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Simple Augmented Reality System for 3D Ultrasonic Image by See-through HMD and Single Camera and Marker Combination

Shun'ichi Tano, Keisuke Suzuki, Kenji Miki, Natsuko Watanabe, Mitsuru Iwata, Tomohiro Hashiyama, Junko Ichino, Ken Nakayama

***Abstract*—Thanks to the rapid progress of ICT, significant progress has been made in both the *"generation"* and *"display"* of the advanced medical information. However, serious problems still remain in both the *"generation"* and *"display"*. Therefore, we propose a simple augmented reality system that can display an ultrasonic image of exactly the same plane in the body of the patient that a doctor is looking at. The key idea is to utilize the fact that an ultrasonic probe moves inside the doctor's field of view and within the accessible range of the arm in order to simplify the augmented reality system. The prototype has been developed using only a see-through HMD and single camera and marker combination. Three simple interaction methods compensate for the limitations in 3D position sensing. We worked with a medical doctor to test the prototype system and found it to be effective.**

I. Introduction

A. Background

Due to the rapid progress of Information Communication Technology (ICT), much research has been conducted to develop a medical support system enhanced by ICT. Recently, the advanced medical information such as CT, MRI, and the computational anatomy model have become available. Moreover, augmented reality (AR) technology enables the display of advanced medical information from the surface or inside of a patient's body. In addition, significant progress has been made in both the ***"generation"*** and ***"display"*** of the advanced medical information.

However, serious problems still remain in both the ***"generation"*** and ***"display"*** of the advanced medical information. In terms of ***"display"***, the AR technology currently used in hospitals demands large-scale equipment. In terms of ***"generation"***, since the current advanced medical information is almost totally static in nature, it cannot adapt to the changing status of the patient. For example, the doctor checks CT and MRI information precisely before liver surgery, but the liver changes shape during the operation because of its softness. Therefore, the advanced medical information such as CT and MRT are almost completely useless in the operating room. They should be selected and modified in accordance with the dynamic status of the patient.

Manuscript received November 10, 2011. S. Tano, K. Suzuki, N. Watanabe, T. Hashiyama, J. Ichino and K. Nakayama are with the University of Electro-Communications, Chofu-shi, Tokyo, 182-8585 JAPAN (e-mail: {tano, hashiyama, ichino}@ is.uec.ac.jp). K. Miki is with Showa General Hospital, Kodaira-shi, Tokyo, 187-8510 JAPAN (e-mail: miki-kenji@umin.ac.jp). M. Iwata is with Tokyo Metropolitan College of Industrial Technology, Shinagawa-ku, Tokyo, 140-0011, JAPAN (e-mail: miwata@s.metro-cit.ac.jp)

B. Our Final Goal

Our goal is to improve the medical front line by developing a **simple** AR system to display the **real-time** advanced medical information. Our approach has three distinctive elements.

(i) We focus on the ultrasonic image because it has a real-time nature and most hospitals have ultrasonic diagnostic machines.

(ii) We use the ultrasonic image as the key data to select and modify the advanced medical information.

(iii) We utilize the fact that the ultrasonic probe moves inside the doctor's field of view and within the accessible range of the arm in order to simplify the AR system.

Figure 1 shows the architecture of our final goal. Our system is made by the simple combination of the image processing PC, the camera and marker combination used as a 3D position sensor, and the see-through head mounted display (HMD). Our system is connected to the conventional ultrasonic diagnostic equipment via the external video output and the advanced medical information server via the internet.

