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Clinical Evaluation of a 3-D Automatic Annotation Method for Breast Ultrasound Imaging

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3-D Annotation for Breast Ultrasound

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Abstract

The routine clinical breast ultrasound annotation method has the limitations of time-consuming, inconsistent, inaccurate and incomplete notation. A novel 3-D automatic annotation method for breast ultrasound imaging has been recently developed, which used a spatial sensor to track and record conventional B-mode scanning so as to provide more objective annotation. The aim of this study is to test the feasibility of the automatic annotation method in clinical breast ultrasound scanning. An ultrasound scanning procedure using the new method was established. A comparison between the new method and the conventional manual annotation method was performed with 46 breast cancer patients (49 ±12 years). The time used for scanning a patient was recorded and compared for the two methods. The intra-observer and inter-observer experiments were performed and the intraclass correlation coefficients (ICCs) were calculated to analyze the system reproducibility. The results demonstrated that the average scanning time of using the new annotation method was reduced by 36 s or 42.9% in comparison with the conventional method. There were high correlations between the results of the two annotation methods ($r = 0.933$, $P < 0.0001$ for distance, $r = 0.995$, $P < 0.0001$ for radial angle). Intra-observer and inter-observer reproducibility were excellent, with all ICCs larger than 0.92. The results showed that the 3-D automatic annotation method is reliable for clinical breast ultrasound scanning and it can greatly reduce the scanning time. Although large-scale clinical studies are still needed, this work verified that the new annotation method has potential to be a valuable tool to help breast ultrasound examination.

Key words: Breast ultrasound, Breast imaging, Annotation, 3-D ultrasound, Breast cancer, Clinical study

Introduction

Breast ultrasound is a common diagnosis method for patients with breast cancer in clinics because it is non-invasive, real-time and less expensive (Dixon 2008; Huang et al. 2008; Jackson 1990). It has good sensitivity in dense breasts and, thus, is employed as a complementary method to mammography for breast screening (Chen et al. 2004; Svensson 1997). In clinics, breast ultrasound can also be used to differentiate benign from malignant lesions, which can help to reduce the number of biopsies (Cho et al. 2006; Hong et al. 2005).

Figure 1(a) is a typical ultrasound display during breast examination, which consists of an ultrasound image and a corresponding image annotation. The annotation is used to register the image location with respect to the breast (American College of Radiology 2011). Because the follow-up diagnosis, evaluation and treatment are performed based on the stored annotation, it is crucial to provide accurate and complete annotations. The stored annotation is also very important for surgery. The women with large tumors, such as a malignant lesion located across different quadrants, are usually recommended to have the mastectomy (American Cancer Society). As shown in **Figure 1(a)**, there are two parts on the annotation, graphic pictogram and textual sequence. In the graphic pictogram, the circle represents the breast region. The irregular part next to the circle means the arm, which is used to indicate the laterality (left or right) of the breast. The arrow is the probe icon, which represents the probe location. The arrow direction means the probe direction and the movable arrow can be manipulated by the operator to reflect the current location of the ultrasound image. Most commonly, a trackball on the ultrasound machine is employed to manipulate the position of the probe icon relative to the breast marker region. There are three types of breast marker, as shown in **Figure 1(b)**. The operator can choose a suitable pictogram to annotate the image according to the image location. The spatial information is also indicated in the textual sequence. In the **Figure 1(a)**, L means left breast, 3 represents 3 clock radial direction and 4 indicates 4 cm to the nipple.

During breast examination, when one image is useful for diagnosis, a series of complex hand motions need to be performed to annotate the image (Jackson and Chenal 2006; Kuzara and Brown 2006). The sonography operator firstly freezes the ultrasound image using the freeze button on the ultrasound machine. Then the sonography operator changes the probe icon position according to the estimation. Finally, the textual sequence is typed using the keyboard. In hospital, patient care and productivity are the main concerns. However, this manual annotation method causes a variety of issues.

One issue arises from the complex manual annotation procedure. The above actions are repeated for every ultrasound image, which are time-consuming (Entrekin 2010). Compared with the breast scanning procedure, the annotation even takes more time in the whole breast ultrasound examination, especially for new staff with little experience. In China, the clinical practice guideline recommends that two operators are needed in breast ultrasound examination (Chinese Medical Association 2004). One manipulates the ultrasound machine to scan the breast and the other records the image and annotates it. This method can effectively decrease the examination time. But it is obviously a waste of human resources in healthcare institutions. In addition, the highly repetitive annotation procedure is also fatigue causing for the operator.

Another problem caused by the manual annotation method is subjective registration of the image location, which is set according to the estimation of the probe location relative to the breast by the sonography operator. The manual estimation depends on the sonography operator’s training and experience, and may lead to inaccurate results or even errors. Furthermore, different operators may annotate images in their own way, which can cause inconsistency in image recording (Brandli 2007). For example, as shown in Figure 1(a), some operators may type the textual sequence near to the breast marker region while others may type it on the ultrasound image. The inconsistent ultrasound images can cause difficulties to the follow-up image processing or statistical analysis (Cupples et al. 2004). In addition, as shown in **Figure 1(a)**, the 2-D annotation cannot display all spatial information in 3-D space, such as the probe tilt angle. This can also cause problems to the downstream evaluation and treatment. According to the incomplete spatial information, different clinicians may have different judgements on the image location in 3-D space.

