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Research paper

Data mining framework for breast lesion classification in shear wave ultrasound: A hybrid feature paradigm

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ABSTRACT

Assessment of elasticity parameters of breast using ultrasound elastography (USE) provides exclusive information about the cancerous tissue. Shear wave elastography (SWE), a new USE imaging procedure is increasingly used for elasticity evaluation of breast lesions. SWE examination is gaining popularity in the characterization of benign and malignant breast lesions as it has high diagnostic performance accuracy. However, some degree of manual errors, such as probe compression or movement may cause inaccurate results. In addition, the systems cannot measure elasticity values in small lesions where the tissues do not vibrate enough. Thus, computer-aided methods suppress these technical or manual limitations of SWE during evaluation of breast lesions. Therefore, this paper proposes, a novel methodology for characterization of benign and malignant breast lesions using SWE. Original SWE image is subjected to *three* levels of Discrete wavelet transform (DWT) to obtain different coefficients. Second order statistics (Run Length Statistics) and Hu's moments features are extracted from DWT coefficients. Extracted features are subjected to sequential forward selection (SFS) method to obtain the significant features and ranked using ReliefF feature ranking technique. Ranked features are fed to different classifiers for automated characterization of benign and malignant breast lesions. Our proposed technique achieved a significant accuracy of 93.59%, sensitivity of 90.41% and specificity of 96.39% using only *three* features. In addition, a unique integrated index named ***Shear Wave Breast Cancer Risk Index (sBCRI)*** is formulated for characterization of malignant and benign breast lesion using only *two* features. The proposed index, *sBCRI*, provides a single number which characterizes the malignant and benign cancer faster. This system can be employed as an ideal screening tool as it has high sensitivity and low false-positive rate. Hence, the women with benign lesions need not undergo unnecessary biopsies.

1. Introduction

Breast cancer is one of the leading cancers (malignancies) in women and the second primary cause of cancer-associated deaths [11,56,119]. According to World Health Organization (WHO), in 2011, more than 508,000 breast cancer deaths are reported in women worldwide [112]. It is reported that, 1.8 million women are diagnosed with breast cancer worldwide in 2013 [48] and it is projected that in 2016, in the United States of America (USA) alone, approximately 246,660 new cases of invasive breast cancer will be diagnosed among women [23].

Breast cancer is the result of uncontrolled multiplication of cancer cells in the breast and commonly it begins at the lobes of mammary glands [1]. This group of rapidly dividing cancer cells in the breast may eventually form a lump known as breast tumor. Breast lesion can be benign (not cancerous) or malignant (cancerous) depending on their characteristics and the degree of risk they carry [1]. Imaging of breast lesions is now regarded as essential in addition to the clinical diagnosis of breast malignancies [122]. Mammography and ultrasound (US) remain as the standard front line techniques for both screening and symptomatic disease evaluation. However, mammography performed on the dense breast may frequently produce false-negative results [22,68,69,101] and

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thus delay the diagnosis of cancer. Few studies have demonstrated that adding an US scan to screen women having the dense breast tissue together with a mammography can detect additional cancers per 1000 women [20,55]. Even though the US is highly sensitive [106,126] when applied to dense breast, lack specificity [19,31] resulting in an alarming number of false-positive; thus increasing the rate of unnecessary biopsies [49,101]. Report suggests that, using conventional US, it is difficult to precisely distinguish isoechoic lesions from the surrounding fat [89]. Therefore, despite of having regular screening tests, the breast cancers fail to be diagnosed at an early curable stage.

Clinically, it is essential to evaluate the lesion location surrounding tissue and the lesion characteristics such as size and shape according to the Breast Imaging-Reporting and Data System (BI-RADS) criteria using either mammography or an US for characterization of malignancies [87]. The primary characteristics of breast lesions include the clarity and contour of the lesion margins, the orientation and shape of the lesion, boundary echoes, the echo texture and echogenicity [17,61,106,109]. In addition, the lesion compressibility and vascularity may also be evaluated. Benign breast lesions appear round, oval minimally lobulated in shape with intense boundary echoes and homogenous internal echoes [8,18,106]. While the malignant breast lesions appear without proper margin or boundary, and may exhibit heterogeneous echo patterns, and an increased anteroposterior dimension [106]. Breast US can be used to characterize these physiological and pathological characteristics of both palpable and nonpalpable breast lesions [18,106]. Despite this, it lacks fundamental and quantitative information on the tissue elastic properties as cancer tissue is harder, stiffer (less elastic) and less compressible compared to normal breast tissue [43,102]. Moreover, improved breast US imaging modalities such as US tomography [37,98] and multi-modal US tomography (ultrasound transmission tomography (UTT) and ultrasound reflection tomography (URT)) [94,125] are intensively becoming effective in assessing the breast lesion characteristics [94,98]. Although the initial results are promising, further work with larger set of breast cancer patients are required to demonstrate their diagnostic efficacy before clinical application [94,98].

Currently, to conquer these limitations and attain more precise lesion characterization, breast US elastography (USE) is introduced [13,15,35,54,99]. Breast USE technique is used in breast lesion assessment and characterization [60]. Numerous works testified that it can improve the B-mode US specificity in distinguishing the malignant and benign breast lesions [27,28,60]. It is used to assess the tissue deformity (elasticity) and quantify the stiffness of the tissue [60,93,103].

