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An Automated 3D Annotation Method for Breast Ultrasound Imaging *

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Abstract—**Image spatial annotation is one of the most important steps in breast ultrasound scanning examinations because follow-up evaluation, diagnosis and treatment may be performed based on the annotation. The conventional annotation method is manual and highly dependent on the operator's experience. Therefore, it is time-consuming and prone to errors. This paper introduced a novel annotation method for breast ultrasound imaging. A spatial sensor was attached to the ultrasound transducer to obtain the real-time image location information. 3D virtual models of breasts and probe were shown on screen together with ultrasound images to display the spatial data intuitively. A program was developed to acquire ultrasound images and spatial signals, compute the image locations relative to the breast, and display images together with their corresponding 3D annotations. It was demonstrated that this novel annotation method could provide automated and accurate annotations in phantom experiments. This method also showed its potential to continuously annotate breast ultrasound images in relative short time in the preliminary in-vivo experiments.**

I. Introduction

Breast cancer is a great threat to women's health. It was reported that more than 207,000 American women were diagnosed with breast cancer and about 39,840 women died from this disease in 2010 [1]. However, if the cancer can be diagnosed at its early stage, the survival rate of patients will increase a lot [2]. Therefore, accurate and effective breast diagnostic method can save numerous patients from breast cancer. Breast ultrasound imaging is one of the most common diagnosis methods for breast cancer because its advantages of non-ionizing, non-invasive, real-time, low-cost and great value in differentiating cyst and malignant tumor [3].

For clinical breast ultrasound examinations, it is critical to accurately annotate the image location since the later evaluation, diagnosis and treatment may be performed based on the image annotation. In American College of Radiology (ACR) practice guidelines, it is recommended that all breast ultrasound images should be properly labeled [4]. The incorrectly annotated image is positively dangerous, and of less-value than no image at all [5].

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The typical clinical breast ultrasound annotation picture is shown in Fig. 1. It consists of graphical annotation and textual sequence. The graphical pictogram represents the breast and arm. The arm is used to indicate the right or left breast. The arrow on the breast pictogram represents the ultrasound image location on the breast. The textual sequence usually consists of several letters and numbers. The minimum information included by the sequence is identification of laterality (right or left), radial location (1-12 clock face segmentation) and distance from nipple (in centimeters) [5]. The R34 in the image means a position 4cm from the nipple in the 3 o'clock direction of the right breast.

Clinical ultrasound procedures highly depend on the operator's experience and training. Most commonly, the operator holds the ultrasound probe in one hand and uses the other hand to handle the ultrasound machine controls. If one image needs to be saved, the operator freezes the display and then annotates the image by changing the arrow location and entering textual annotation sequence. This action requires the operator to move hands away from the transducer and perform a series of hand motions. So the annotation is a highly fatiguing, time-consuming and repetitive task for operators [6]. In addition, the manual annotation involves the approximate positional recording according to the operator's estimation. This procedure may lead to inaccurate annotation or even errors.

In order to solve above problems, we introduced a new method that could provide automated, continuous, and 3D annotation for breast ultrasound imaging. The image spatial data, obtained by a spatial sensor attached on the probe, and ultrasound images were captured and sent to the computer. A program was developed to collect these signals and display ultrasound images and their corresponding annotations. Virtual 3D breast and probe models together with the conventional graphical and textural annotations were used to indicate the image location. The system components and experimental methods were introduced in section Ⅱ. The phantom and subject experiment results were presented in section Ⅲ. The conclusions were drawn and the future developments were discussed in section Ⅳ.