Compared with conventional B-mode ultrasound (2-D), 3-D ultrasound can overcome limitations of 2-D viewing and measuring of 3-D anatomy (Chang et al. 2015; Fenster et al. 2011; Huang et al. 2005; Huang et al. 2015). The applications of 3-D breast ultrasound have been reported in the literature including the image guidance of biopsy and surgery (Albrecht et al. 2006; Fenster et al. 2004; Tamaki et al. 2002; Weismann et al. 2000), breast cancer diagnosis (Kelly et al. 2010; Shipley et al. 2005; Kotsianos-Hermle et al. 2009; Kuo et al. 2008; Lin et al. 2012), image evaluation of intraductal cancer spread (Sato et al. 1998), and mammary ducts imaging in lactating women (Gooding et al. 2010). Compared with the above studies at the stage of lab research, two 3-D breast ultrasound products have begun to be applied in clinical diagnosis. One is Automated Breast Ultrasound (ABUS) of the GE Healthcare and the other is the Automated Breast Volume Scanner (ABVS) of Siemens. It was reported that the above automated 3-D breast ultrasound systems had obvious advantages, including the higher diagnosis accuracy, less operator dependency, and better lesion size prediction, compared with the conventional hand-held 2D ultrasound (Chang et al. 2015a; Chang et al. 2015b; Lin et al. 2012). However, for the above two systems, specially designed probes are required, which are expensive and bulky for the clinical routine use. In addition, the sonography operator cannot move the probe to the desired position freely because the moving manner of the probe is predefined. Therefore, though 3-D breast ultrasound is a promising imaging method, there is still a long way to go before it can be widely used in routine clinical breast examination. 2-D ultrasound imaging is still the dominant scanning mode for breast ultrasound examination, considering the equipment and training costs of using 3-D system, the sophisticated experiences gained by clinicians using 2-D ultrasound.

As the routine clinical examination tool, the existing breast ultrasound annotation system has the problems of time-consuming, inconsistent, inaccurate and incomplete. To overcome the problems of the existing manual annotation, a 3-D automatic annotation system was developed (Jiang et al. 2014). A 2-D ultrasound scanner was utilized in this system to capture the ultrasound images. An electromagnetic spatial sensor was mounted to the ultrasound probe to obtain the positional information of the images. The 3-D virtual models of breast and probe were employed to display the image locations. The technical details including the system components, the calibration method, the software development, the annotation parameters calculation, the selection of reference points, and the annotation display method were reported in the previous study (Jiang et al. 2014). The aim of this study is to evaluate the feasibility of the newly developed 3-D automatic annotation system in clinical breast ultrasound scanning on patients with breast tumors. The scanning procedure using the automatic annotation method was established. The comparison between the new method and the manual annotation method was performed. The reproducibility of the method was also investigated.

Methods

Patients

This study was approved by the human subject ethics committee of the institution and all patients gave the informed consent in this study. The experiments were conducted in the Sun Yat-Sen University Cancer Center (Guangzhou, China). In December 2013, 46 patients (all female patients; mean age, 49 years ±12 (standard deviation); range, 24-65 years) who met the following criteria were prospectively recruited. The inclusion criterion was presence of breast lesions in breast ultrasound examination. 19 patients had benign lesions and 27 patients had malignant tumors (2 patients with ductal carcinoma in situ (DCIS), 20 patients with invasive ductal carcinoma (IDC) and 5 patients with invasive lobular carcinoma (ILC)). Patients were excluded if they had mastectomy before and one or two of their breasts were cut off. This clinical study included two parts, which were the comparison study of manual annotation method and the 3-D automatic annotation technique, and the reproducibility test of this new annotation method. 21 of recruited patients participated in the first part, and 25 of them participated in the second part of this study.

The 3-D automatic annotation method

The novel annotation technique has been developed to provide 3-D, automatic and continuous annotation for breast ultrasound imaging. Jiang et al. (2014) previously reported the development of this method, and some key features were described here. The new annotation system consisted of an ultrasound machine (DC-8, Mindray, Shenzhen, China) with a linear 2-D probe (L12-3E, Mindray, Shenzhen, China, 3.0-13.0 MHz), an electromagnetic spatial equipment (medSAFE, Ascension Technology, Burlington, VT, USA) and a computer installed with a video capture card (NI-IMAQ PCI/PXI-1411, National Instruments, Austin, TX, USA) and a customized program, as shown in **Figure 2**. The spatial equipment was comprised of a spatial sensor, a control box and a transmitter. The spatial sensor was fixed on the ultrasound probe using a custom-designed mounting kit, also shown in **Figure 2**. Real-time spatial information (three positions (x, y, z) and three orientations (azimuth, elevation, roll)) of probe were captured by this sensor and sent to the computer through the control box. During scanning, ultrasound images from the ultrasound scanner were also sent to the computer through a video capture card.

The ultrasound images and the corresponding spatial data were acquired by a custom-developed program, with its interface shown in **Figure 3**, which contained the tool bar and display window. The display window was divided into two parts, annotation window (left part of the display window) and image window (right part of the display window). During the breast scanning, ultrasound images were displayed on the image window. Meanwhile, the corresponding annotations were shown on the annotation window in real time. In this annotation method, four types of display modes were used, including the 2-D annotation pictogram, textual annotation sequence, 3-D annotation models and annotation value, as shown in **Figure 3**. The first two annotation modes were used in conventional annotation method, which were familiar to clinicians. The 3-D models including breast model and probe model were adopted in this system to intuitively annotate the image location. By changing the position of probe model on the breast model, the image location could be displayed. The 3-D annotation models can display all spatial information such as the probe tilt angle which cannot be indicated in conventional annotation method. The accurate values of image distance to nipple and radial angle were displayed by the mode of annotation value. All these spatial indicators including the arrow of 2-D pictogram, textual sequence, 3-D probe model and the annotation values were changed automatically according to the spatial data from spatial sensor when ultrasound probe moved across the breast.

In this system, the positional data were acquired by the spatial sensor. A cross-wire phantom was used to establish the offsets between the spatial sensor and the ultrasound probe (Barry et al. 1997). Based on the spatial data of the sensor and the calibration matrix, the positional information in 3-D space of the ultrasound image could be calculated. Then the positional information was displayed using the above four types of display modes. However, in this annotation method, the sizes of 3-D breast model and the 2-D pictogram were established in advance. For different patients, the sizes of breasts are different. To resize the actual breast to the breast model, four reference points, including the nipple points of left and right breasts, and border points of left and right breasts, were used in this method. Before each scanning, the operator held the probe and puts it on the nipple point and border point of each breast. The spatial data of the four points were recorded by the system. Then the radius and height of the actual breasts were calculated and scale parameters between the actual breast and breast model were obtained. According to the scale parameters and the calibration matrix, the spatial data acquired using the spatial sensor was then automatically displayed on the annotation model.

