Proposal of transesophageal echo examination support system by using CT image

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Abstract. Transesophageal echocardiography and CT imaging have used to provide definite diagnosis of cardiac diseases such as angina and myocardial infarction. Transesophageal echocardiography has performed by manually adjusting probe depth and the ultrasound irradiation angle while referring to the echo image. However, it is difficult to grasp the three-dimensional (3D) position of the heart only with echo images. Moreover, it takes a long time and puts a heavy burden on patients and doctors. Therefore, we propose a new method in order to create a preoperative plan smoothly. This method replaces conventional transesophageal echocardiography with CT images. Our system can inspect CT images interactively, and the examination time is shorter and there is no burden on the patient compared to transesophageal echocardiography.

1 Introduction

Transesophageal echocardiography is a method of providing definite diagnosis of cardiac diseases such as angina and myocardial infarction. Transesophageal echocardiography has performed by manually adjusting probe depth and the ultrasound irradiation angle while referring to the echo image. The doctor operates the probe while checking the condition of the patient. The probe is capable of rotating the back and forth and side curved knobs, clockwise and counterclockwise. The echo image by transesophageal echocardiography has generated using the ultrasonic echo from the tip of the probe inserted in the esophagus.

However, echo images have low image quality, and it is difficult to capture the position and shape of parts accurately. Moreover, it takes a long time and puts a heavy burden on patients and doctors. Therefore, we propose a new method in order to create a preoperative plan smoothly. A more accurate diagnosis can be realized by creating a pseudo echocardiogram from the CT image. Moreover, transesophageal echocardiography is invasive to the patient. If transesophageal echocardiography can be replaced by CT images, the direct invasion to the patient and burden on the doctor and can be reduced, which is a great advantage.

Our paper is organized as follows. Section II introduces our virtual transesophageal echo examination support system that we proposed. The image filtering algorithm for echo cardiogram display is explained in Section III. We explain how to operate pseudo probe in our system in Section IV. Section V details our evaluation and its result. Section VI concludes the paper with a summary and view on future work.

2 Transesophageal echo examination support system

This section introduces our transesophageal echo examination support system. The system has the following functions; 1) Display of CT section imitating echocardiogram echo image, 2) Presentation of echo display location on volume rendering display, and 3) Measurement on a pseudo echocardiogram from the CT image. Fig.1 shows the user interface.

Display of CT section imitating echocardiogram image

The echocardiogram image is a fan-shaped image centered on the probe position shown in Fig.1. This system imitates echocardiogram and generates a CT cross-section (hereafter referred to as CT echo image) of specified range and angle from the virtual probe position. By using this function, it is possible to facilitate the correspondence between echocardiography and CT echo images.

Presentation of echo display location on volume rendering display

This function displays the area currently displayed by beam simulation has displayed in the same three-dimensional (3D) space as the volume rendering display shown in Fig.2. By using this system simultaneously with the actual echocardiography, it becomes possible for the doctor to accurately grasp the current position of the probe being operated in three dimensions. However, there are cases in which CT echo images become difficult to read depending on the state of volume rendering and the position of the probe. Therefore, we extended the function that the doctor could optionally set the transparency and transfer function of volume rendering.

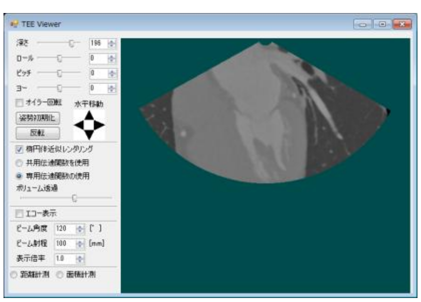

Fig. 1 User interface of our system

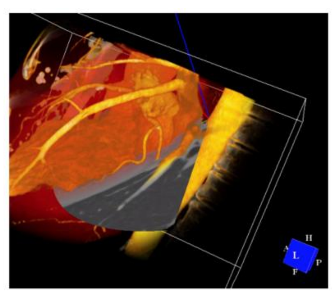

Fig. 2 Echo display location on volume rendering display

Measurement on a pseudo echocardiogram from the CT image

This function can measure the distance and the area on virtual echo image (That is, CT image cut at an arbitrary plane) shown in Fig. 3. These figures have currently displayed on the unit of mm. The start and end points for distance measurement can be displayed on virtual echo images on volume rendering. In this system, the user designates an area with a line segment on the virtual echo image, and automatically calculates the area of the enclosed area.