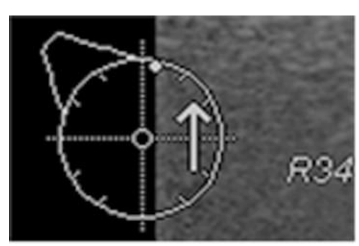

Figure 1. The typical breast ultrasound annotation picture

II. METHODS

A. System description

The new annotation system was shown in Fig. 2. It consisted of an ultrasound scanner (Hitachi EUB-8500, Hitachi, Ltd., Tokyo, Japan), a compact electromagnetic spatial sensing device (medSAFE, Ascension Technology Corporation, Burlington, VT, USA), and a computer with customized software and video capture card respectively. The linear probe (EUP-L65/6-14MHz, Hitachi, Ltd., Tokyo, Japan) of the ultrasound scanner was used to scan the breast, also shown in Fig.2. The video signal generated by the ultrasound scanner was transferred into the computer through a cable. A video capture card (NI-IMAQ PCI/PXI-1411, National Instruments Corporation, Austin, TX, USA) was installed in the computer to digitize real-time 2D ultrasound images. The electromagnetic spatial sensing device medSAFE included three parts: the sensor, transmitter and the control box. This spatial sensing device sample rate was 100Hz so enough data could be collected to ensure the accuracy of the spatial information. The size of the medSAFE spatial sensor was 1.5mm*7.7mm so it was easily to be fixed. The sensor was mounted on the ultrasound probe using the mounting kit to get the real-time image spatial data.

B. Calibration method

The spatial calibration was performed to determine the position and orientation offsets between ultrasound image and spatial sensor. The calibration was conducted before experiment using a cross-wire phantom [7]. Two cotton wires were crossed and submerged into the water. The wire ends were attached on the tank. The ultrasound probe was used to detect the wire cross. If the cross was found on the ultrasound image, this image and its corresponding location data obtained from spatial sensor were recorded. Totally about 60 images which clearly displayed the cross from various directions were captured. Then the pixel position of the cross on the image was indentified manually. According to the positional information on the image and the position and orientation information read from the spatial sensor device, the position and orientation offsets could be calculated using Levenberg-Marquardt non-linear algorithm [8].

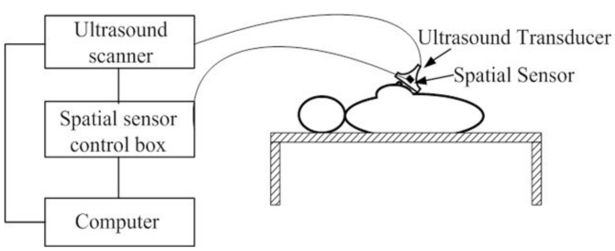

Figure 2. The system components

C. Software interface

A software platform for ultrasound images annotation was developed in Visual C++ to acquire ultrasound images and spatial signals, compute the image locations relative to the breast, and display images together with their corresponding 3D annotations. Visualization toolkits (VTK, Kitware Inc. NY, USA) were integrated into the software system for signal and image processing and visualization.

The software interface is shown in Fig. 3. It mainly consisted of two parts: the image 3D annotation window and the ultrasound image display window. The annotation on the left window corresponded to the ultrasound image on the right window. When ultrasound images changed, the annotations on the left window would change simultaneously. They were displayed in real time during breast scanning examinations and could be saved for the later review. The parameters for acquiring and displaying such as the image size could be adjusted by the operator using the control bar of the software, also shown in Fig. 3.

D. Annotation models

In conventional annotation method, the image spatial information is indicated by 2D pictogram, as shown in Fig. 1. This 2D method ignores some important spatial information such as the probe tilt angle. However, different probe tilt angle leads to different image position. Therefore, this 2D annotation method may cause errors in the follow-up examination and treatment.

In order to solve the above problem, 3D breast and probe models were used to indicate the image location in this new annotation system, as shown in Fig. 4. The two models were established by the software Autodesk 3ds MAX (Autodesk Inc., NY, USA) and DAZ 3D (DAZ Productions Inc., Draper, Utah, USA) in advance and stored in the computer. In this system, the breast model was established according to the usual breast size. During the scanning examination, the real beast was resized to this breast model.