Among the two available USE techniques such as strain elastography (SE) and shear wave elastography (SWE) [116], SWE is the only one that is highly reproducible [32,40,50,88]. In SWE, transversely aligned shear waves are produced by an acoustic radiation force during the application of an ultrasound probe to the tissue [77]. The waves travel faster in stiff (hard) tissues than in soft tissues [49]. For every pixel in the region of interest (ROI), it provides an image with color-code presenting the shear wave elasticity (kilopascals, kPa) or velocity (m/sec) [115]. Commonly, a color scale of 0 (dark blue) is used for the soft breast lesions and +180 kPa (red) for hard lesions [77]. In addition to the qualitative parameters (lesion and an adjacent tissue stiffness, lesion size, shape, and rim stiffness), quantitative parameters of the lesion such as mean elasticity (Emean), maximum and minimum elasticity (Emax, Emin) and elasticity ratio (Eratio) can be assessed using the SWE and are used in classification of benign and malignant breast lesions [10,67].

According to a study, elasticity parameter measured in the breast lesions (benign lesions <80 kPa and malignant lesions >100 kPa) can be a good indicator for differentiation of benign and malignant lesions [108]. Various cutoff values for the elasticity parameters such as 80 kPa [24], 30 kPa [78] and 65 kPa [21] are proposed by different studies [21,25,39]. Olgun et al. [91] assessed the minimum, mean and maximum elasticity values with different cutoff in differentiating the malignant from benign lesions using a SWE. The study results showed the sensitivity and specificity of (i) 96% and 95% for the mean elasticity with a cutoff value of 45.7 kPa, (ii) 95% and 94% for the maximum elasticity with a cutoff value of 54.3 kPa, and (iii) 96% and 95% for the minimum elasticity with a cutoff value of 37.1 kPa respectively. In general, the velocity is higher for the stiffer tissue in order for the waves to travel through them. The simple lumps produce 0 velocity, because of the presence of non-viscous fluids in which the shear waves do not travel [16]. Thus, using the SWE, the degree of tissue deformation is evaluated where the stiffer tissues infiltrated with cancer deform less and stiffer (less elastic), thereby can be easily differentiated from the normal and benign surrounding tissues [71]. Various research studies are conducted for evaluating these quantitative SWE parameters in order to differentiate the malignant breast lesions from benign breast masses [21,25,40,52,66,75,76,110,114,29]. Table 1 summarizes a few of the studies on breast lesion identification using the SWE image parameters. In most of the studies, the SWE parameters are significantly higher for malignant breast lesions than the benign cases [21,25,39,76,110,123]. The mean stiffness elasticity has been found to be a useful parameter in yielding an accurate benign and malignant differentiation of solid masses [40]. In addition, for invasive breast cancers, it is shown that the breast lesions are stiffer compared to the normal lesions [41] and often produce areas of stiffness that are larger than the gray-scale abnormality generated by B-mode ultrasound [60].

However, often during the breast SWE assessments, difficulties are faced in inferring the significance of elasticity values, due to the various scanning angles providing different elasticity values. The reason for these difficulties is that breast lesions are heterogeneous and three dimensional structures [44]. To resolve this issue, Kim et al. [64] conducted a study for evaluating the effect of scanning angle on the diagnostic performance of the SWE in discriminating the breast malignancy from benign lesions. Results propose that the use of two orthogonal views that capture the images will increase the diagnostic performance of breast SWE.

Many recent studies suggest that the SWE improved the diagnostic performance accuracy and specificity of conventional US alone in the diagnosis of breast lesions [21], [26,40,75,76,82,110,113,124]. By adding SWE, about 90% of 4a masses are downgraded to BI-RADS category 3, thus, unnecessary biopsies on the benign lesions can be reduced [12,25,39,80,117]. However, it is observed that the small breast cancers are not as stiff as the larger cancers, indicating that the tumor size as well as the specific histological type can also affect the stiffness value [44,76]. In contrast, it has been reported that the diagnostic performance of elastography is better than the conventional US in the characterization of small masses (1 cm) [86]. Therefore, in 2015, Kim et al. [65] evaluated the diagnostic performance of SWE features combined with an US in the assessment of small ($\leq$ 2 cm) lesions. The study reported that by combining the two techniques, specificity increased and the number of unnecessary biopsies can be reduced while evaluating the small breast lesions. It is also shown that the breast lesion stiffness quantitatively measured by the SWE is a helpful predictor of under-estimated malignancy in an US-guided 14-gauge core needle biopsy (CNB) [95]. Lee et al. [79] claimed that the SWE is highly sensitive in an accurate identification of the presence of residual breast malignant lesions even after a neoadjuvant chemotherapy (NAC) and showed an improved diagnostic performance (sensitivity 83.6% and specificity 80%) compared to the B-mode US (sensitivity 72.1% and specificity 50%).

Recently in 2016, Ng et al. [90] investigated the efficiency of the SWE in classifying benign and malignant using 159 SWE breast

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