Breast Tumour Visualization Using 3-D Quantitative Ultrasound Methods

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ABSTRACT

Breast cancer is one of the most common cancer types accounting for 29% of all cancer cases. Early detection and treatment has a crucial impact on improving the survival of affected patients. Ultrasound (US) is non-ionizing, portable, inexpensive, and real-time imaging modality for screening and quantifying breast cancer. Due to these attractive attributes, the last decade has witnessed many studies on using quantitative ultrasound (QUS) methods in tissue characterization. However, these studies have mainly been limited to 2-D QUS methods using hand-held US (HHUS) scanners. With the availability of automated breast ultrasound (ABUS) technology, this study is the first to develop 3-D QUS methods for the ABUS visualization of breast tumours. Using an ABUS system, unlike the manual 2-D HHUS device, the whole patient's breast was scanned in an automated manner. The acquired frames were subsequently examined and a region of interest (ROI) was selected in each frame where tumour was identified. Standard 2-D QUS methods were used to compute spectral and backscatter coefficient (BSC) parametric maps on the selected ROIs. Next, the computed 2-D parameters were mapped to a Cartesian 3-D space, interpolated, and rendered to provide a transparent color-coded visualization of the entire breast tumour. Such 3-D visualization can potentially be used for further analysis of the breast tumours in terms of their size and extension. Moreover, the 3-D volumetric scans can be used for tissue characterization and the categorization of breast tumours as benign or malignant by quantifying the computed parametric maps over the whole tumour volume.

Keywords: 3-D imaging, automated breast ultrasound (ABUS), breast cancer, quantitative ultrasound, tumour visualization

1. INTRODUCTION

According to the World Health Organization, every year, about 1.4 million women are diagnosed with breast cancer worldwide, which accounts for 25% of all cancer cases [1]. It resulted in 1.68 million cases and about half a million deaths in 2012 [1]. An early cancer detection and treatment plays a vital role in increasing the survival rate of patients with breast cancer. Currently, mammography is the most common imaging modality for breast cancer screening. However, mammography has two main drawbacks in screening breast cancer: first, it exposes to ionizing radiation that may cause health problems in longitudinal screening and second, its screening ability to identify abnormal structures such as cancerous tumours significantly declines in cases with dense breasts [2]. Considering the high percentage of women with dense breasts (e.g., in United States, over 46% of all women [3] and over 74% of women in ages between 40 to 49 years [4] have dense breasts), the latter limitation of mammography imposes a high risk on monitoring breast cancers. The problem is more serious as there is an increased risk of developing cancer in women with dense breasts [5].

In this context, *quantitative ultrasound* (QUS) methods provide a promising framework that can non-invasively and inexpensively be used for the early detection of breast cancer in real-time mode [6]. QUS techniques have also been applied to a variety of other tissue characterization applications to detect tissue abnormalities in, for example, the eye [7], the prostate [8], and the myocardium [9].

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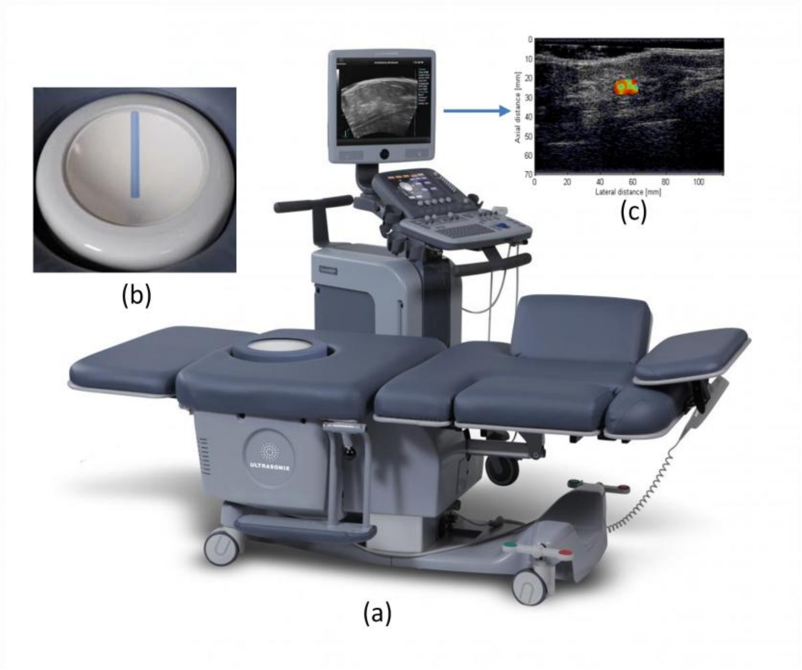

Figure 1- (a) Ultrasonix SonixEmbrace^{TM} automated breast ultrasound (ABUS) System, (b) concave L14-5/115 transcducer, (c) two-dimensional parametric map overlaid on the corresponding B-mode image.