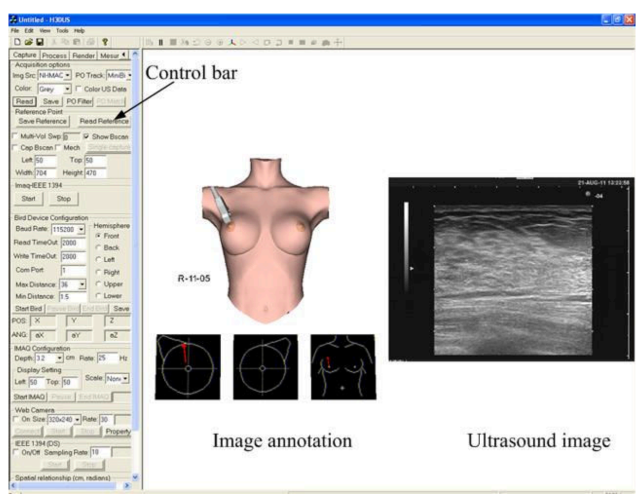

Figure 3. Software interface

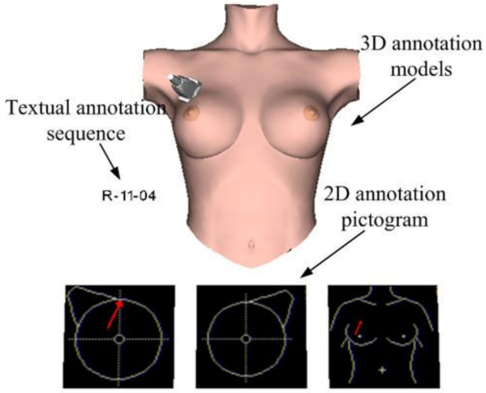

Figure 4. The new system annotation methods

Except 3D models, other two annotation ways were also used, as shown in Fig. 4. The textual annotation sequence and the 2D annotation pictogram were similar to the conventional annotation method. Two kinds of 2D annotation pictograms were used. The left two pictograms represented right and left breast respectively. The right pictogram depicted two breasts in one picture. All the image location indicators including the 3D probe model and the red arrows on 2D breast pictograms were set automatically according to the real-time positional data from the spatial sensor. The textual sequence was also automatically generated and continuously updated.

E. Phantom and subject experiments

Two breast phantoms (Breast Elastography Phantom Model 059, CIRS Inc., Norfolk, Virginia, USA) which could mimic the ultrasonic characteristics of tissues in an average human breast were used to test our new annotation system. The phantom contained several solid masses to mimic the breast lesions. Lesions-mimicking targets with diameters from 2mm to 10mm and were randomly positioned throughout the background. The size and shape of the phantom were simulated that of an average patient in the supine position. The phantom was 15cm in maximal length, 12cm in maximal width and 7cm in maximal height.

During phantom experiments, two breast phantoms were put side by side and fixed to simulate woman's left and right breasts. The operator held the probe and scanned the phantom continuously in a certain scanning pattern. Ultrasound images together with their corresponding spatial data were acquired by the software. The images were shown in real time on the display window. The image location relative to the breast was computed by the system and displayed by the annotation models automatically. The textual annotation sequence also changed according to the image spatial data. A camera (Sony DCR-HC90E, Sony Corporation, Osaka, Japan) was added in the phantom experiments to record the scanning procedures. The video was shown on the software display window in real time. The annotation was compared with the video to verify its accuracy.

For the in-vivo experiments, a healthy woman (25 years old) was recruited for scanning. A bed was put near the electromagnetic sensing sensor device. The subject lay on the bed in supine position. She was asked to put her ipsilateral arm abducted and the hand under the head in order to flatten the breast, which is the traditional position for the breast ultrasound examination. After ensuring the right position, the operator held the probe and scanned the whole breast. All ultrasound images of the whole breast together with their corresponding spatial data were automatically recorded by the software. The camera was removed in the in-vivo experiments to protect the subject's privacy. Only the ultrasound images and their annotation pictures were shown on the window.

III. RESULTS

During phantom experiment, two breast phantoms were scanned continuously and the images, annotations and video of the whole scanning procedure were all recorded and displayed by the software. Fig. 5 shows six software display screenshots of the phantom experiment. The left window was the annotation. The right upper window displayed the video and the right lower window was the ultrasound image. The experiment video was used to verify the accuracy of the annotation. The phantom inclusion could be seen from the ultrasound images. According to the annotation, all positional information including probe's position and orientation could be clearly displayed. From the comparison of the annotation and the video image, it was found that the real probe on the video and the 3D probe model on the annotation were almost on the same location relative to the breast. The comparison result suggested that this annotation system could accurately and intuitively indicate the image location in real time.

