Development of Pseudo 3D Visualization System by Superimposing Ultrasound Images

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Abstract

This paper presents the development of pseudo 3D visualization system of organs using 2D ultrasound images for a new medical instrument. The new instrument consists of an ultrasonic endoscope and an electro-magnetic measurement sensor. The pseudo 3D volume is reconstructed by superimposing ultrasound images captured by the ultrasonic endoscope. So the new instrument shows not only the surface of organs, but also the 3D volume of inside of organs. However, it was reported that the ultrasound probe influenced the accuracy of the sensors, so it is necessary to investigate the influence of the ultrasound endoscope to the sensor. In this paper, we propose a 3D volume reconstruction system using 2D ultrasound images, and show experimental results of accuracy measurement experiments of two kinds of electro-magnetic measurement sensors and 3D visualization with actual ultrasound images.

1. Introduction

Endoscopic surgery is a minimally invasive surgical operation compared with the conventional surgical operation, so it has been widely applied for a favorable postoperative process. However, it requires a higher level of surgical skills than conventional operations, such as sophisticated use of endoscopic instrument. Moreover, since the field of operation provided by the endoscope is limited, for secure endoscopic surgery, enough preoperative preparation is indispensable.

To reduce the load placed on the surgeon before and during the surgery, we are now developing an intelligent medical instrument, which consists of an ultrasonic endoscope. The ultrasonic endoscope, which consists of an endoscopic camera and ultrasound probe placed at the tip of the endoscopic camera, enables to capture images of both surface and inside of organs. As one of systems of the new instrument, pseudo 3D volume data is reconstructed in real-time by superimposing ultrasound images captured by the ultrasonic endoscope. So the new instrument shows not only the surface of organs, but also the 3D volume of inside of organs. In this paper, we propose a pseudo 3D visualization system of organs using 2D ultrasound images.

A lot of methods for 3D reconstruction and volume rendering of 2D ultrasound images have been proposed so far [1] [2]. However none of these methods use ultrasound images captured by the ultrasonic endoscope. Moreover, although a 3D ultrasound camera is recently used instead of the 2D ultrasound camera [3] [4], it is not enough small to be placed at the endoscopic camera.

The proposed system consists of an ultrasonic endoscope, an electro-magnetic measurement sensor which are placed at the tip of an endoscope, and a software for pseudo 3D visualization. To reconstruct the 3D volume data, ultrasound images are captured by the ultrasonic endoscope, and the position and orientation of the ultrasound probe are measured by the electro-magnetic measurement sensor simultaneously. And then the pseudo 3D volume is visualized by the software. However, Hastenteufel $et al.$ showed that the ultrasound probe influenced the accuracy of the sensor [5]. So it is necessary to investigate the influence of the ultrasonic endoscope to the sensor. In this paper we investigate the accuracy of electro-magnetic measurement sensors for endoscopic ultrasonography.

This paper is organized as follows. Section 2 describes the system configuration for pseudo 3D visualization. Section 3 shows the results of accuracy measurement experiments of electro-magnetic measurement sensors for endoscopic ultrasonography, and a pseudo 3D visualization experiment with real ultrasound images.

2. System configuration for pseudo 3D visualization

In this section, we describe the proposed pseudo 3D visualization system. This system consists of an ultrasonic endoscope, an electro-magnetic measurement sensor which are placed at the tip of an endoscope, and a software for pseudo 3D visualization. Figure 1 shows the flow of the pseudo 3D visualization with the proposed system. Firstly, ultrasound images of the stomach wall are captured by the ultrasonic endoscope. At the same time with the ultrasound images, the position and orientation of the ultrasound probe are measured by the electro-magnetic measurement sensor. The captured images and the measured pose are sent to the software, and then the 3D volume is reconstructed by superimposing the images whose pose are changed based on the measured pose. Finally, the pseudo 3D volume is visualized by volume rendering. Details are explained in the following sections.