Development of a clinical procedure using the 3-D automatic annotation method

In clinical breast ultrasound scanning, a foot switch was connected to the computer of this system to achieve functions of computer mouse so it can control the action of the software such as the acquisition of ultrasound image. This design could help the operator to release hand from the computer mouse during scanning the breast. During the scanning, the patient lay on the bed in supine position with her arms abducted and hands under the head to flatten the breast. To reduce the influence of patient motions, the patient was asked to keep still during the scanning procedure and lighten her breath as possibly as she could. At the beginning of the scanning, the software prompted the physician to record the four reference points. The physician put the probe on the corresponding point of the breast, stepped on the foot switch, and the spatial data of this point was recorded by the software. The software then reminded the operator to record the next reference point until four reference points were captured. After that, the ultrasound image from the probe and the corresponding annotation were displayed on the interface of the software (**Figure 3**) and the physician could begin the breast scanning. In this study, the physician held the ultrasound probe to scan across the breast in orthogonal antiradial scanning pattern (Stavros 2004), which is one of the most common scanning patterns in clinics. During scanning, ultrasound images and their annotations changed in real time. If an ultrasound image contained the information of lesion, the physician stepped on the foot switch and this image together with its annotation was saved. This action took less than one second and there was almost no influence to the whole scanning procedure. The scanning continued until both of the two breasts were covered and all images of lesions were saved. The scanning procedure is shown in **Figure 4**. During scanning, if the patient has any motion which breaks the continuous scanning, it is necessary to define the reference points again before continuing the scanning.

Comparison study between manual annotation and 3-D automatic annotation

To investigate the performance of the new annotation method, the comparison between the 3-D annotation method and the clinical manual annotation was performed. 21 patients (all female patients; mean age, 49 years ±12 (standard deviation); range, 25-65 years) were contained in this comparison test. A physician who has 3 years' experience in breast ultrasound was involved in this study. The annotation time and results using the two methods were compared. The ultrasound machine and probe were the same in the two annotation methods.

Ultrasound examination

In this comparative experiment, results of two annotation methods on the same lesion were compared. To ensure that the ultrasound probe was put on the same position in two scanning procedures, the patient was asked to keep stationary until two annotations were completed. In addition, before the comparative scanning, an extra ultrasound scanning was performed so that the physician could investigate the lesion and found a suitable position of the probe on the breast to record the ultrasound image. In the following comparative scanning, the operator would put the probe on the same location and annotate the ultrasound image.

The patient lay on the bed and the physician held the probe to scan two breasts in orthogonal antiradial scanning pattern. After two breasts were covered, the physician swept the probe to the lesion region to investigate the ultrasound images of this lesion. The operator adjusted the probe to get the suitable image which could clearly display the lesion. The probe location and ultrasound image were remembered in the mind by the operator as the reference of the following scanning.

3-D automatic annotation

After the ultrasound examination, a scanning procedure using the developed 3-D automatic annotation method was performed by the physician. The scanning and annotation procedure was described in the previous section. In this procedure, the program interface (**Figure 3**) was displayed on the computer. When the suitable ultrasound image was found, the operator acquired this image together with its annotation by stepping on the foot switch. This action was repeated if another lesion was found until two breasts were scanned. The time of the whole scanning procedure including the definition of four reference points was recorded. The recorded scanning time did not include that spent on the preparation work of the computer setup, spatial equipment initiation, and the ultrasound machine setup. The whole preparation work took about 2 min. The setup would only be performed once and could be used for all patients until the system was shut down.

Manual annotation

Following the 3-D automatic annotation procedure, manual annotation was performed by the same physician. In this procedure, the physician used the ultrasound machine interface. The orthogonal antiradial scanning pattern was also adopted in manual annotation scanning. After two breasts were covered, the physician moved the probe to the lesion region to find the suitable ultrasound image. When such an image was found, the operator froze the ultrasound image to annotate it. The physician firstly chose a suitable graphic pictogram from the three types of graphic pictograms (**Figure 1(b)**). According to the laterality of the lesion, one graphic pictogram was chosen using the tracking ball of ultrasound machine. The physician then changed the arrow position and orientation on the graphic pictogram according to her estimation on actual probe location. Finally, the physician typed the textual sequence using the keyboard of the ultrasound machine. When the above three steps were finished, this ultrasound image was completely annotated and saved. If there were more than one lesion, this annotation procedure was repeated for each lesion.

Reproducibility test of the 3-D automatic annotation method

To further study the performance of this new annotation method, the reproducibility test in clinical settings was performed. In total, 25 patients (all female patients; mean age, 49 years ±12 (standard deviation); range, 24-65 years) involved in this test. Besides the first physician involved in the above comparison test, the second physician who also has 3 years' experience in breast ultrasound attended this test. Before the reproducibility assessment, an extra ultrasound examination similar to the above comparison test was conducted. In this examination, both of the two physicians scanned the breasts and found the same suitable position for each breast lesion as the reference of the later reproducibility test.

The reproducibility test included intra-observer and inter-observer repeatability assessment. The patient was scanned and annotated by the first physician using the 3-D automatic annotation method twice with a 15 minutes interval for the intra-observer repeatability. During the scanning, the patient lightened her breath as possibly as she could. During the interval, the patient could breathe normally but keep still. For the inter-observer repeatability assessment, the second physician repeated the scanning using the same annotation system. The other data for inter-observer repeatability analysis was from the first data set of the intra-observer repeatability assessment.

Data analysis

In the manual annotation method, only parameters of the radial angle and the distance to nipple were annotated with numerical value. Values of the two parameters were compared in the two annotation methods. The Pearson correlation coefficient r was calculated to assess the correlation between the manual and 3-D automatic annotation methods. The scanning times on different patients using the two methods were compared. To assess the system reproducibility, the intraclass correlation coefficient (ICC) for intra-observer test and inter-observer test was used. A P value of less than 0.05 was considered to indicate a significant difference. All statistical evaluations were performed using the statistical software (SPSS for Windows, version 17.0; SPSS, Chicago, IL, USA).