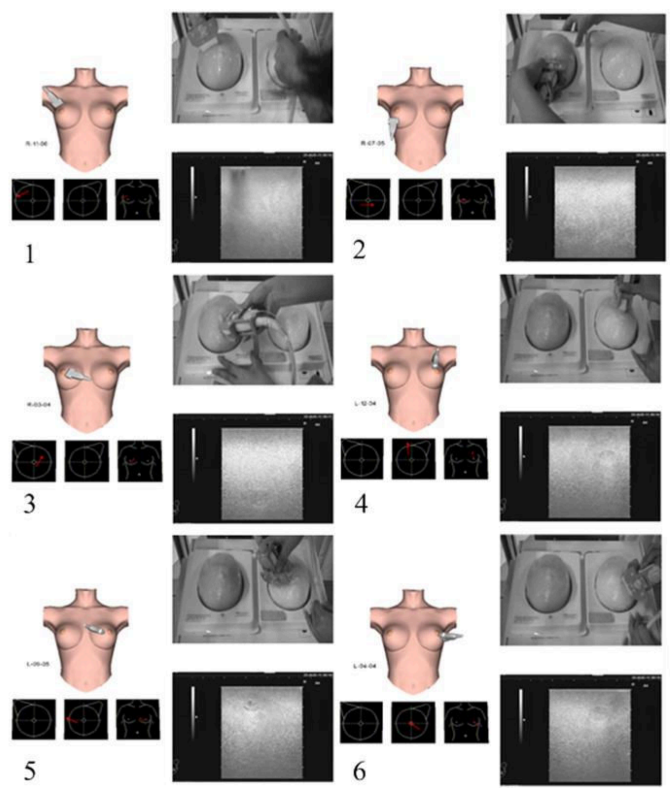

Figure 5. Breast phantom experiment results

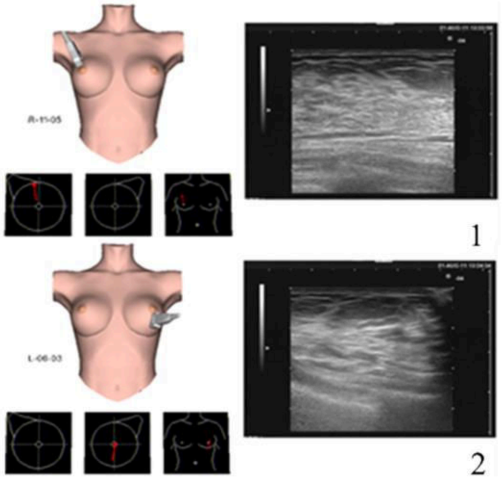

Figure 6. Subject experiment results

In subject experiment, after ensuring the right position of the subject, the operator scanned the left and right breasts with the linear array transducer. The time to scan two breasts and save the spatial annotation was only about one minute. Fig. 6 shows two screenshots of the subject experiment. The right window was the breast ultrasound image. The image's location could be clearly indicated by the annotation on the left window.

IV. DISCUSSION AND CONCLUSIONS

Ultrasound is popular in clinical breast diagnosis because of its advantages of low-cost, radiation-free and high difference between malignant and benign lesions [9]. However, the clinical ultrasound scanning just provides 2D images and annotations. Clinicians have to image the lesion location in the mind according to the 2D information. This can lead to inaccurate estimation of the breast lesion.

During recent years, new systems for 3D breast ultrasound scanning such as Siemens's Automated Breast Volume Scanner (ABVS) have been evaluated [10]. This approach provides a good way to solve the above problem. However, these 3D systems are mainly based on mechanical scanning method which requires bulky system. In addition, the mechanical scanning method usually cannot cover the whole breast such as the axillary part. The operator has to scan this part using handheld ultrasound system. This causes inconvenience in the clinical scanning. Therefore, there are still many problems to be solved before 3D breast ultrasound scanning system can be widely used in clinics.

In this paper, we reported a new 3D automated annotation method for breast ultrasound imaging. This method provides 3D annotation for the breast ultrasound images so it can avoid inaccurate estimation of the breast ultrasound image. In addition, this method is based on the clinical handheld ultrasound scanning system so it's flexible and can cover the whole breast. This method used a spatial sensor to obtain the image location and 3D models to display the spatial data intuitively. It was demonstrated that this new system could provide real-time 3D annotation during breast scanning examination. After comparison of our 3D annotation results and real scanning video in phantom experiments, it was found that the annotation method could display the image spatial information correctly and intuitively. In the in-vivo experiments, this new system also showed its potential to provide continuous annotations to the breast ultrasound images in relative short scanning time.

However, the phantom experiments in this study just provided qualitative comparison results. More quantitative experiments will be conducted to test the system annotation accuracy. In addition, more subjects including women with breast tumors will be recruited and more in-vivo experiments will be performed to compare the new annotation method with the conventional manual method. Parameters such as scanning time, annotation accuracy will be compared. The system reproducibility of annotating images will also be investigated in the future.

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