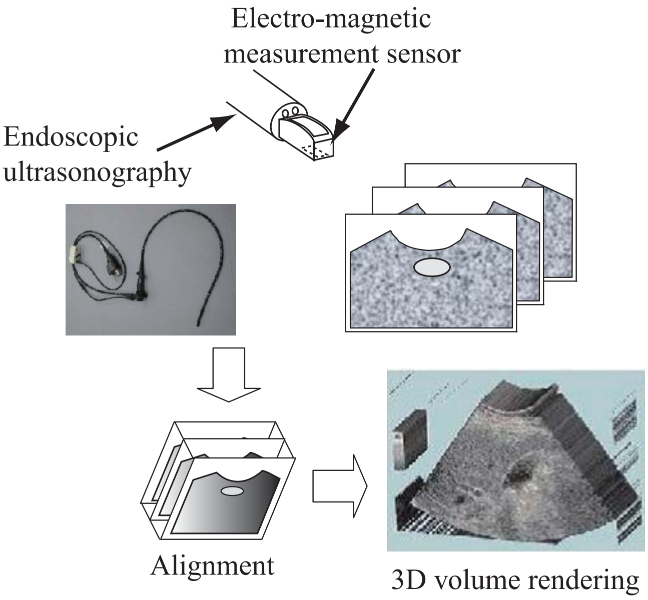


Figure 1. Flow of the pseudo 3D visualization.

2.1. Ultrasonic endoscope

The ultrasonic endoscope (EG-3870UTK, Hoya) as shown in Fig. 2, which consists of an endoscopic camera and ultrasound probe placed at the tip of the endoscopic camera, enables to capture images of both surface and inside of organs. Figure 3 shows endoscopic and ultrasound images, and surgeons provide diagnosis by using these images.

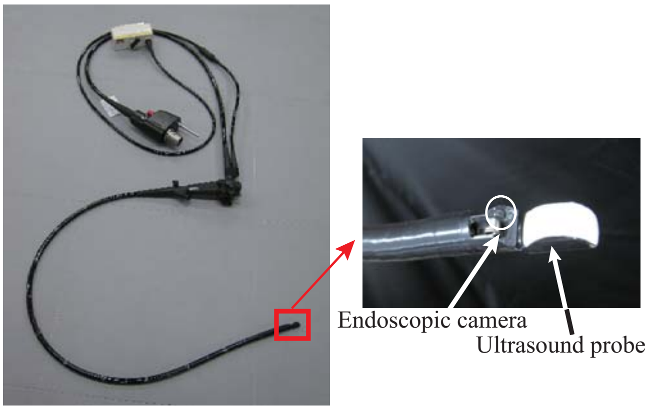


Figure 2. Ultrasonic endoscope (G-3870UTK, Hoya)

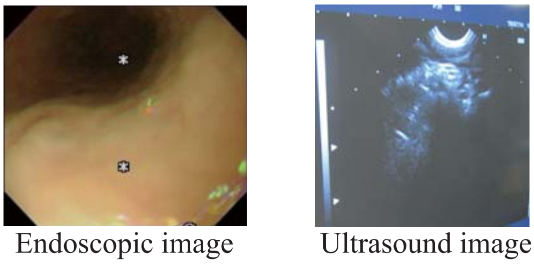


Figure 3. Examples of Endoscopic and ultrasound images

2.2. Electro-magnetic measurement sensor

The electro-magnetic measurement sensor consists of a transmitter and receiver sensors, and the position and orientation of sensors are measured in a coverage area where the electro-magnetic field of the transmitter is generated. In this paper, we use two electro-magnetic measurement sensors which can measure 6 degree of freedom (DOF), and those are Aurora (Northern Digital Inc., Canada) and Mircrobird (Model 180, Ascension Technology Co. USA). Figures 4 and 5 show the transmitter and the electronics unit of Aurora and Microbird respectively. The coverage area of Aurora and Microbird are 500 $\times$ 500 $\times$ 500 [mm^3] (x=0 to 500 [mm], y=-250 to 250 [mm], z=-250 to 250 [mm]

from the transmitter origin), and $400 \times 400 \times 360$ $[mm^3]$ (x=-200 to 200 $[mm]$, y=-200 to 200 $[mm]$, z=100 to 460 $[mm]$ from the transmitter origin), respectively.

2.3. Software for pseudo 3D visualization

We use VirtualPlace SDK (AZE) as a software for 3D visualization, which is a medical software for clinical application, and we develop a software for 3D visualization as a plug-in software for VirtualPlace. For visualization of 3D volume, we use volume rendering method [6], and one of the typical techniques for volume rendering is ray casting. In this method, the 3D volume is equally divided into small voxels, and color and transparency in each voxel are determined before rendering the 3D volume on a view plane. For each pixel on the view plane, a ray is cast through the 3D volume along the viewing direction, and then the color at each pixel of the view plane is determined based on colors and transparencies in voxels along the ray.