Results

Scanning time

Among 21 patients that were scanned in the comparative study, 18 of them had one lesion, two patients had two lesions and one patient had three lesions. The scanning times were summarized in **Table 1**. Student's t-test was used to analyze the scanning time and a significant difference ($P < 0.001$) was demonstrated between the two annotation methods (84s for manual method, 48s for automatic method). For patients with one lesion, the average difference was 36 s, which took 42.9% of the whole manual scanning time (84 s). For the two methods, the scanning procedures were almost the same so the time difference was mainly caused by the annotation procedure. This automatic annotation could obviously save scanning time. Moreover, as shown in **Table 1**, when there was more than one lesion, the time difference became larger. That was because the manual annotation procedure was repeated for each lesion which spent much time in the whole scanning procedure. While in the new automatic method, the annotation procedure took little time in the whole scanning examination. Therefore, the increased breast lesion had little influence on the whole scanning time.

Annotation results comparison between the manual and automatic methods

Figure 5 shows the typical annotation results of the manual method and the automatic method for the same breast lesion. In the manual annotation, the quantitative values were given by the textual sequence. The distance to the nipple was indicated by the last number in the sequence in centimeters, as shown in **Figure 5(a)**. The radial angles were expressed in clock format and they were changed to values in degree. For the automatic method, the quantitative values of the two parameters were displayed on the interface, as shown in **Figure 5(a)**. **Table 2** is the Person correlation coefficient of the two annotation methods (r = 0.933, P < 0.0001 for distance, r = 0.995, P < 0.0001 for radial angle), which demonstrated excellent positive correlations with respect to the two analyzed parameters. The correlation plots and the Bland-Altman plots are shown in **Figure 6**.

Repeatability of automatic annotation method

As shown in **Table 3**, for the measurement of distance, the intra-observer ICC was 0.989 (95% confidence interval: 0.976, 0.995) and inter-observer ICC was 0.927 (95% confidence interval: 0.840, 0.968). For the parameter of radial angle, values of ICC were both 0.998 (95% confidence interval: 0.995, 0.999). Excellent repeatability was indicated by these results.

Discussion

In this clinical experimental study, we were able to demonstrate that the new annotation method can provide 3-D automatic annotation for breast ultrasound examination. The 3-D automatic annotation method helped save scanning time compared with the existed manual annotation method, especially for patients with more than one lesion. The annotation results showed excellent correlation with the current clinical annotation method. In addition to the spatial data used in conventional method, this developed method could provide probe tilt angle, which helped record the complete spatial information of the ultrasound image in 3-D space. All the spatial data could be stored and displayed using the developed software in the follow-up examination. Quantitative measurements in intra-observer and inter-observer assessment were reproducible.

In the light of potential future clinical application of the 3-D automatic annotation method, there were several limitations in this study. One limitation is that the detection range of the electromagnetic spatial sensor is 46cm (medSAFE Manual, Ascension Technology). In this study, to ensure that the patient was in the detection range, the transmitter was fixed on the scanning bed and the patient was asked to lie as near as possible to the transmitter. However, it is inconvenient for the scanning because the breast is close to the transmitter. In addition, the obese patients may be out of the detection range. To solve this problem, in the future study, a planar transmitter with larger detection range such as the Aurora sensor of Northern Digital (Hummel et al. 2008) can be used. In this study, before scanning, the patients had to remove all metallic wears and electronics goods to avoid the influence to the magnetic field. Another limitation is that the experimental results were obtained based on the condition that patients kept stationary and lightened their breath as possibly as she could. The involuntary movements or breath may cause errors to our annotation because these motions change positions of reference points while the new spatial data cannot be updated. Motion compensation has been studied in different fields such as surface modeling in reconstructive surgery and ultrasound imaging for residual limb assessment (Patete et al. 2009). One useful method is to place markers on the surface and use cameras to track these marks to further measure the movements (Patete et al. 2009; Sanders and Lee 2008). Another solution reported is the motion compensation methods based on image features (Douglas et al. 2002; Xue et al. 1997; Zheng et al. 2001). In this automatic annotation system, instead of increasing cameras, another spatial senor can be used to track the motion. This sensor can be attached on the body of patient and the data from this sensor are acquired in real time. The initial positional data is recorded. When there is movement, the difference can be obtained so the spatial data of reference points can be modified according to this difference. Another limitation of this new annotation method is the deformation of the soft breast tissue. During clinical breast ultrasound scanning, a certain force is applied on the breast when the probe sweeps across the breast. This force can cause the breast deformation, which may affect results of the annotation. Different methods have been proposed to solve the problem of soft tissue deformation (Crum et al. 2004; Gee et al. 2003; Guo et al. 2006; Khallaghi et al. 2012; Krucker et al. 2002; Leung et al. 2009; Lu et al. 2009a; Lu et al. 2009b; Treece et al. 2002; Xiao et al. 2002). One approach is the use of non-rigid registration methods (Crum et al. 2004; Guo et al. 2006; Leung et al. 2009). It was demonstrated that the registration method could help to correct the deformations over 85% in validation experiments (Krucker et al. 2002). Another study reported that the registration error was less than 0.19 mm when this method was used to register breast deformations on ultrasound images (Xiao et al. 2002). A feature-based registration algorithm was reported and the experiments demonstrated its potential for recovering non-rigid deformations (Khallaghi et al. 2012). The combination of non-rigid registration method and the optical sensing device has also been proposed to assess the deformations in 3-D ultrasound scanning (Gee et al. 2003; Treece et al. 2002). On the basis of these studies, non-rigid registration method will be developed for our annotation system to correct the breast deformation during the clinical scanning. Compared with conventional manual annotation method, time-saving is an obvious advantage of this developed annotation method, especially for patients with more than one lesion. However, in this study, only three patients with multiple lesions were analyzed. Additional studies are needed to specially study cases with multiple lesions to further demonstrate the value of the 3-D automatic annotation method. Considering the clinical applications, the use of a spatial sensor makes the scanning system more complicated. In addition, as previously described, the preparation work, including the computer setup and the spatial equipment initiation, also increases the setup time. In future study, the spatial sensor can be integrated to the ultrasound probe and the software can be combined into the interface of the ultrasound machine to facilitate the clinical use.