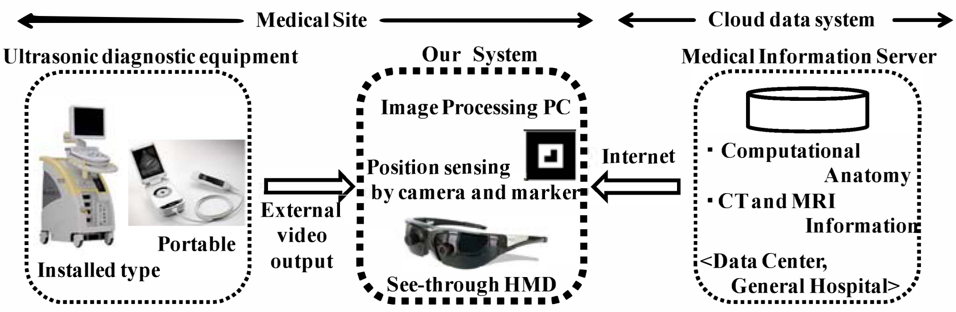


Fig. 1. System Architecture of Our Final Goal

II. Related Works and Prototype System

A. Related Works

A lot of research has been conducted to develop a ICT-based medical support system. Some systems have utilized ultrasonic images because of their simplicity and the real-time nature [2, 5-8]. Some systems have been built on the basis of AR technology [4, 9-10]. As pointed out above, the problems of ***"generation"*** and ***"display"*** remain. For example, Hansen et al. [1] show them in case of liver surgery.

B. Prototype System

Our final goal is shown in Fig. 1. To achieve it, we apply the three distinctive elements of our approach listed above, i.e., *(i) focus on ultrasonic images, (ii) select and modify on the basis of ultrasonic images, and (iii) simplify equipment by utilizing characteristics of ultrasonic probe operation.*

We have developed the prototype system to verify the feasibility of (iii) as the first step toward our final goal [3].

In the following sections, we describe the design process of the prototype system in detail.

III. TWO PRELIMINARY EXPERIMENTS

The following two preliminary experiments were done to evaluate the feasibility of (iii) quantitatively.

A. Experiment 1 of ultrasonic probe operation

Figure 2 shows the Experiment 1 setup. Two magnetic 3D sensors (Liberty: Polhemus) were attached to the doctor's glasses and the ultrasonic probe to measure accurately the 3D position of the doctor's eye and the probe. The doctor was asked to examine the liver by using the ultrasonic imaging machine.

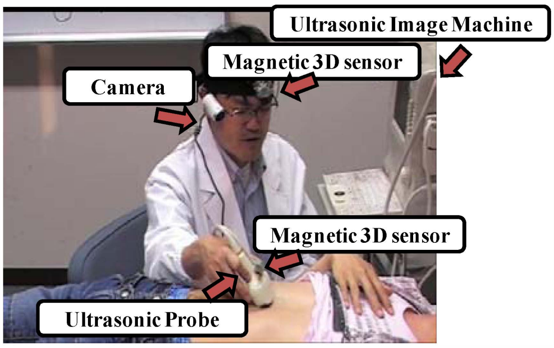


Fig. 2. Setup of Experiment 1.

Figure 3 shows the distance between the doctor's eye and the probe during the liver examination. We found that the distance was between 20 cm and 80 cm.

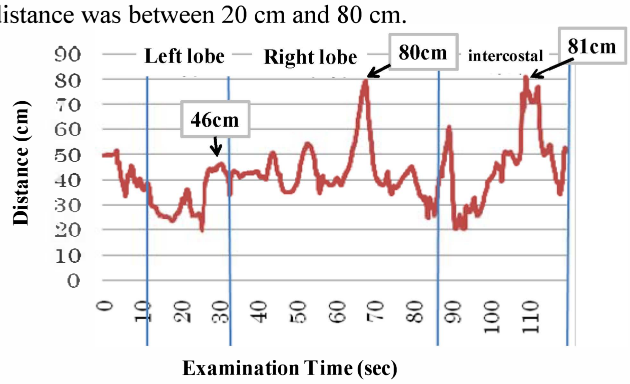


Fig. 3. Distance between doctor's eye and probe.

A camera was also attached to the doctor's glasses to find out whether the probe stays in the doctor's field of view. Figure 4 shows the results. We found that the probe stayed in the camera's field of view during the examination.