To develop this system, we determine the color and transparency in each voxel by superimposing ultrasound images capture by the ultrasonic endoscope. To impose images, we transform the pose of each image from the sensor coordinate to transmitter coordinate as shown in Fig. 6. $\sum^O$, $\sum^S$, and $\sum^U$ show the transmitter coordinate, the sensor coordinate, and the ultrasonic endoscope coordinate, respectively The pose ${}^U D$ of each ultrasonic endoscope is transformed as followings.

$$ {}^O D = {}^O T_S + {}^O R_S \times {}^S T_U + {}^O R_U \times {}^U D \quad (1) $$
$$ {}^O R_U = {}^O R_S \times {}^S R_U \quad (2) $$

Here, R and T are transform matrices of orientation and position, respectively, and $({}^S R_U, {}^S T_U)$ is a transform matrix to change the pose from $\sum^S$ to $\sum^U$.

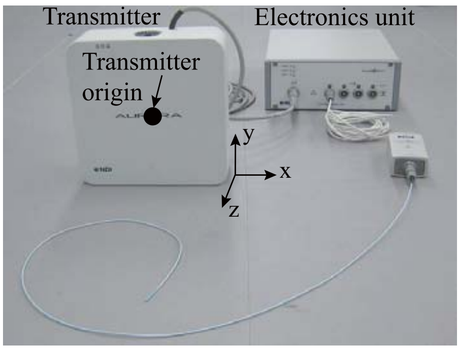


Figure 4. Transmitter and electronics unit of Aurora

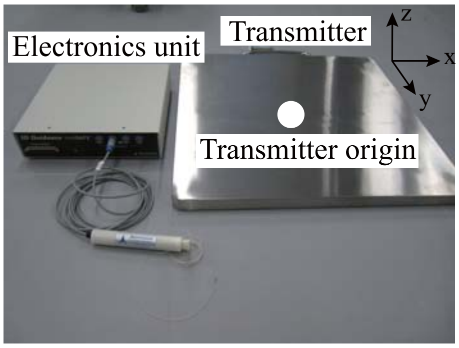


Figure 5. Transmitter and electronics unit of Microbird

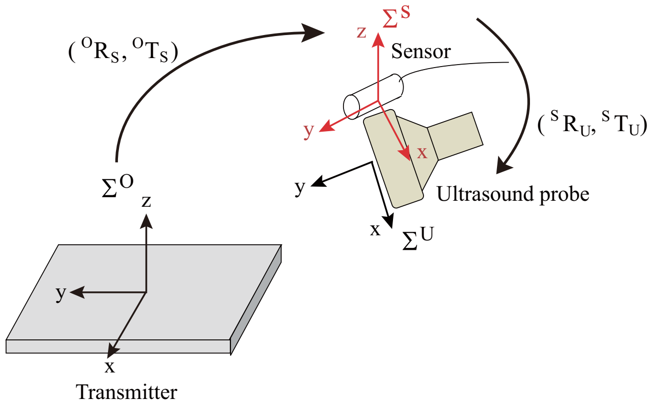


Figure 6. Coordinate transform

3. Experiments

In this section, we describe results of accuracy measurement experiments of electro-magnetic measurement sensors for endoscopic ultrasonography, and a pseudo 3D visualization experiment with real ultrasound images.

3.1. Accuracy measurement of electro-magnetic measurement sensors

In this section, we carried out the accuracy measurement experiments of electro-magnetic measurement sensors for endoscopic ultrasonography to investigate the influence of the probe to the sensor. In these experiments, the electro-magnetic measurement sensor was placed at the tip of the endoscopic ultrasonography, and then the endoscopic ultrasonography was placed at the tip of a high-precision mechanical measurement sensor (microcord C604, Mitsutoyo) as shown in Fig. 7. The accuracy of the electro-magnetic measurement sensor was measured by the following ways: (i) changing the position of the mechanical sensor, (ii) turning on or off the endoscopic ultrasonography. The position was changed 80 times with respect to each 100 [mm] along the x, y, z-axis as shown in Fig. 8, and the area where the sensor moved was $300 \times 400 \times 300$ [mm^3].

The root mean square error (RMSE) and the standard deviation (SD) are calculated as shown in Tables 1 and 2. To apply this system to clinical applications, the RMSE should be less than 2 [mm] which is based on the size of sentinel lymph-node. Although the RMSE with 80 positions is higher than 2 [mm], it would be smaller near the transmitter. Figure 9 shows RMSE at each measured position, and it can be seen that the RMSE at position near the transmitter is smaller than that away from the transmitter. So we calculated the RMSE and SD with 12 positions near the transmitter. As shown in Tables 3 and 4, the RMSE is around 1 [mm], therefore it can be said that both Aurora and Microbird can be used as the sensor for the proposed pseudo 3D visualization system.