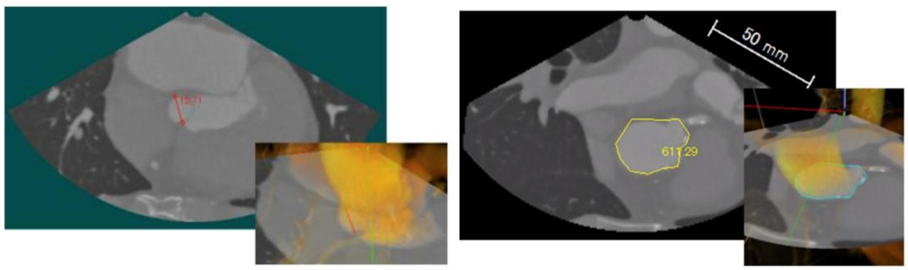

Fig. 3 Virtual echo image and measurement (distance and area)

3 Image filtering algorithm for echo cardiogram display

Even if the same region has displayed, echocardiography and CT images look completely different. By filtering the CT image and making it close to the echocardiographic image, the echocardiographic image and the CT image can be easily contrasted. The structure of this image filter is as follows. Let *k* be the position of the starting pixel of the beam in the pseudo echo image generated on the two-dimensional image, (x , y) be the position of an arbitrary pixel, and $c\ (x\ ,\ y)$ be the luminance value of that pixel. According to Eq. (1), the distance of k and (x , y) can be calculated.

$$l = \sqrt{(x_k - x_c)^2 + (y_k - y_c)^2} \tag{1}$$

The sampling range n is calculated by using Eq. (2). n is proportional to l. Therefore, a wider range of sampling is performed for pixels far from the beam center. w is the width of the pseudo echo image, and the unit is pixel. A sampling interval s of this filter is calculated.

$$n = \begin{cases} \left\lfloor 10\frac{l}{w} \right\rfloor^2 & \left\lfloor 10\frac{l}{w} \right\rfloor^2 \%2 = 1 \\ 3 & \left\lfloor 10\frac{l}{w} \right\rfloor^2 < 3 \\ \left\lfloor 10\frac{l}{w} \right\rfloor^2 + 1 & \left\lfloor 10\frac{l}{w} \right\rfloor^2 \%2 = 0 \end{cases} \tag{2}$$

$$s = \begin{cases} \left\lfloor \frac{n}{r} \right\rfloor & \frac{n}{r} \geq 1 \\ 1 & \frac{n}{r} < 1 \end{cases} \qquad (3)$$

Here, r is a constant. As s approaches *1*, a smoother image is obtained. *P* is defined as Eq. (4). The pixel c ' is calculated by Eq. (5).

$$P = \frac{n-1}{2s} \qquad (4)$$

$$c'(x, y) = \frac{\sum_{i=-P}^{P} \sum_{j=-P}^{P} c(x+si, y+sj)}{(2P+1)^2} \qquad (5)$$

This is a smoothing filter with a sampling interval *s*, in which the range in *x* and *y* directions is [- *Ps; Ps*]. The difference in the results when the sampling interval is changed has shown in Fig. 4 and Fig. 5. This filter reproduces a state in which the intensity has extended in the direction away from the probe position as in an original echo image shown in Fig. 6. This smoothing filter is fast and suitable for interactive operation.

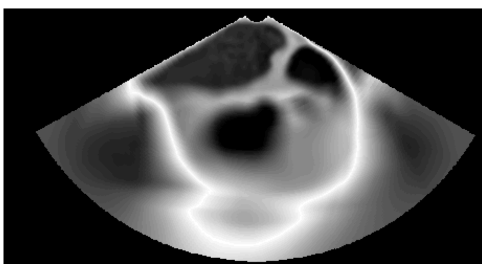

Fig. 4 Case of sampling with high density

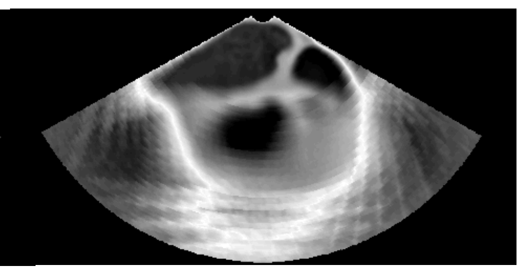

Fig. 5 Case of sampling with low density

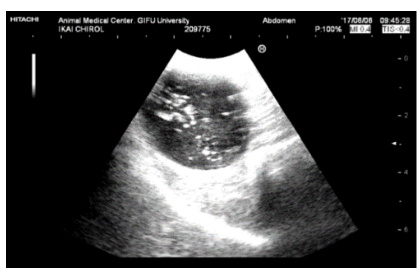

Fig. 6 Original echo image

4 Pseudo probe operation

4.1 Position specification

Fig. 7 shows an image of actual probe movement and how it is handled in this system. Probe operation includes movement in the depth direction, movement on the CT slice, and rotation of the beam irradiation direction. Since transesophageal echocardiography has basically performed by inserting a probe into the transesophagus, only movement in the depth direction is the only parameter.

However, it is difficult to recognize the transesophagus from the CT image, and the pseudo probe is not able to be moved along the transesophagus in the CT image. Therefore, we implemented the function so that parallel movement can be performed on the slice where the probe exists, with the depth being movement in the slice direction of the CT image. Thereby, fine adjustment can be easily performed. However, only the setting of the initial position of the artificial probe is automatically calculated from the information by detecting the vena cava from the CT image [1].