The results suggest that the simplest way to use the AR system was to attach the visual marker (i.e. AR- marker) to the probe and the camera to the doctor's glasses. Since the camera can constantly focus on the visual marker, the relative 3D position to the probe can be calculated by simple image possessing.

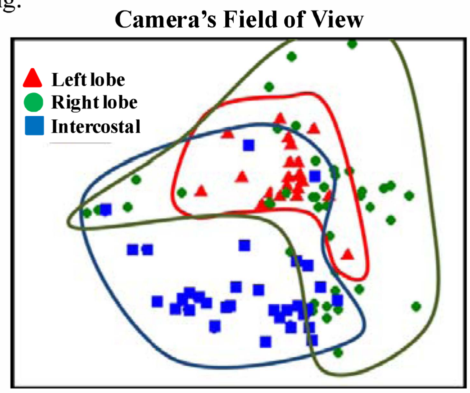


Fig. 4. Probe's position in camera's field of view

B. Experiment 2 of accuracy of image processing

Figure 5 shows the Experiment 2 setup. The accuracy of the 3D position was evaluated from a 16-86 cm distance and at a 0-80 degree inclination. In the experiment, we used the AR-tool kit to calculate the 3D position by image processing of the marker [11, 12].

Because the distance is limited to a small area (16-86 cm), the accuracy was high enough for the medical examination. Moreover, it was robust against the inclination. It successfully worked up to an 80-degree inclination of the marker.

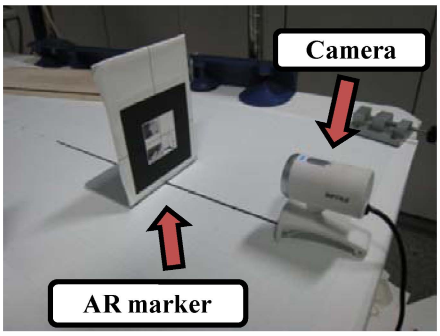


Fig. 5. Setting of Experiment-2

IV. PROTOTYPE AR SYSTEM

A. Basic Architecture

The fundamental function of the prototype AR system is to display the ultrasonic image at exactly the same plane in the body of the patient. The ultrasonic image is the standard 2D picture shown Fig. 6. Thus, the doctor can watch the ultrasonic image of the inside of the patient's body as if the screen (i.e. Fig.6) were inserted into the organ at the scanned plane.

Figure 7 is the simplest realization of the prototype based on the analysis of the previous section. The doctor wears a see-through 3D HMD with a camera. The AR-marker is attached to the ultrasonic probe. One camera and marker combination detects the relative 3D position between the doctor's head and the probe. The ultrasonic image can show exactly the same plane in the body of the patient only at the relative 3D position because the current ultrasonic image at the top of the probe can be displayed.

Fig. 6. Example of 2D ultrasonic image.

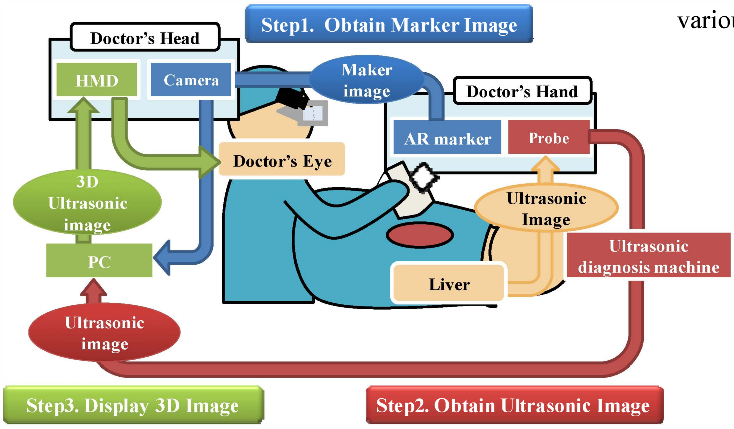


Fig. 7. Simple architecture using see-through HMD and single camera and marker combination.

