Flinders UNIVERSITY

Classifying breast masses in volumetric whole breast ultrasound data: a 2.5-dimensional approach

Gobert N. Lee[1]*, Toshiaki Okada[2], Daisuke Fukuoka[3], Chisako Muramatsu[2], Takeshi Hara[2], Takako Morita[4], Etsuo Takada[5], Tokiko Endo[6], and Hiroshi Fujita[2]

[1] School of Computer Science, Engineering and Mathematics, Flinders University, Sturt Road, Bedford Park, Adelaide SA 5042, Australia
[2] Department of Intelligent Image Information, Division of Regeneration and Advanced Medical Sciences, Graduate School of Medicine, Gifu University, 1-1 Yanagido, Gifu 501-1194, Japan
[3] Technology Education, Faculty of Education, Gifu University, 1-1 Yanagido, Gifu 501-1193, Japan
[4] Department of Mammary Gland, Chunichi Hospital, 3-6-38 Marunouchi, Naka-ku, Nagoya,Aichi 460-0002, Japan
[5] Division of Medical Ultrasonics, Center of Optical Medicine, Dokkyo Medical University, 880 Kitakobayashi, Mibu, Tochigi 321-0293, Japan
[6] Department of Radiology, National Hospital Organization Nagoya Medical Center, 4-1-1 Sannomaru,Naka-ku, Nagoya, Aichi 460-0001, Japan
*Correspondence author:gobert.lee@flinders.edu.au

Abstract. The aim of this paper is to investigate a 2.5-dimensional approach in classifying masses as benign or malignant in volumetric anisotropic voxel whole breast ultrasound data. In this paper, the term 2.5-dimensional refers to the use of a series of 2-dimensional images. While mammography is very effective in breast cancer screening in general, it is less sensitivity in detecting breast cancer in younger women or women with dense breasts. Breast ultrasonography does not have the same limitation and is a valuable adjunct in breast cancer detection. We have previously reported on the clinical value of volumetric data collected from a prototype whole breast ultrasound scanner. The current study focuses on a new 2.5-dimensional approach in analyzing the volumetric whole breast ultrasound data for mass classification. Sixty-three mass lesions were studied. Of them 33 were malignant and 30 benign. Features based on compactness, orientation, shape, depth-to-width ratio, homogeneity and posterior echo were measured. Linear discriminant analysis and receiver operating characteristic (ROC) analysis were employed for classification and performance evaluation. The area under the ROC curve (AUC) was 0.91 using all breast masses for training and testing and 0.87 using the leave-one-mass-out cross-validation method. Clinically significance of the results will be evaluated using a larger dataset from multi-clinics.

Keywords: ultrasound breast mass, classification, geometric feature, echo feature

1 Introduction

Mammography is very effective in breast cancer detection. It is the routine technique used in breast cancer screening in women who have no symptom of breast cancer. However, mammography is less sensitivity in detecting breast cancer in younger women or women with dense breasts. This is due to the inherited limitations of x-ray employed in the image acquisition in mammography. Breast ultrasonography is another long-standing technique in breast imaging and is a valuable adjunct in breast cancer detection. Distinguished from mammography, the technique employs acoustic waves and does not have the same limitation as mammography. However, it is not without its shortcomings.

Currently, ultrasound breast examination is routinely performed by an ultrasonographer or ultrasonologist. A small hand-held probe of size about 4 cm is used and the ultraonographer/ ultrasonologist runs the probe over the entire breast or pre-identified regions during an examination. The technique can provide very valuable information in the hands of experienced examiners but is in general time consuming. Results are operator independent and reproducibility is poor. A novel breast scanning system that can acquire the data of the entire breast quickly, systematically and repeatedly with precision will be of great advantage.

We have previously introduced a prototype whole breast ultrasound scanner for auto-acquisition of volumetric breast ultrasound data [1]. Diagnostic value of the data was investigated [2]. The volumetric ultrasound data of a whole breast consist of a stack of two-dimensional images, each depicting an axial slice image of the breast. In exploiting the benefit of volumetric data, three-dimensional analysis was used in our previous study in classifying malignant and benign breast masses [3].

One issue noted in our previous three-dimensional analysis was that the data was anisotropic. Anisotropic data are generally computationally cumbersome. One of the common practices would be to resample the data to create isotropic voxel. However, this would not be a good practice for our volumetric whole breast data as the resolution in one direction (z-direction, normal to the axial plane) is about 8 to 10 times lower than that in the other two directions. The discrepancy is large and a reliable model for interpolation cannot be guaranteed. Another option is to increase the number of data points in the z-direction in the raw data. This could be achieved by reducing the interval between adjacent slice images. Options for slice intervals are 2 mm, 1 mm and 0.5 mm. Corresponding unilateral breast study contains 84, 168 and 336 (axial) images, respectively, with acquisition time increases from 20, to 40 and 80 seconds, respectively. The increase in number of axial unnecessarily burdens the interpreters while longer acquisition time leads to problems such as image blurring due to patient movement. Neither of the above options is desirable in this situation as the first one relied on interpolated slice images of which accuracy of the image details to be employed in the computer-aided image analysis cannot be guaranteed. The second one imposes on a clinical practice to collect extra data which is a burden to the practice at no clear clinical benefits. After taken the above into consideration, this paper investigates the efficacy of a 2.5-dimensional analysis, a step between 2-dimensional and 3-dimensional analyses.

