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A novel breast ultrasound system for providing coronal images: System development and feasibility study

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ABSTRACT

Breast ultrasound images along coronal plane contain important diagnosis information. However, conventional clinical 2D ultrasound cannot provide such images. In order to solve this problem, we developed a novel ultrasound system aimed at providing breast coronal images. In this system, a spatial sensor was fixed on an ultrasound probe to obtain the image spatial data. A narrow-band rendering method was used to form coronal images based on B-mode images and their corresponding spatial data. Software was developed for data acquisition, processing, rendering and visualization. In phantom experiments, 20 inclusions with different size (5–20 mm) were measured using this new system. The results obtained by the new method well correlated with those measured by a micrometer ($y = 1.0147x$, $R^2 = 0.9927$). The phantom tests also showed that this system had excellent intra- and inter-operator repeatability (ICC > 0.995). Three subjects with breast lesions were scanned in vivo using this new system and a commercially available three-dimensional (3D) probe. The average scanning times for the two systems were 64 s and 74 s, respectively. The results revealed that this new method required shorter scanning time. The tumor sizes measured on the coronal plane provided by the new method were smaller by 5.6–11.9% in comparison with the results of the 3D probe. The phantom tests and preliminary subject tests indicated the feasibility of this system for clinical applications by providing additional information for clinical breast ultrasound diagnosis.

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1. Introduction

Breast cancer is the most common cancer in women worldwide. In the Global Health Estimates of World Health Organization (WHO), it was estimated that 508,482 women died of breast cancer in 2011 in the world [1]. In America, it was reported that 226,870 women were diagnosed with breast cancer and 39,510 of them died of breast cancer in 2012 [2]. According to the report of Breast Cancer UK, breast cancer accounted for 31% of cancers diagnosed in women [3]. Up to now, there has not been an effective method to prevent breast cancer and early detection has remained the cornerstone for breast cancer control [4]. Among all breast cancer detection methods, ultrasound plays an important role in breast cancer deaths decline for its advantages of radiation-free, real-time and suitable for dense breast [5,6]. Ultrasound has long been recognized as a valuable tool to distinguish between cysts and solid masses. With the rapid development of ultrasound techniques and greatly increased images quality, breast ultrasound can now not only be used for characterizing cysts, but also differentiating benign from malignant lesions. In a breast abnormalities (259 carcinomas, 1820 benign) examination, ultrasound could help to avoid unnecessary biopsy with benign diagnosis results in 71 suspicious cases at palpation or mammography [7]. Therefore, routine ultrasound examination can help to reduce unnecessary biopsies.

In clinical breast ultrasound examination, 2D ultrasound probe is routinely used which can only provide transverse and longitudinal images but no coronal images. However, information on this plane has been proved to be beneficial for clinical diagnosis [8–14]. Rotten et al. analyzed images of normal breast tissue and breast lesions and found four diagnosis features on coronal plane [8]. Among these features, one was defined as compressive pattern which was thought to be associated with benign lesions. In this pattern, the continuous hyperechoic bands of tissue peripheral to

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the masses appeared to be distinct from the central part. Another feature was called converging pattern which was a typical characteristic of malignant lesions. For this pattern, a stellate distortion consisting of alternating hypoechoic and hyperechoic lines converged towards to the hypoechoic central masses [8]. In the study of Chen et al., the two features were described as hyperechoic rim and retraction phenomenon. They were used independently to differentiate breast lesions and good accuracy (95.9% for hyperechoic rim; 96.8% for retraction phenomenon) and specificity (92.8% for hyperechoic rim; 100% for retraction phenomenon) were reported [9]. In fact, the feature of retraction phenomenon on coronal plane, also called spiculation, was reported by other researchers with high specificity (98.4% in [10]; 94.6% in [11]) in tumor diagnosis. In the report of Meyberg-Solomayer et al., the coronal plane could provide tumor classification information when the infiltrative zone was not visible (17 of 39 cases) or unclear (6 of 8 cases) in 2D ultrasound imaging [12]. This result demonstrated that the image on this plane could offer a better assessment when the infiltrative zone surrounding the lesion was unclear or not visible on conventional 2D images, which could help to reduce biopsies. Images along coronal plane were also beneficial for tumor extent measurement [13] and ultrasound-guided vacuum-assisted core-needle biopsy [14]. Based on images on coronal images, various computer-aided diagnosis (CAD) methods were presented to help to automatically detect tumor candidate [15], mark spiculated masses [16,17], and classify tumor stages [18,19].