B. 3D slice image display and 3D volume data display

Fundamental functions can be achieved by the architecture in Fig. 7. However, sometimes it is necessary to generate the volume data and display it by volumetric visualization.

Therefore, our prototype system must support the three tasks shown in Fig. 8. The doctors usually check the real-time 3D slice data showing the inside of the patient's body. They may find something wrong in the cross-section image of a blood vessel, so they will want to scan the slice data by moving the probe and viewing them as volumetric visualization. In the example in Fig. 8, the network of the blood vessels is recognized and displayed by the volumetric visualization.

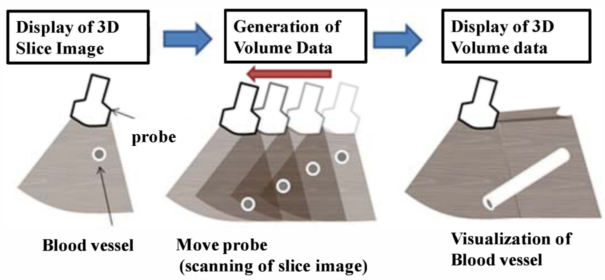
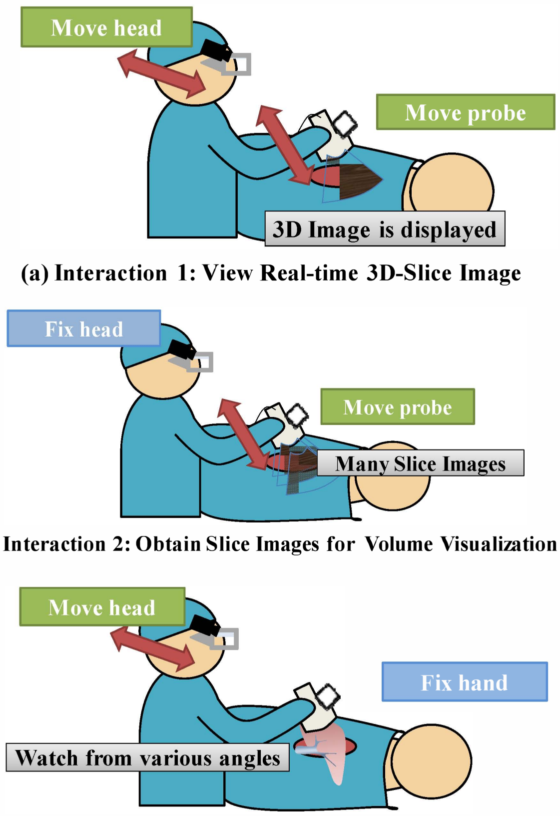


Fig. 8. Necessity of 3D Volumetric Visualization.

C. Three Interaction Modes

It is impossible for only a camera and marker combination to handle the three tasks (Fig.8). To overcome this, we devised three interactions. The idea is very simple, but it enables the volumetric visualization to compensate for the limitations. The interactions are summarized in Fig. 9. Interaction 1 is the normal mode. The doctors can move their heads and the probe freely. The current ultrasonic image is displayed at the top of the probe as a 3D image. Interaction 2 is for the scanning. In this interaction, the doctors must fix their heads and move the probe to obtain several slice images. Because the head is fixed, the series of the slice data can be reconstructed as volumetric data. Interaction 3 is for viewing the volumetric data. In contrast to Interaction 2, the doctors have to fix the probe and can move their heads to watch at the various angles.



(a) Interaction 1: View Real-time 3D-Slice Image

(b) Interaction 2: Obtain Slice Images for Volume Visualization

(c) Interaction 3: Visualize 3D-Volume Data

Fig. 9. Three Interactions for Volumetric Visualization.

V. Evaluation

A. Overall Evaluation by Doctor

The prototype has been developed as shown Fig. 10 to check the effectiveness of our system. The 3D-HMD is Z800 3D Visor. The camera is a cheap web camera.