Despite recent advances in QUS methods, these techniques are currently limited to 2-D analysis and visualization [10-19]. This is mainly because these methods are based on images acquired using hand-held ultrasound (HHUS) devices. Image acquisition using HHUS, however, is relatively time consuming and highly dependent on the experience of the sonographer, in addition to providing only a partial 2-D view of the breast. These limitations have recently been mitigated by the introduction of automated breast ultrasound (ABUS) technologies [20-23]. ABUS performs automatic, therefore, operator-independent image acquisition from each breast in relatively short time (< 2 minutes). It also enhances the localization of tumour in 3-D within the breast.

In this work, for the first time, ABUS system was used in conjunction with QUS spectral and backscatter coefficient (BSC) methods to provide a 3-D visualization of breast tumours. This can potentially improve the performance of a tissue characterization system based on the QUS methods as a true volumetric analysis of the tumour becomes feasible.

2. METHODS

2.1 Ultrasound data acquisition

Data was acquired from 10 patients over the last 4 months. Ultrasound B-mode and raw radiofrequency (RF) data were acquired using a SonixEmbrace^{TM} (Ultrasonix Med. Corp., Richmond, BC, Canada) ABUS system (Figure 1a) equipped with a concave L14-5/115 transducer (Figure 1b) with the centre frequency of 5.8 MHz and an adjustable imaging bed. The patient lay on the bed in prone position with the breast resting in the imaging dome. The custom concave US transducer embedded into the imaging dome rotated around the entire breast by an automated step motor capturing 154 2-D frames with a known angular radial distance.

2.2 Quantitative ultrasound analysis

The analysis of ultrasound RF data was performed across all frames with identifiable tumour regions by selecting a region of interest (ROI) containing the tumour. Power spectra were calculated using a Fourier transform of the raw radiofrequency data for each scan line through the ROI using a sliding window method. Data were normalized with the averaged power spectrum obtained from an agar-embedded glass-bead phantom model [24]. Linear regression analysis was performed on the averaged power spectrum within a central-frequency based -12 dB window to generate a best-fit line[25]. Three *spectral* parametric maps were subsequently computed including the normalized power at the centre frequency termed as mid-band fit (MBF), spectral intercept (SI) as the intercept of the fit line to the vertical axis, and spectral slope (SS), which was the slope of the fit line. The same normalized power spectrum was used to estimate the *backscatter coefficient* (BSC) parameters over the ROIs using the reference phantom technique [26]. Subsequently, by a least-squares fitting of the Gaussian form factor to the BSC, parameters of this form factor were computed [27], which were corresponding to the maximum coefficient of determination. The parameters computed were including effective acoustic concentration (EAC) and effective scatterer diameter (ESD).

2.3 3-D Visualization

The concave transducer of the ABUS system scanned the breast by rotating around the centre of the dome (see Figure 1b), collecting the frames radially. Therefore, the image acquisition was essentially performed in polar coordinates. Hence, for a 3-D rendering of the parametric maps, the frames could not simply stack on top of each other, and a conversion from polar to Cartesian coordinate was required as a pre-processing step. The conversion was performed with the known angular space between the successive frames as well as the known radius of the dome/transducer. Since the frames were acquired in discrete angular positions, an interpolation was needed as an intermediate step to obtain all X, Y, and Z coordinates of the entire tumour volume. The resulting 3-D matrix was eventually visualized using a transparent color-coded rendering code to enable observation of different layers of the entire tumour all at once.

3. RESULTS

The study involved 10 patients from the ages of 31 to 67 (53 ± 12/mean ± SD), among which two patients were confirmed as having malignant masses and the other 8 as benign cases. Figure 2 displays the results of 3-D visualization of a representative breast tumour using the proposed method for the spectral and BSC parametric maps. The size of tumour and its extension can be read from the axes. The colour bar indicates the range of changes for each parametric map. A transparent rendering was performed to enable visualization of the tumour in all layers at once. Tumours appeared less defined in terms of their borders compared to benign cases. Benign cases also demonstrated more homogenous internal structure compared to tumours.