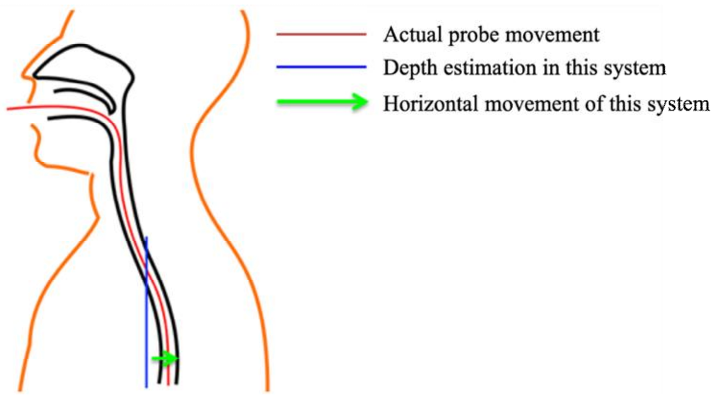

Fig.7 Probe movement path

4.2 Rotation matrix

In this system, two types of functions have implemented as a rotation method of the pseudo probe. The first function is 1) Euler angle rotation, and the second function is 2) Local coordinate rotation of pseudo echocardiography. In the actual examination, the degree of rotation has specified by the doctor's sense. Therefore, it is desirable to use local coordinate rotation (Function 2), which emphasizes that rotation from the current position can be performed intuitively. On the other hand, when assuming reproducibility of user’s operation, it is also possible to switch to Euler angular rotation (Function 1) that is easy to calculate. At Euler angle rotation, the rotation matrix R calculated by the Eq. (6) is applied to the initial state of the pseudo probe.

$$\mathrm{R} = R_x R_y R_z \qquad (6)$$

$$R_x(\theta) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{pmatrix} \qquad (7)$$

$$R_y(\theta) = \begin{pmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{pmatrix} \qquad (8)$$

$$R_z(\theta) = \begin{pmatrix} \cos\theta & \sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix} \qquad (9)$$

In the case of relative rotation, the following calculation has performed. Here, n is the rotation axis of length 1, and R is the rotation formula of Rodriguez rotating the axis n by θ.

$$n = (n_1, n_2, n_3) \qquad (10)$$

$$R(n) = \begin{pmatrix} \cos\theta + n_1^2(1-\cos\theta) & n_1 n_2(1-\cos\theta) - n_3\sin\theta & n_1 n_3(1-\cos\theta) + n_2\sin\theta \\ n_2 n_1(1-\cos\theta) + n_3\sin\theta & \cos\theta + n_2^2(1-\cos\theta) & n_2 n_3(1-\cos\theta) - n_1\sin\theta \\ n_3 n_1(1-\cos\theta) - n_2\sin\theta & n_3 n_2(1-\cos\theta) + n_1\sin\theta & \cos\theta + n_3^2(1-\cos\theta) \end{pmatrix} \qquad (11)$$

When the current rotation axes are x_a, y_a, z_a (Where $x_a \perp y_a \perp z_a$ and $x_a \neq y_a \neq z_a$), a new rotation axis x_a', y_a', z_a' when rotates about the x_a is expressed as x_a', y_a', z_a' shown in Eq. (12) to (14).

$$x_a' = x_a \qquad (12)$$

$$y_a' - R(x_a)y_a \qquad (13)$$

$$z_a' = R(x_a)z_a \qquad (14)$$

5 Evaluation

The existing transesophageal echo apparatus does not have simultaneous display of beam range and volume rendering and distance measurement function.

Subjective evaluation was performed using this system for one doctor. The doctor tried out the following three functions shown in Section 2. The functions are 1) Display of CT section imitating echocardiogram echo image, 2) Presentation of echo display location on volume rendering display, and 3) Measurement on a pseudo echocardiography from the CT image.

Smooth operation was realized for all functions despite the fact even if the user interface was different from the actual probe operation. As for the decline in operability, all functions were not pointed out. The doctors using this system have reported their effectiveness.

On the other hand, it was pointed out that the echocardiographic filter was not faithfully reproduced. This requires further improvement of the reproduction method.

6 Conclusion

Transesophageal echo examination support system is proposed in this study. Our system replaces conventional transesophageal echocardiography with CT images. Our system can inspect CT images interactively, and the examination time is shorter and there is no burden on the patient compared to transesophageal echocardiography.

In order to improve the quality of medical examination by transesophageal echocardiography, simulated transesophageal echocardiography was created by using the special smooth filter from CT images. The system has three functions as follows; 1) Display of CT section imitating echocardiogram echo image, 2) Presentation of echo display location on volume rendering display, and 3) Measurement on a pseudo echocardiogram from the CT image.

The existing transesophageal echo apparatus does not have simultaneous display of beam range and volume rendering and distance measurement function. In order to evaluate the practicality of this system, few doctors actually used the function of this system and made a subjective evaluation. Smooth operation was realized for all functions despite the fact even if the user interface was different from the actual probe operation. The echocardiographic filter was not faithfully reproduced. Further improvement of the reproduction method is our future plan. In addition, we will proceed with the implementation of a more intuitive interface reflecting the opinions of doctors who actually use it.

Acknowledgments

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