In the experiment, first, the doctor familiarized himself with all the functions of the prototype system and then asked to examine the liver of the subjects.

We were afraid of trouble in the three interaction modes and poor visibility of the see-through HMD. However, unexpectedly, we received quite positive comments from the doctor about the usability of the three interaction modes as well as the overall effectiveness of the prototype system. The doctor said "I could feel the blood pulse when I touched on the displayed vessel" and "I'd like to use it in my hospital".

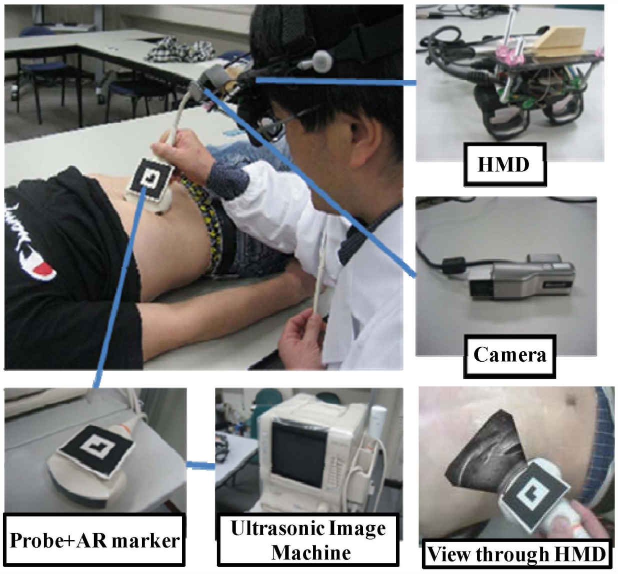


Fig. 10. Current Prototype System.

B. *Stability of 3D position sensing*

The 3D position sensing of the prototype system depends on the single camera and marker combination. Flickers were observed when the 3D position sensing failed. We counted the occurrences of the flickers during each five-second period and then added them up. Experiments were done for each of the three tasks (Fig.8 (a),(b) and (c)) several times. No flicker was observed in task (b). Therefore, Fig. 11 shows one set of task (a) data and six sets of task (c) data. On average, no flicker was observed in more than 60% of any time period. This proved the stability of 3D position sensing.

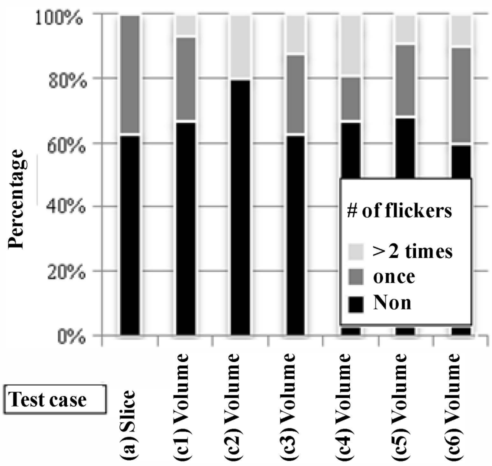


Fig. 11. Flicker caused by 3D position sensing failure.

VI. CONCLUSIONS AND FUTURE WORKS

Due to the rapid development of ICT, the significant progress has been made in both the ***"generation"*** and ***"display"*** of the advanced medical information.

However, serious problems still remain in both the ***"generation"*** and ***"display"*** of the advanced medical information.

To overcome with these problems, we applied the three distinctive elements to our approach: *(i) focus on ultrasonic image, (ii) select and modify on the basis of an ultrasonic image, and (iii) simplify equipment by utilizing characteristics of ultrasonic probe operation.*

The prototype was achieved by using only a see-through HMD and single camera and marker combination. Three simple interaction methods compensated for the limitations in 3D position sensing.

The doctor who tested it commented quite positively on the usability of the three interaction modes as well as the overall effectiveness of the prototype system. Moreover, the stability of 3D position sensing was proved by the quantitative data.

We are now extending the prototype system to meet the requirements of our final goal.

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