Dimensional Data from Images, Springer-Verlag, Singapore, 1998

Yoshihiro Yasumuro (Non-member) Dr. Yoshihiro Yasumuro received the B.E in Mechanical Engineering Division, Osaka University, Osaka, Japan in 1995. He received the M.E. and Ph.D. degree in Grad School of Information Science, Nara Institute of Science and Technology (NAIST), Nara, Japan in 1997 and 2000. He was a research associate in Faculty of Medicine in Osaka University in 2001. He is now working as an Assistant Professor in NAIST since 2001. His major interests include image processing, computer graphics, virtual reality.

Agus Prayitono (Non-member) Agus Prayitono received B.S. in Engineering degree at Osaka University Department of Electronic, Information and Energy Engineering and received M.S. in information science from Nara Institute of Science and Technology, Japan, in 2004. He is currently working at Toyota communication systems co.,ltd.

Kazuhiro Kohyama (Non-member) Kazuhiro Kohyama received B.S. in electronic and information engineering from Kyoto Institute of Technology, Japan, in 2003. He is currently working on ultrasonic medical image processing.



Masataka Imura (Non-member) Masataka Imura is an assistant professor at Nara Institute of Science and Technology, Japan since 2001. He received B.S. and M.S. in physics from Kyoto University, Japan, in 1996 and 1998, respectively. He then received M.E. and Ph.D. in information science from Nara Institute of Science and Technology, Japan, in 2000 and in 2002, respectively. He is currently working on computer graphics, virtual reality, especially for haptic engineering.

Yoshitsugu Manabe (Non-member) Yoshitsugu Manabe graduated in 1991 from Department of Control Engineering, Faculty of Engineering Science, Osaka University, where he obtained a Dr. of Eng. degree in 1995. Between 1995 and 1999, he was a Research Associate in Department of Systems Engineering. Since 1999, he has been an Associate Professor of Graduate School of Information Science, Nara Institute of Science and Technology.

Osamu Oshiro (Member) Osamu Oshiro is a professor of Graduate School of Engineering Science at Osaka University, Japan. He received a BE from Osaka University, Japan, in 1985. He then received an ME and PhD in control engineering from Osaka University, Japan, in 1987 and 1990, respectively. He is mainly working on medical image processing and 3 dimensional visualization.

Kunihiro Chihara (Non-member) Kunihiro Chihara is a professor at Nara Institute of Science and Technology (NAIST), Japan. He is also a director of Research Center for Advanced Science and Technology at NAIST. He received a BE from Osaka University, Japan, in 1968. He then received an ME and PhD in engineering science from Osaka University, Japan, in 1970 and 1973, respectively. He is working on ultrasoni medical imaging and bio-medical visualization.