Despite these restrictions of this study, our results suggest that the developed annotation method has the potential to overcome limitations of the current manual annotation method. The use of quantitative spatial data from the spatial sensor instead of operator subjective estimation to annotate the ultrasound image is an important step toward more accurate diagnosis results. Another improvement is that automatic annotation procedure, which can help physician avoid high repetitive work and save examination time. This advancement has opened up the opportunity to provide breast ultrasound to more patients with current clinical conditions. The implementation of this developed annotation method is another milestone. Unlike the current 3-D ultrasound scanners (Kelly et al. 2010; Lin et al. 2012; Nelson and Pretorius 1998; Porter and Seck 2009; Rao and Varghese 2008; Shung 2002; Tozaki et al. 2010), which need a specially designed ultrasound machine, this method is based on the routine 2-D scanner and only a spatial sensor is attached on the probe. In addition, with the development of ultrasound technique, the electromagnetic spatial sensor has been integrated to the ultrasound scanner system (Thiele and Chang 2003). Based on such equipment, the 3-D automatic annotation method is easily to be implemented.

In conclusion, the present study indicated that the 3-D automatic annotation method was feasible in clinical breast ultrasound examination and had advantages compared with current manual annotation method. With the further improvement of this method and large-scale clinical tests, this new annotation method is expected to facilitate clinical breast ultrasound examination.

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Tables

Table 1. Scanning time comparison results of manual annotation method and the 3-D automatic annotation method

	Time for 1 lesion (s)		**Time for 2 lesions (s)**		**Time for 3 lesions (s)**
	Average	Range	Average	Range	One patient
Manual annotation	84.0	61.0-121.0	132.0	131.0-133.0	189.0
Automatic annotation	48.0	27.0-79.0	65.5	62.0-69.0	76.0
Difference	36.0	28.0-47.0	66.5	64.0-69.0	113.0

Table 2. Correlation results of distance to nipple and radial angle with 3-D automatic annotation method in comparison with manual annotation method

Parameter	P Value	Pearson r
Distance to nipple	<0.0001	0.933
Radial angle	<0.0001	0.995

Table 3. Repeatability results of the developed 3-D automatic annotation method in intra-observer and inter-observer assessment

	Intra-observer ICC	**Inter-observer ICC**
Distance to nipple	0.989	0.927
Radial angle	0.998	0.998

Figure Captions

Figure 1. A typical ultrasound display in breast examination. (a): the typical annotation components including the graphical pictogram and the textual sequence. (b): three common types of graphic pictogram.

Figure 2. The components and modules used for the 3-D automatic annotation system.

Figure 3. The software interface of the 3-D automatic annotation system.

Figure 4. The flow chart of the scanning procedure using the new 3-D automatic annotation method.

Figure 5. A typical annotation results of the manual and automatic methods for the same breast lesion. (a): the manual annotation result. (b): the automatic annotation result.

Figure 6. The scatter plots (left) and Bland-Altman plots (right) of the analyzed parameters for the two annotation methods. Excellent correlations were found between the two annotation methods. SD = standard deviation.