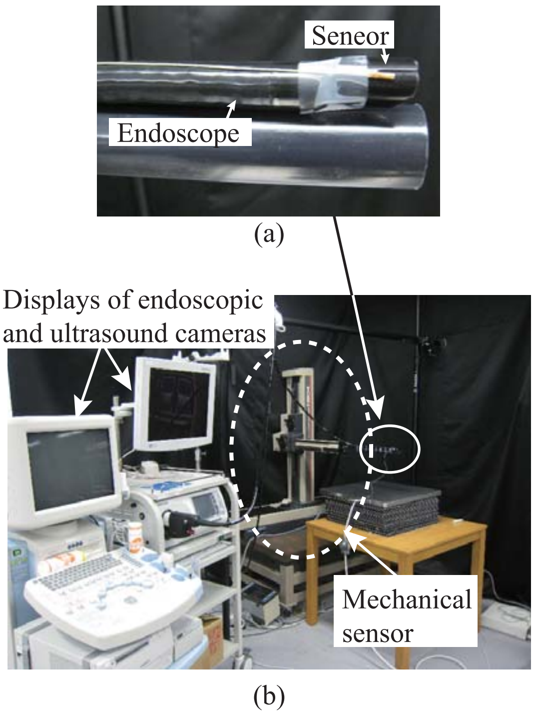


Figure 7. System configuration for accuracy measurement

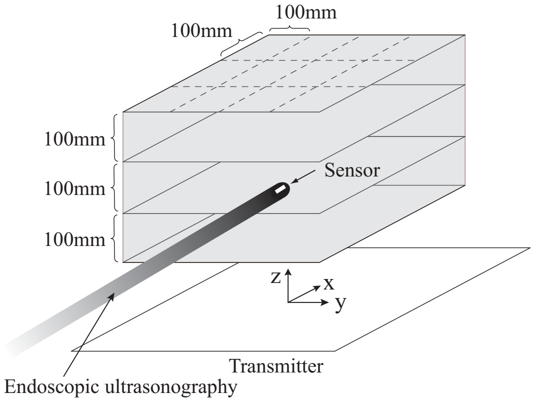
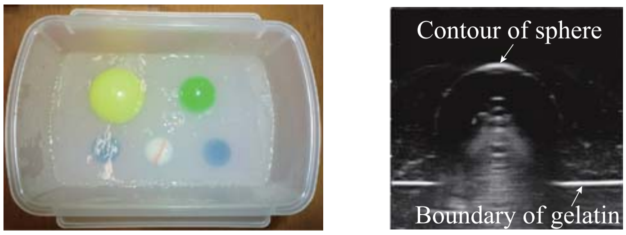


Figure 8. Measurement area

3.2. Pseudo 3D visualization using real ultrasound images

In next experiment, we applied the proposed system to real ultrasound images. In this experiment, we used a glass sphere in Japanese gelatin (Fig. 10 (a)) and visualized the 3D volume of the sphere. The number of captured images was 30 images, and Fig. 10 (b) shows an example of captured ultrasound images. Figure 11 shows the result of 3D visualization, and in this figure a boundary of the gelatin and a contour of the sphere are shown. However, the contour is not clear due to the scattered ultrasound.



(a) Glass sphere in Japanese gelatin (b) Ultrasound image

Figure 10. Glass spheres and an example of ultrasound images

4. Conclusion

This paper described a pseudo 3D visualization system for a new intelligent medical instrument. The proposed system consists of an ultrasonic endoscope, an electromagnetic measurement sensor, and a software for pseudo 3D visualization. We investigated the influence of the ultrasonic endoscope to the sensor, and showed that the both

	Microbird	Aurora
Ultrasound OFF	2.04	3.15
Ultrasound ON	2.12	3.11

Table 1. Root mean square error with 80 positions [mm]

	Microbird	Aurora
Ultrasound OFF	0.42	0.26
Ultrasound ON	0.71	0.30

Table 2. Standard deviation with 80 positions [mm]

	Microbird	Aurora
Ultrasound OFF	1.05	0.86
Ultrasound ON	1.09	0.87

Table 3. Root mean square error with 12 positions [mm]

	Microbird	Aurora
Ultrasound OFF	0.27	0.04
Ultrasound ON	0.42	0.05

Table 4. Standard deviation with 12 positions [mm]

