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Verification of ultrasonic image fusion technique for laparoscopic surgery

超音波を用いた腹腔鏡手術支援システムにおける画像統合法の検討

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1. Introduction

Laparoscopic surgery is less-invasive operation compared with general abdominal operation. In the laparoscopic operation, information of operative field is provided to operators as a narrow visual field image from laparoscope. Additionally, laparoscopic surgery is one of the most difficult operation for operator, since neither depth nor inside information of internal organs which is the target for the operation are understood. In recent years, a new laparoscopic surgery technique was proposed by Prof. Igarashi at Chiba University. This technique is called water filled lapaloscopic surgery (Wafles)[1]. The most characteristic feature of this surgery technique is inside of the abdominal cavity filled with liquid as a substitute for gas in undergoing the operation. One of the advantage of this surgery technique is the high possibility of observation of 3-D structures of organs using ultrasonic diagnostic equipment from body surface. In our previous research, we proposed a overlap display system of a 3-D ultrasonic image and a 3-D laparoscope image for the aid of presentation of the detailed information of a treated area and the guiding of surgical instruments in laparoscopic surgery[2]. The 3-D registration of the two different imaging modalities was performed using the iterative closest point (ICP) algorithm[3] based on the surface shape of the internal organs. The 3-D surface shape of an internal organ was observed by stereo laparoscope, and the detail structure of inside of same organ was observed by ultrasonic diagnostic equipment. It was possible to understand the structure on a treated area by low invasive observation method by overlapping two 3-D images(**Fig.1**).

In this study, the availability of proposed system was verified by measuring the registration accuracy of an optical surface shape image and an ultrasonic surface shape image with *in vitro* experiment with tissue mimicking phantom. The verification was the registration accuracy was performed with optical surface image and two different kind of ultrasonic surface image. Ultrasonic surface images are acquired by two types of US probes, an usual 1-D array convex probe (2-D probe) and a mechanical moved convex probe (4-D probe). It is imagined that using 4-D probe which can be easily acquired 3-D ultrasonic image at high speed is useful for aid of laparoscopic operation.

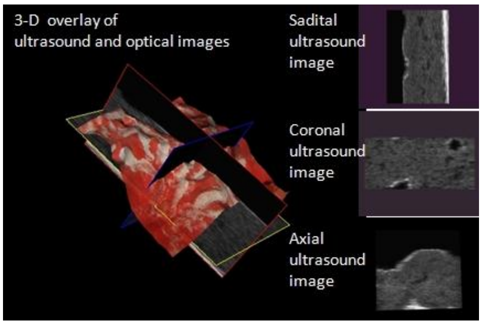

Fig. 1 overlap display system of 3-D ultrasonic image and 3-D laparoscope image

2. Method

In our method, the 3-D surface shape of internal organs is observed by a stereo laparoscope. The surface shape of the target organ can be reconstructed by 3-D nonlinear deformation of two optical images with the principle of the triangulation. In this study, we used simplified method from 3-D reconstruction method proposed by Okada et al to reconstruction of the surface shape[4]. This method is performed by multi-resolution decomposition, piecewise bilinear maps and block matching for search of corresponding points.

A volumetric ultrasonic image is acquired by ultrasonic diagnostic environment using usual 2-D probe and 4-D probe. A volumetric ultrasonic image is built from the number of B-mode images accumulated by usual 2-D probe from body surface. The other one is acquired as single frame of 4-D ultrasonic data by the 4-D probe. In, both 3-D images it is possible to understand the surface shape

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and the structure of the internal organ.

The registration of optical 3-D image and ultrasonic 3-D image is performed by ICP algorithm based on the conformity of surface shapes of internal organs of both image. The mean square error of distance of manually selected point from optical and ultrasonic surface images is used for the verification of registration accuracy.

3. Experiment

We verified registration accuracy by *in vitro* experiment with a tissue mimicking phantom. The phantom was put into the water tank that filled with the water shown as **Fig. 2**.

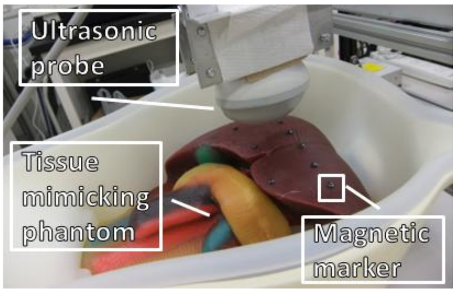

Fig. 2 experiment environment with tissue mimicking phantom

Two optical images were acquired from two different positions by moving a commercial optical digital camera in parallel direction like as the stereo laparoscope. The distance of the central position between two optical images and the size of each optical image were 5 mm and 135 × 100 mm in 640 × 480 pixels, respectively. A 3-D ultrasonic image was built from 250 slices of ultrasonic B-mode images acquired at a 0.4 mm step by a 2-D probe of 5.5 MHz center frequency. The other 3-D ultrasonic image was acquired as single frame obtained by 4-D probe in same angle from 2-D probe. The size of the 3-D ultrasonic image of 2-D probe which uses to build surface shape was 93.3 mm in lateral × 9.3 mm in depth of each slice image and 100.0 mm in slice direction. 2-D surface lines of the phantom were extracted from each slice of ultrasonic image and the 3-D surface shape was constructed by 250 2-D lines. In the case of 4-D probe, the size of 3-D ultrasonic image which uses to acquire surface shape was 77.8 mm in lateral × 14.8 mm in depth × 39.3 mm in slice direction. 2-D surface lines were extracted from each separated slice image from single frame and 3-D surface shape was constructed by 160 2-D lines.

The verification of registration accuracy was calculated as mean square error of a distance of marker pasted on phantom surface. Marker was ferrite magnet and the size of marker was 5.25 mm in diameter, 2.5 mm thick. Marker position was manually selected from each 3-D surface image. Number of marker was decided along with acquired surface shape size. Three markers and five markers were chosen in 2-D probe case and 4-D probe case, respectively.

4. Result

The constructed 3-D surface shape image using visualization tool kit (Kitware Inc.) is shown in **Fig. 3**. The surface shape of almost same area of phantom can be constructed. The calculated mean square error and standard deviation in 3-D image registration is shown in **Table 1**. SD of 4-D probe case was large though MSE was comparable value from 2-D probe case.

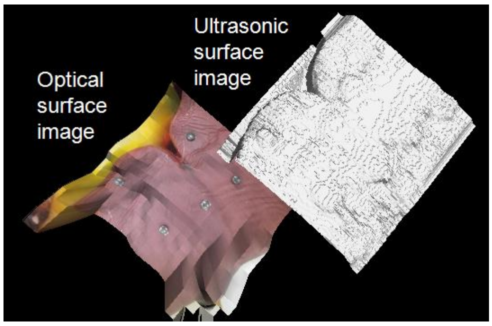

Fig. 3 3-D surface images of optical and ultrasonic before registration

Table 1 registration accuracy with optical surface image

	MSE [mm]	SD [mm]
Using 2-D probe	11.0	2.89
Using 4-D probe	11.2	5.50

5. Conclusion

The standard deviation of registration result between optical image and ultrasonic image is large in the case of 4-D probe compared from 2-D probe. It may be caused from that the viewing range of 4-D probe is narrower than 2-D probe. If the target organ does not have feature texture pattern, reconstruction accuracy of optical surface shape is low. Therefore, narrow viewing range will become a reason of low accuracy. However, since mean square error in 4-D probe case is equivalent to 2-D case, it is also expected that precision sufficient by 4-D is acquired with devising processing of the optical image.

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