2 Method

2.1 Ultrasound Data

Volumetric full-breast ultrasound data were used in this study. The data included 63 breast masses. Of them 33 were malignant and 30 (16 cysts; 14 fibroadenomas) were benign. The malignant and benign masses were related to 29 and 24 breasts, respectively. All the masses were annotated by a radiologist experienced in breast ultrasound and the malignant masses were proven by biopsy. With the patient in prone position, a diagnostic ultrasound system Prosound-II SSD-5500 (Aloka Co., Ltd, Japan) and a prototype full-breast scanner ASU-1004 (Aloka Co., Ltd, Japan) (Figure 1) were used to acquire the full-breast images. The scanner ASU-1004 was equipped with a 5-10 MHz 6 cm linear probe. Operating in a fixed pattern, the probe scanned an area of 16×16 cm^2 in 3 sweeps, covering the full-field of a breast. The original scan images were B-mode breast section images in DICOM format with an overlap margin of 1 cm on each of the 'stitching' side. Volumetric full-breast data were generated by 'stitching' corresponding images in the 3 sweeps together (Figure 2). Details of the scanner can be found in [4-6].

The full-breast ultrasound scans were performed in the period 2003-2004 at the Center of Optical Medicine, Dokkyo University School of Medicine, Tochigi, Japan where a prototype full-breast scanner ASU-1004 was located. The size of each (stitched) B-mode image in the constructed volumetric full-breast data was 694×400 pixels with a spatial resolution of 0.23 mm/pixel and a slice-to-slice interval of 2 mm.

Figure 1. The prototype full-breast scanner ASU-1004 (right) with a patient in prone position (left).

The images had a gray scale resolution of 8 bits. For each mass, a series of axial slice images containing that mass is employed in the 2.5-dimensional analysis (Figure 3). Features are measured individually on each slice image. The same feature measured on difference slice images are combined at a later stage.

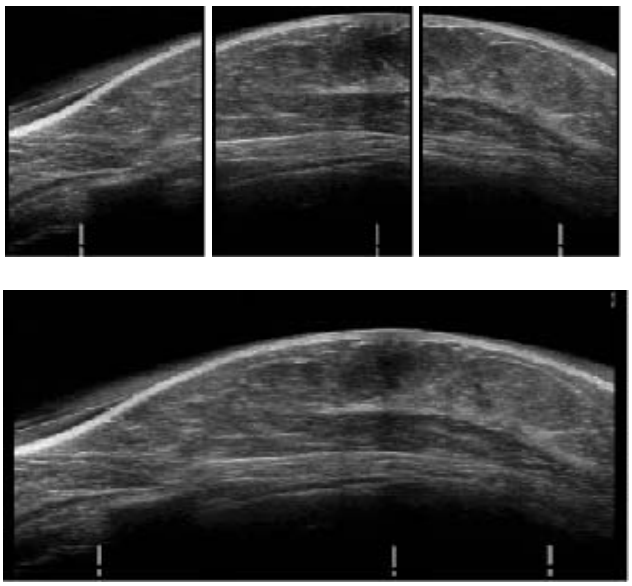

Figure 2. Corresponding breast section slice images in the 3 sweeps (above) are 'stitched' together to form a slice image in the volumetric full-breast data (below).

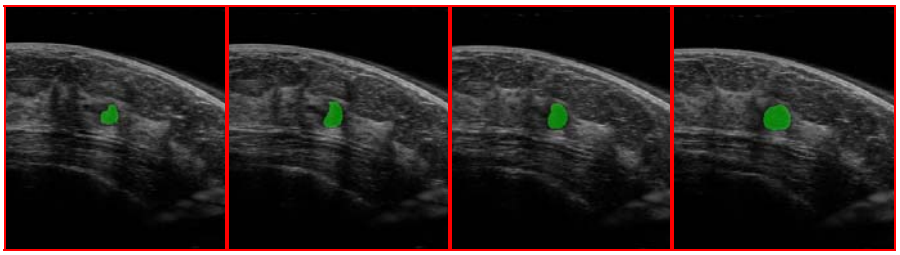

Figure 3. 2.5-dimensional analysis. In this example, a series of 4 images containing the mass were used in the analysis. The same set of features is measured on each images and is combined at a later stage according to a set rule.

2.2 2.5-Dimensional Analysis

For each mass lesion, a number of axial images containing the mass lesion were identified. The number of associated slice images depends on the size of the mass and the slice-to-slice interval. With the use of a 2 mm slice-to-slice interval and the lesion size ranges from 5 mm to over 3 cm in this study, the number of associated slice image for a mass varies from a minimum of 1 to 2 images to a maximum of over 10 images, with the majority being 4 to 6 images. With the series of slice images containing the mass lesion identified, lesion boundaries were delineated manually and lesions in each of the slice images were segmented.