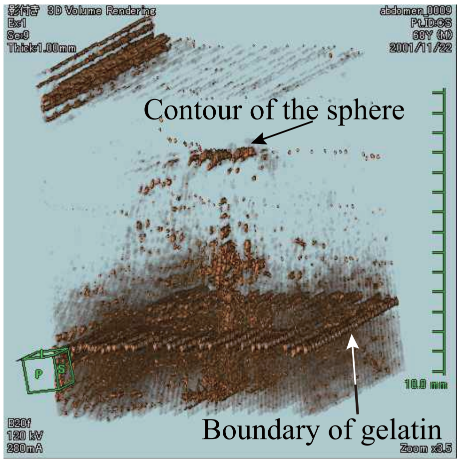


Figure 11. Result of 3D visualization

electro-magnetic measurement sensors, Aurora and Microbird, can be used as the sensor for the proposed pseudo 3D visualization system. As a future work, we will apply the proposed system to a phantom organ.

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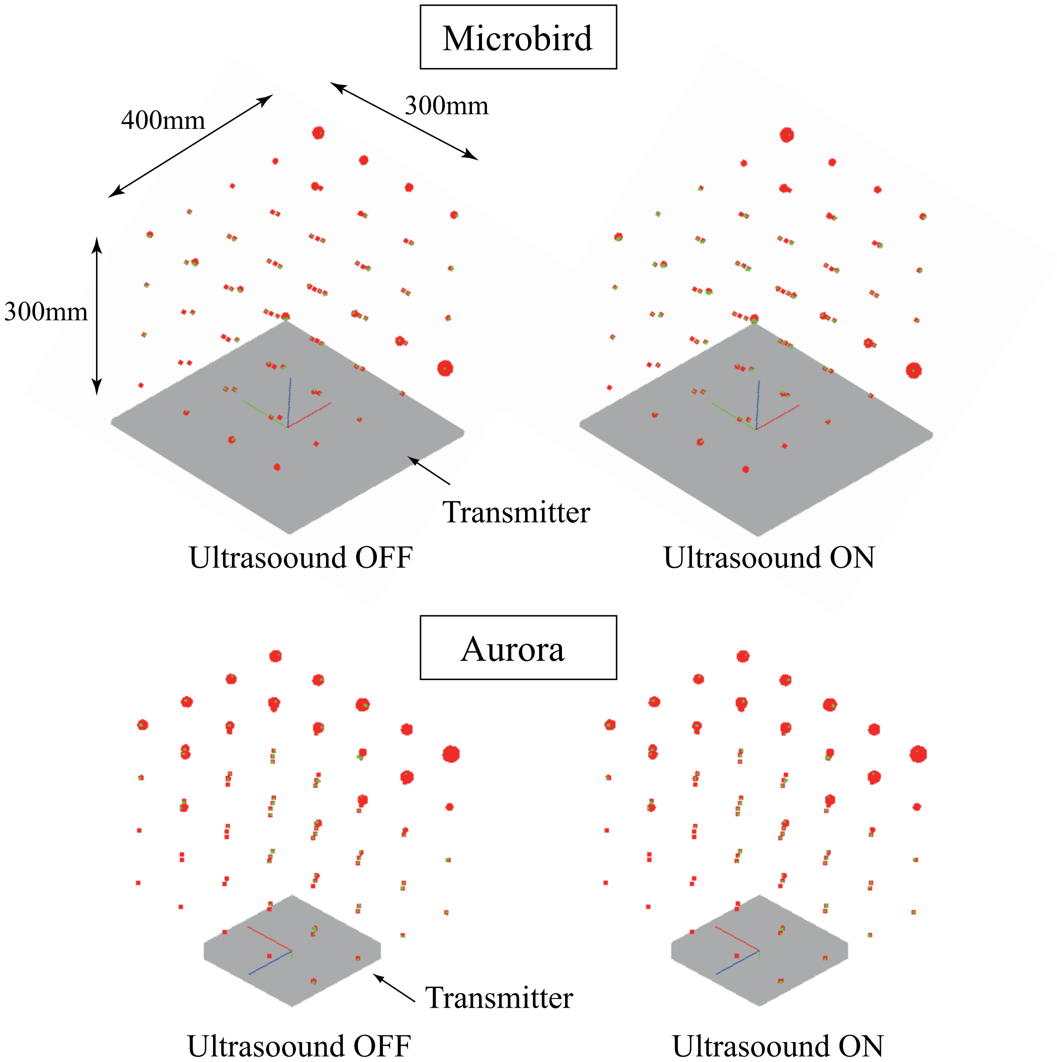

Figure 9. Root mean square error