Figure 1

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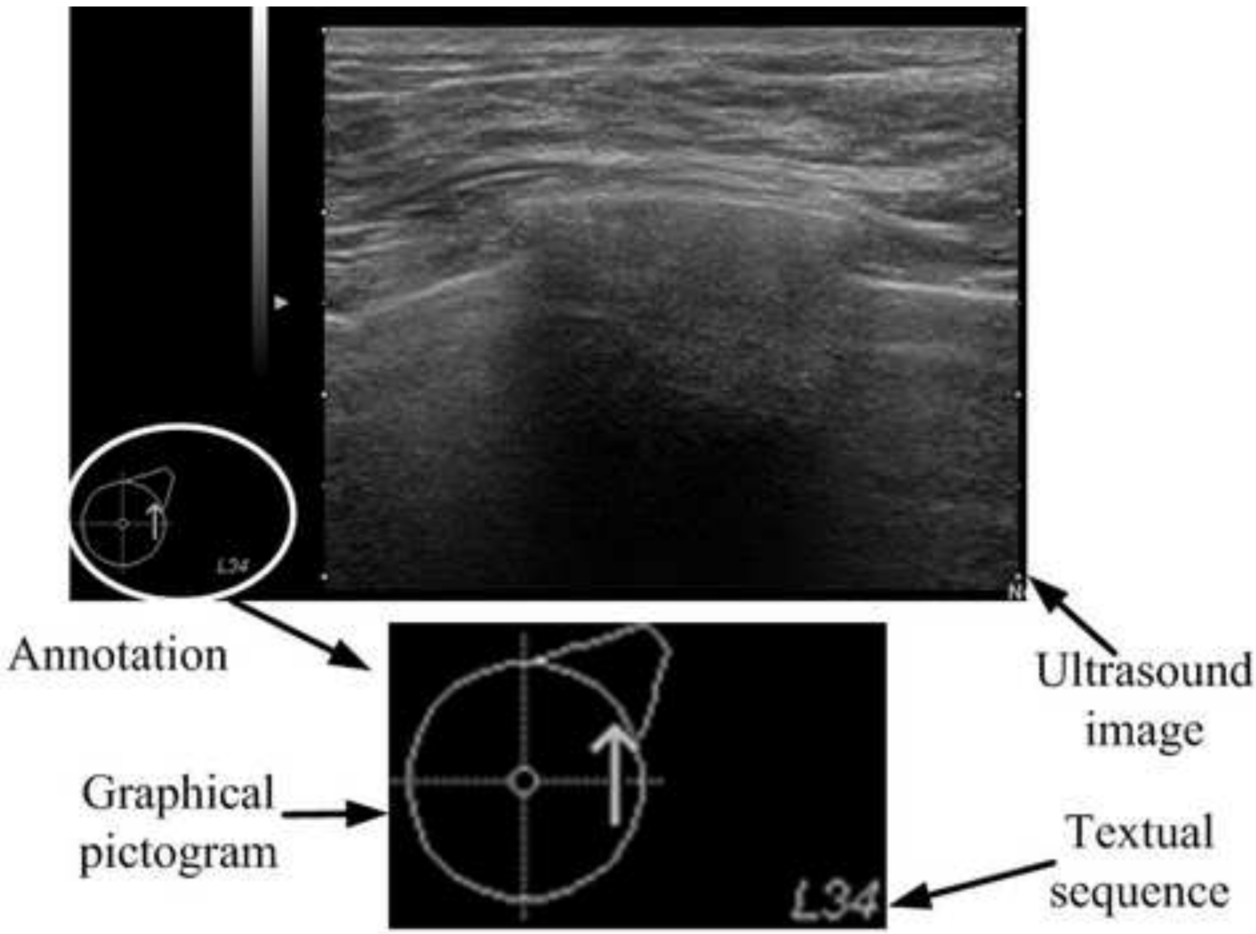
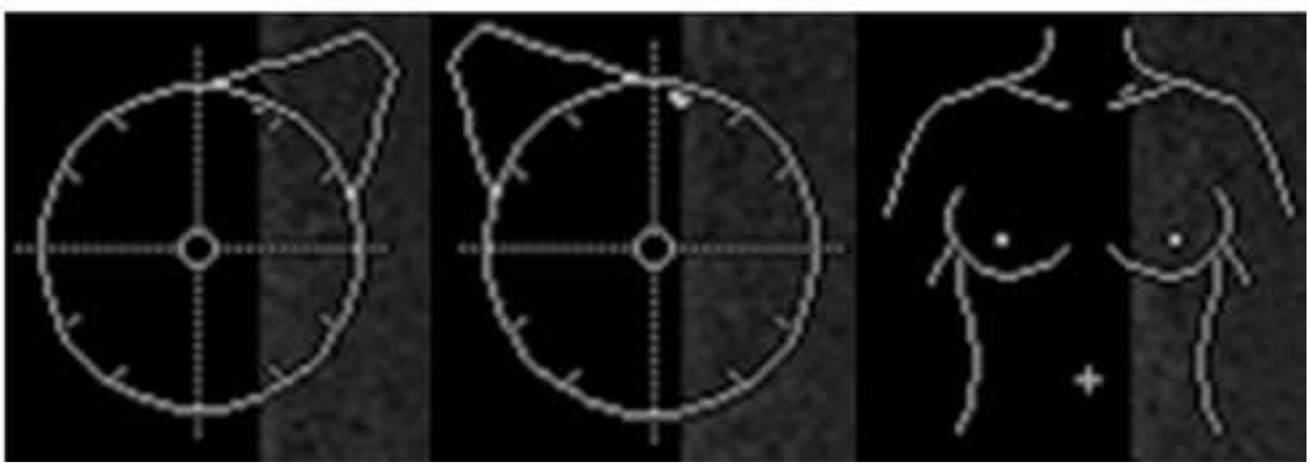
(a)



(b)



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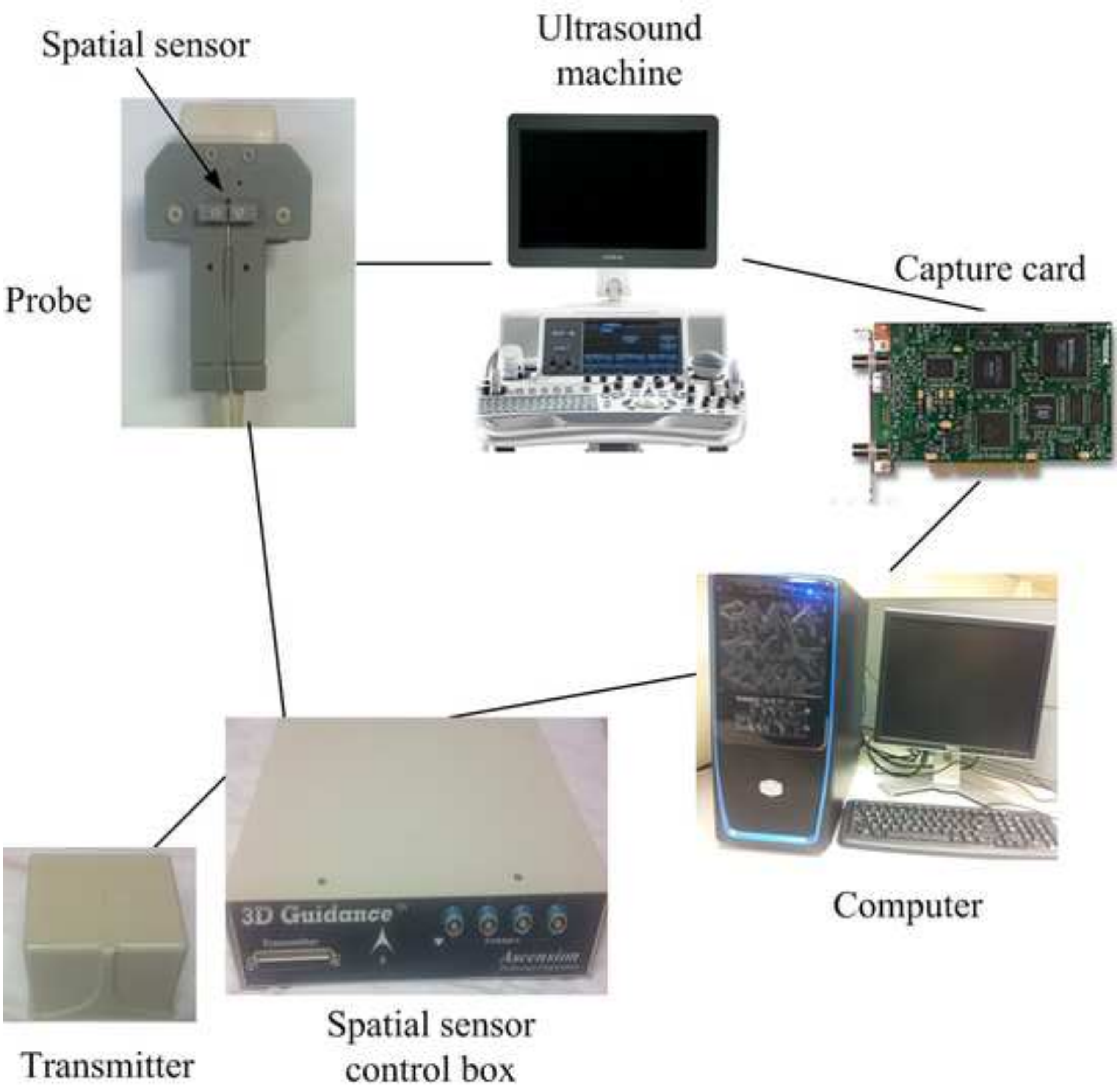