Breast coronal images can be provided by the technique of three-dimensional (3D) ultrasound imaging. Many researchers have been studying on this technique. One approach of 3D breast ultrasound imaging was to scan the breast using the conventional 2D probe, which was driven by a mechanical motor [20–22]. A typical representation of this approach was the method proposed by Kotsianos-Hermle et al. [20]. In this method, breast was compressed by two paddles and a probe was driven mechanically on the top of the paddle to acquire the breast images. Another approach was to scan the patient with a specially designed probe when the patient was in supine position, such as the commercial products Automated Breast Volume Scanner (ABVS) of Siemens and the Automated Whole-Breast Ultrasound (AWBU) of Sonocine [23–25]. Another approach for 3D ultrasound imaging is the 2D array ultrasound probe which uses electronic pyramidal scanning [26]. They have been used successfully for real-time 3D imaging of the heart, where high volume frame rate (40 volumes per second) is required [27], but are seldom used for breast imaging. A high volume frame is not as necessary for breast imaging, unless breast tissue motion needs to be tracked in three dimensions in real time, as in 3D elastography [28]. Therefore, the first two approaches of 3D ultrasound imaging can provide breast coronal images. However, in these methods, the driven motor or specially designed probes were required for scanning. These equipments were bulky and large, which were inconvenient for clinical scanning to offer regular motions. In addition, the moving manner of the probe in these systems was predefined so the operator could not move the probe to the desired position freely. Some regions such as axillary region and tissue against the chest wall were not accessible by using these systems. Therefore, there are still many works to be done before 3D ultrasound imaging technique can be widely used in clinical breast examination. 2D ultrasound imaging remains the dominant scanning mode for clinical breast ultrasound diagnosis.

Accordingly, this study was aimed to develop a breast ultrasound system for providing coronal images based on the clinical 2D ultrasound scanner. In the following sections, this system is described in details. The system accuracy and reliability tests based on phantoms are presented. Preliminary clinical tests were also performed to demonstrate the system feasibility.

2. Methods

2.1. System overview

A corresponding freehand 3D ultrasound annotation system was previously developed and successfully used for annotating breast ultrasound images [29]. Fig. 1 shows the diagram of this system. It consisted of three main components: an ultrasound machine (EUB-8500, Hitachi, Tokyo, Japan) with a linear 2D probe (EUP-L65/6–14 MHz, Hitachi, focused probe, 6–14 MHz), an electromagnetic spatial sensing device (med-SAFE, Ascension Technology, Burlington, VT, USA) and a computer with Intel Core i5 3.35 GHz CPU and 3.5 GB of memories. A video capture card (NI-IMAQ PCI/PXI-1411, National Instruments Corporation, Austin, TX, USA) and a customized program were installed on this computer. The electromagnetic spatial sensing device was employed to acquire the image spatial data in this system. The selected device had high spatial accuracy. The documented positional accuracy and angular accuracy of this device were 1.4 mm and 0.5°, respectively (medSAFE Manual, Ascension Technology). The spatial device was comprised of a control box, transmitter and a sensor. The diameter of the cylindric sensor was 2.0 mm and the length was 9.9 mm. This sensor dimension was small so it was easy to be fixed on the ultrasound probe by a custom-designed kit. The image spatial data acquired by this sensor included three positions (x, y, z) and three orientations (azimuth, elevation, roll). These data were sent from the control box of the spatial device to the computer through its serial port. The sampling rate of medSAFE was 100 Hz, which was higher than the ultrasound imaging rate. So sufficient spatial data were collected and averaging was used to improve the accuracy of the system on distance and angle measurement. During scanning, the video stream of 2D B-mode ultrasound images was captured by the video capture card and sent to the computer. Meanwhile, the spatial data of these images were also sent to the computer by the control box of the spatial device. The developed program acquired and recorded these images together with their corresponding spatial information for the further visualization and rendering.

Spatial calibration experiments were performed for the system to determine the position and orientation offsets between the ultrasound image and the spatial sensor. A cross-wire phantom was used to calibrate this system [30,31]. Two wires were crossed and submerged in a water tank and the wire ends were fixed to the tank. The ultrasound probe was moved slowly to scan the wire cross. If an image with a clear cross was found, this image and its spatial information would be recorded. In each experiment, 60 images from various directions were captured. According to the

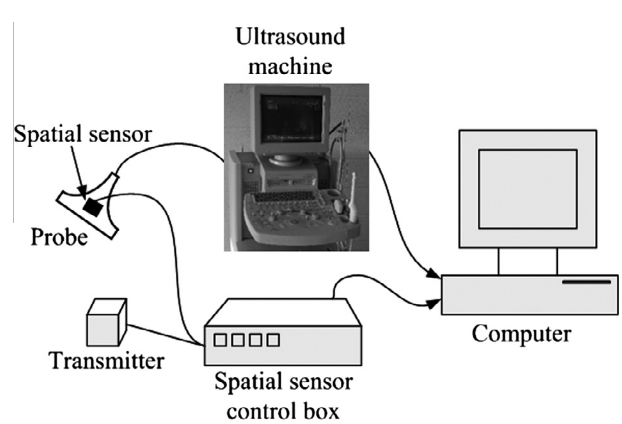

Fig. 1. Diagram of the breast ultrasound rendering system developed in this study, which consisted of an ultrasound machine, a spatial sensing device and a computer.

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