After the segmentation process, features were measured on the lesions depicted in each of the slice images. Six features were defined. They were compactness, orientation, shape, depth-to-width ratio, homogeneity and posterior analysis. These six features were similar to the features selected in our previous study [3] and were based on the image features that radiologists' found useful and routinely consulted in breast ultrasound images interpretations. A summary of the six features is given in the next paragraph.

In general, compactness (C) measures the degree of roundness of an object and is given by

$$C = 4 \times \pi \times A / S^2 \qquad (1)$$

where A and S are the area and circumference of the object, respectively. Benign masses are usually round in shape while malignant masses are more likely to be irregular or oval in shape. Orientation measures the angle (in degrees) between the horizontal axis and the major axis of the ellipse that has the same second-moments as the object and is given by

$$\tan^2 \theta + \frac{M(2,0) - M(0,2)}{M(1,1)} = 0 \qquad (2)$$

where $M(p, q)$ is the pq^{th}-order moment and is given by

$$M(p,q) = \sum_{i,j} i^p j^q .$$

Depth-to-width (DW) ratio is another feature that can provide information of the orientation of an (elongated) object. This feature can be simply defined as the ratio of the height to the width of the smallest bounding box containing the mass. Homogeneity of the mass is computed using the variance of the intensity inside a mass. Benign masses such as cysts generally display homogeneity (small variance) inside the mass. Posterior echo is also another feature to distinguish benign and malignant lesions. The absence of posterior echo is an indicator of malignant lesion.

The above six features were measured on the lesions in each individual slice images. In other words, the six features were repeatedly measured on a series of mass cross-sectional images separated at a fixed interval of 2 mm.

The 2.5-dimensional analysis is based on features measured in a series of 2-dimensional images. For each breast mass, measurements of the same feature measured on a series of images are combined according to a rule which is feature-specific. For example, the depth-to-width (D/W) ratio measures the depth (vertical extent) of a mass to the width (horizontal extent) of a mass in a 2-dimensional image. Malignant lesions are more rigid and less compressible when subject to external force, hence the D/W ratio of malignant lesions is generally high. On the other hand, benign lesions such as cysts, which are usually filled with fluid or lipids, are more compressible and deformable. Hence, their D/W ratios are generally low. In other words, higher the D/W ratio, more likely is the lesion malignant. So in a 2.5-dimensional analysis, the maximum of the D/W ratios measured on a series of 2-dimensional images of a lesion is the strongest evidence for malignancy. Table 1 listed the rules in combining the multi-slice measurements of the same feature towards 2.5-dimensional analysis assuming strongest evidence for malignancy.

Table 1. Rules for combining multi-slice feature measurements in 2.5-dimensional analysis.

FEATURES	*2.5-DIMENSIONAL ANALYSIS*
Compactness	minimum
Orientation	maximum
Depth-to-width ratio	maximum
Posterior echo	minimum
homogeneity	maximum
Shape	maximum

3 Results

Linear discriminant analysis and receiver operating characteristic (ROC) analysis were employed for classification and performance evaluation. Discriminative powers of the six 2.5-dimensional features (combined over slice images) were analyzed in Table 2. The discriminative power of individual feature was indicated by the area under the ROC curve (AUC) obtained when using that feature alone in classifying the mass as benign or malignant. Both the resubstitution AUC using all breast masses for training and testing and the leave-one-mass-out cross-validation AUC are depicted. Table 2 shows that among the six features, three of them have strong discriminative power, namely, orientation, depth-to-width ratio and posterior echo.

When using all the six features for classification, the area under the ROC curve (AUC) was found to be 0.91 using all breast masses for training and testing (resubstitution) and 0.87 using the leave-one-mass-out cross-validation method.

Among a number of classifiers, linear discriminant analysis was chosen for its robustness. Its hyperplane decision surface makes it less susceptible for over-training which is preferable for studies with small samples.

Table 2. Discriminative powers of the six features indicated by the area under the ROC curve (AUC).

FEATURES	*AUC (resubstitution)*	*AUC (leave-one-mass-out)*
Compactness	0.64	0.64
Orientation	0.82	0.79
Depth-to-width ratio	0.83	0.84
Posterior echo	0.84	0.84
homogeneity	0.66	0.50
Shape	0.60	0.58

4 Discussion and conclusion

The classification based on 2.5-dimensional analysis in this study resulted in high accuracy in discriminating malignant and benign lesions in volumetric breast ultrasound data with anisotropic voxel. AUC indices in this study are in general high and similar to that based on 3-dimensional analysis in our previous study [2]. However, direct comparisons cannot be made. This is because the sample sizes in the two studies were different (63 masses in this study and 36 in the previous 3-d study) and shape feature was introduced in the current 2.5-dimensional analysis but not in the previous 3-dimensional study. In addition, though features definitions are very similar in the two studies, different algorithms were used to compute the features in the two studies. Slight variations in the interpretation of individual features may exist.

Plan for further work in this project is two-folded. (1) a larger database is required to confirm the results in this study. (2) Classification categories will also be extended to include normal breast tissue lumps and other artifacts in the breast which are the false positives found in the detection stage.

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