4. CONCLUSIONS

In this study, automated breast cancer (ABUS) ultrasound machine was used, for the first time, in conjunction with quantitative ultrasound methods to provide a 3-D volumetric visualization of breast tumours. The entire tumour was visualized using a transparent color-coded QUS spectral and backscatter coefficient parametric map. Consequently, the changes in QUS parametric maps could be visualized inside the tumour, which could potentially ease the subsequent analysis of the tumour. In future work, we will provide the visualization of the 3-D parametric maps within the B-mode images. Moreover, the volumetric parametric maps will be rendered in three different planes including sagittal, axial, and coronal planes overlaid on the B-mode images of the corresponding frames. A moving bar will facilitate displaying the planes at any desired point inside the tumour. The 3-D volumetric tumour could also be further analyzed for tissue characterization and discrimination between benign and malignant tumour types.

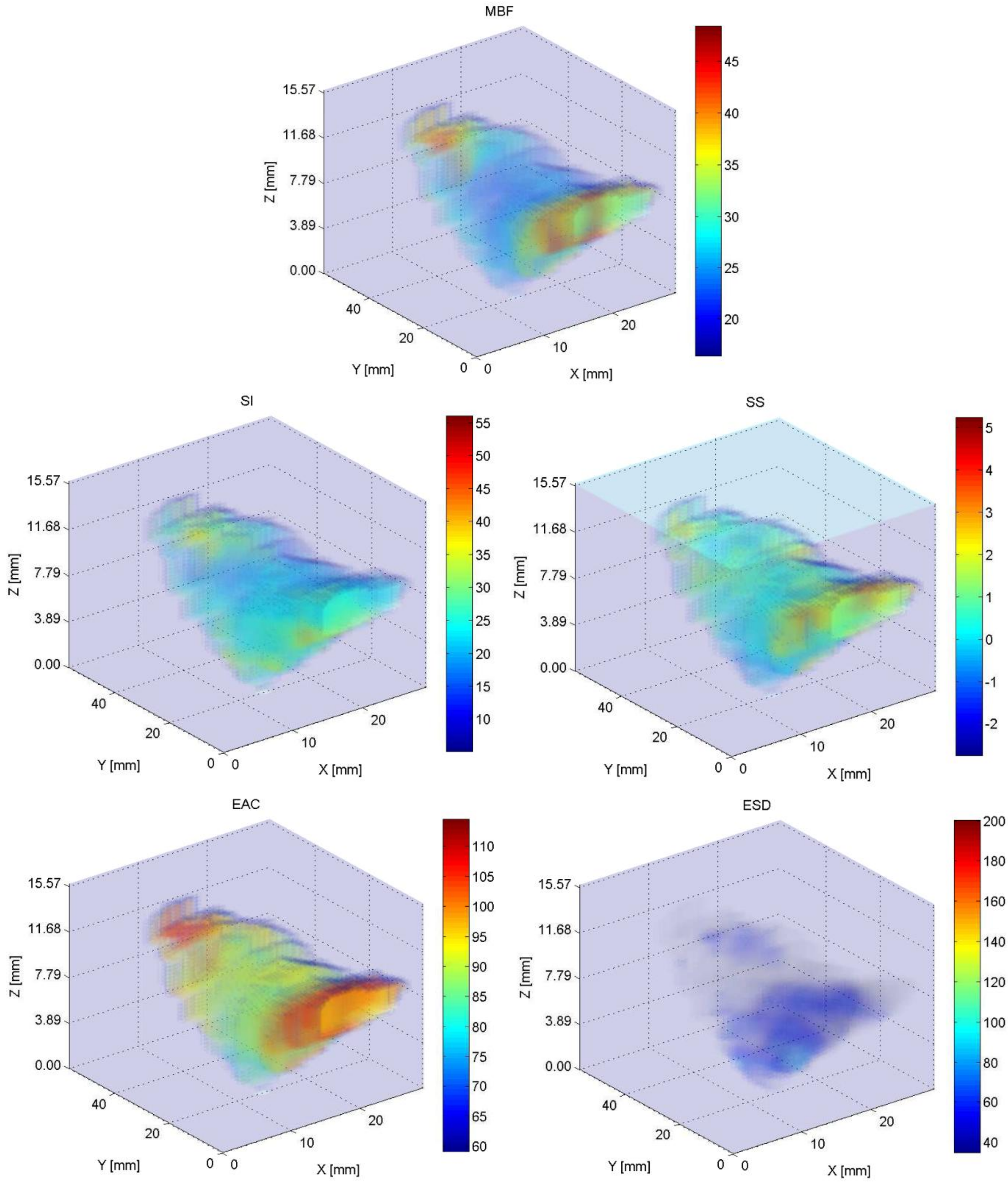

Figure 2-Three-dimensional rendering of a breast tumour using spectral and backscatter coefficient parametric maps computed on the ROIs selected from the frames acquired using an ABUS system.

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