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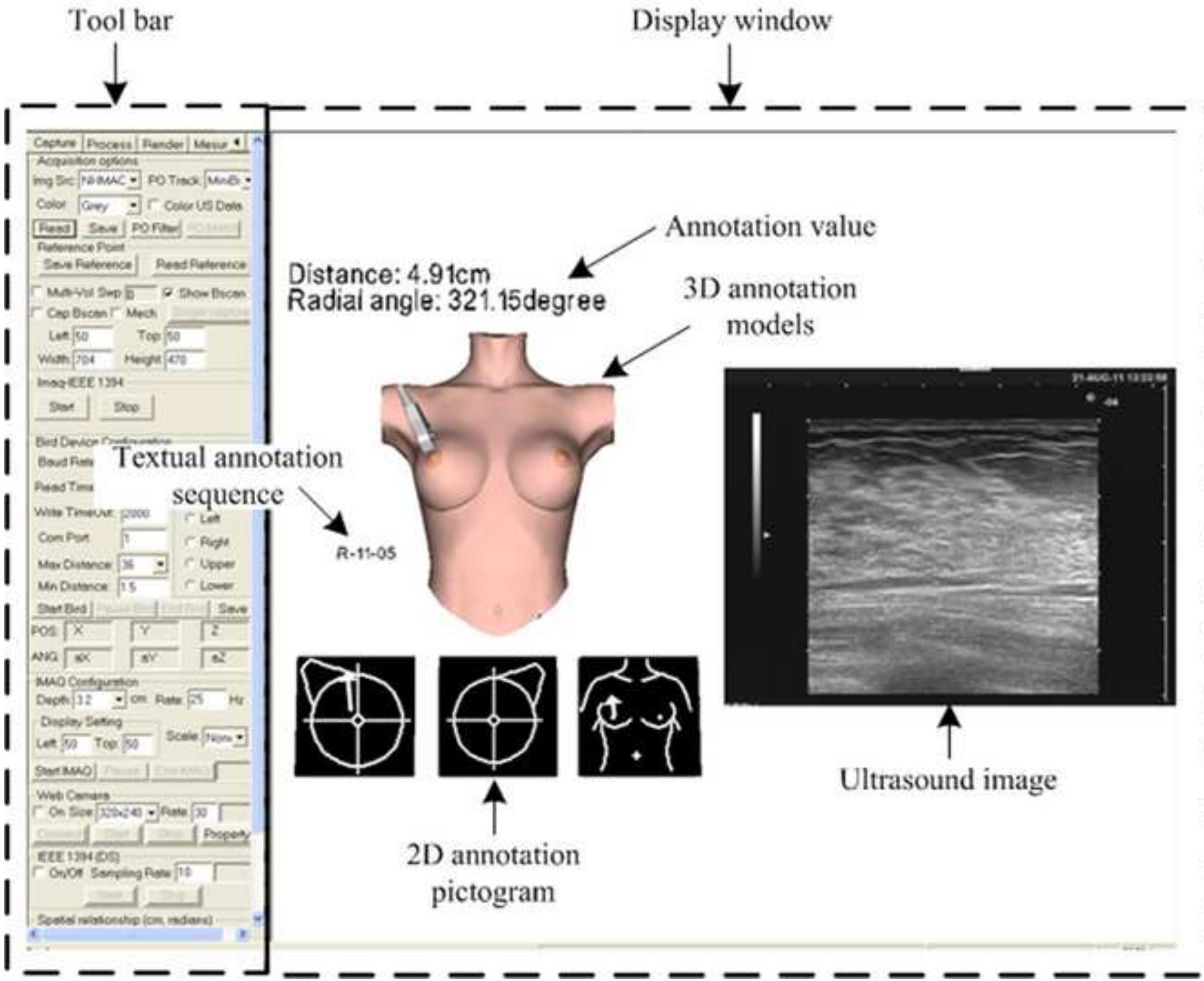

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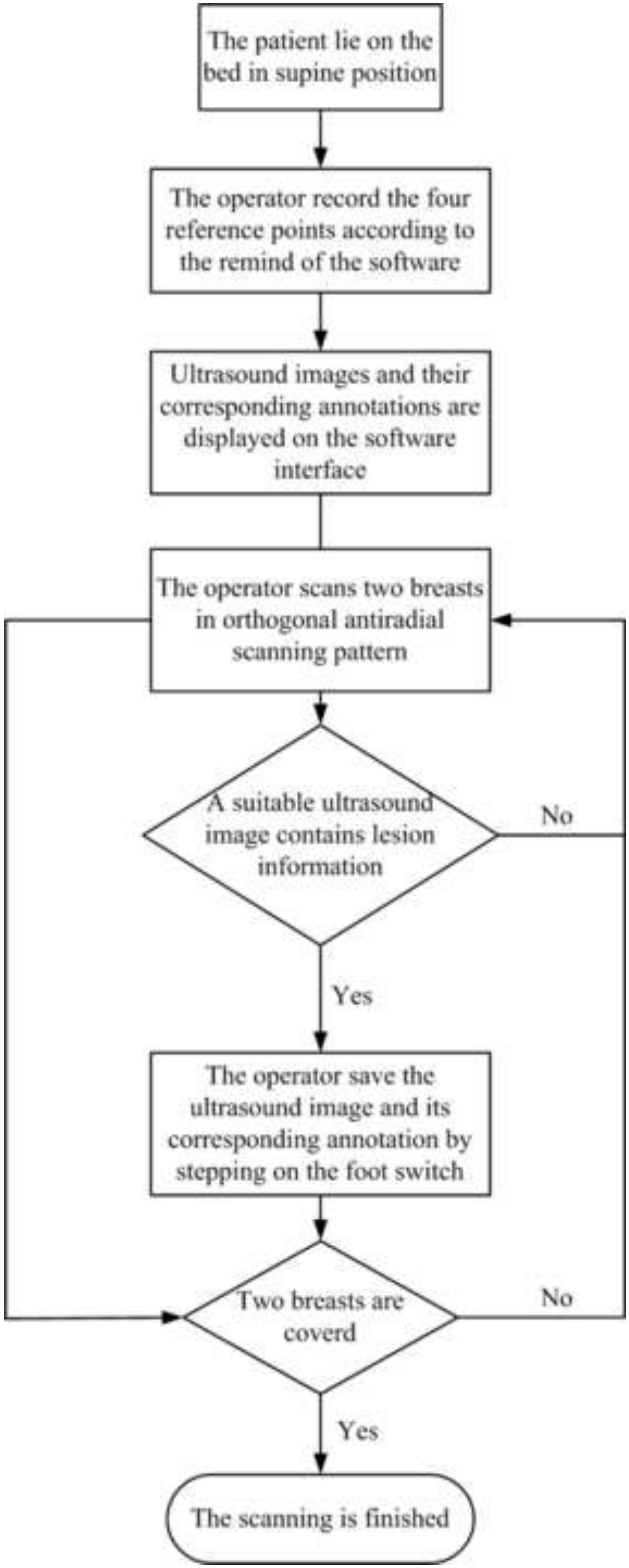

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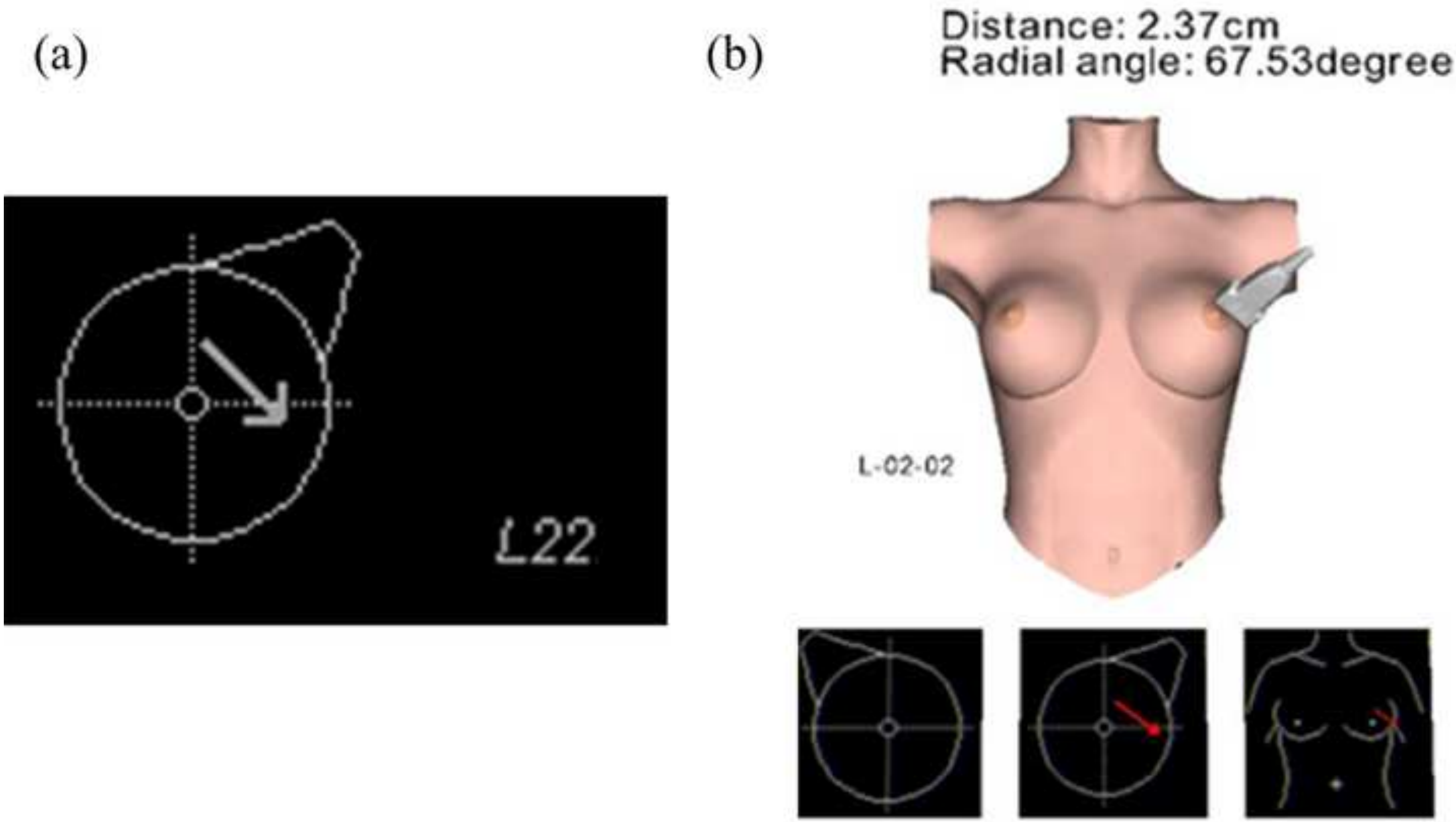

Figure 6
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