Implementation and evaluation of elastographic techniques

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Abstract

Elastography is an ultrasound based imaging technique used to explore the elastic properties of tissues by detecting their mechanical response to an external or internal stimulus. Changes in elasticity are associated with some pathologies like cancer, and hence, elastography is an important tool for the diagnosis of these diseases. The present work addresses the implementation of an image compounding technique using one of these elastographic techniques and reports the results obtained with an elasticity tissue-mimic phantom. Our study includes Acoustic Radiation Force Impulse Imaging (ARFI), which uses the acoustic radiation force (ARF) to produce the stimulus (internal force). The strain image is formed from longitudinal displacement calculation by means of a correlation algorithm. A spatial compounding image is generated by moving the array probe combining individual images, increasing the field of view and improving lesions evaluation. The final objective of this work is to integrate elastography in a multimodal imaging system aimed to the early diagnosis of breast cancer.

1. Introduction

When an elastic body is subject to an external force, its deformation is inversely proportional to the elastic modulus, which accounts for its stiffness along the force direction. This mechanical property is known as elasticity, and can be used to distinguish between different materials based on their hardness. In the case of biological tissues, changes in elasticity are correlated with pathological phenomena like cancer, which appears as hard nodules (Ophir et al., 1991). In the particular case of breast, we can find mainly three kinds of normal tissue: glandular (mammary glands), adipose (fat) and supporting tissue (stroma, collagen and fiber), which are all less stiff than pathological tissues. With age, glandular tissue is subjected to an involution process and it’s transformed into fat, so the breast, after menopause is more uniform, facilitating the manual palpation to detect hard pathologies. However, in the case of premenopausal breast, the detection of hardness through palpation is more difficult. Furthermore, the involution and other dynamic changes in glandular tissue are the source of almost all pathologies in the breast, and hence, early detection of abnormal tissue at a young age is of great value for early diagnosis. Most used techniques for breast

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cancer detection are mammography and ultrasound, being the first the preferred tool for screening. This X-ray based technique is capable of distinguishing microcalcifications and other irregular densities, which are the main candidates recommended for biopsy. However, this technique is uncomfortable and painful and presents some problems, particularly noticeable in the case of dense breasts, where the detection of lesions is more difficult. Conventional ultrasound is a complementary tool used for imaging the breast. It is a non-ionizing, economical and painless technique that shows in real time the morphology of the different structures, based on their acoustic impedance differences. It provides high-contrast images allowing a cleaner distinction between solid mass and fluid filled cysts. The weaknesses of echography are its dependence on operator skills, low repeatability and lack of resolution to detect micro calcifications. In any case, none of these techniques are able to differentiate between hard and soft tissues.

Elastography is a recent ultrasound image modality, able to provide qualitative or quantitative images of tissue elasticity. It assumes that tissues are elastic, isotropic and locally homogeneous, which applies to glandular and adipose tissue. All elastographic methods are based on applying stress to the tissue and measuring its response, but they differentiate in the way this stress is applied. The first techniques (Ophir et al., 1991), applied a static compression to deform the tissue. From the comparison (by cross correlation) of two B-scan, one taken before compression and another one taken after compression, a strain map is obtained, which is an indirect measure of elasticity. More recent techniques as ARFI (Nightingale et al., 2001), replace the static external compression by an impulsive internal force, using the acoustic radiation force generated by the propagation of focused ultrasound beam in lossy media. Another approach, used in techniques as Supersonic shear imaging (SSI) (Bercoff et al., 2004), is to generate shear waves inside the tissue using impulsive radiation forces as in ARFI. Their propagation speed allows obtaining the shear modulus, which in soft tissues (practically incompressible) is directly proportional to the Young modulus. In all cases, elasticity maps are obtained by comparing two or more B-scan acquired with commercial echographs, so they have the same problems as conventional ultrasound imaging due to operator dependence: It requires long scan time and some skill to locate the lesions, and it’s no possible to generate a spatially referenced data volume to be compared in future examinations.

Several automatic imaging systems have been proposed to overcome this limitation (Stozka et al., 2004; Waag et al., 2006; Duric et al., 2005). Our group is developing a multi-modal automated system for breast echography (Camacho et al., 2012), based on a ring transducer with a large number of elements, which surrounds a hanging breast immersed in a water bath. This configuration provides 2D images with high resolution and contrast, which can cover a 3D volume by displacing the ring array in the breast axis direction. The first prototype was constructed with conventional phased array probes that rotate around the breast emulating the ring array. At each position, a single B-scan is obtained, and their combination (image compounding) results in a higher resolution and better contrast-to-noise ratio image.

In this work, we propose to perform this compounding process using ARFI images, instead of reflectivity B-scans. Besides increasing the field of view, it is expected that image quality is also increased. ARFI (Nightingale et al., 2001) is an elastography modality that uses pulsed beams to generate an acoustic radiation force that produces displacement inside the tissue, which are tracked using correlation methods. The beam sequences consist of tracking and pushing beams: The first are standard diagnosis B-mode pulses and the second are high intensity pulses but with a length lower than 1 ms, causing displacement of the order of micron.

2. Method

The experimental arrangement is presented in Fig. 1.a, where a standard medical breast phantom (Blue Phantom, USA), that includes structures with different elasticities to mimic masses and cysts, is placed inside a water tank. A linear 128 element array (Prosonic, Korea) with a center frequency of 5 MHz is attached to a stepper motor system that allows positioning it with high mechanical resolution and low hysteresis. Signal excitation and acquisition were performed with a Sitau-112 phased array system (Dasel, Spain) with 128 parallel pulse-echo and through-transmission channels. Custom developed scripts for Matlab (Mathworks Inc, USA) were used to control the motor movement, acquiring ultrasonic data and processing ARFI images. The spatial composed image was obtained from 10 angular positions at 4º intervals. Each one of these angular images was also the result of compounding five ARFI images focused at different depths (Fig. 1.b and 1.c).
Each one of the ARFI images is formed line by line using the following sequence (Fig. 2): A first tracking beam for acquiring pre-pushing reference data, a 1000 cycles pushing beam to produce the radiation force, and acquisition of a set of tracking beams for post-compression data. This sequence is programmed and executed in the acquisition hardware processor to guarantee timing. Data acquisition is not performed from the pushing beam.

![Image](image_url)

Fig. 1 (a) Experimental arrangement; (b) Scheme of single ARFI image formation process; (c) Scheme of the spatial compounding

At each angular position, four ARFI images were obtained changing the location of the focal point from 10 mm to 30 mm at 5 mm interval. Active aperture size was adjusted in each case to keep F/# constant (F/2), and no apodization was used in the active aperture. RF echo data were up-sampled to 2.4 GHz, which allows measuring a minimum displacement of 0.4 um.

A 1D-cross-correlation algorithm was used to estimate the axial displacement, comparing the initial reference image (pre-pushing) with the first post ARFI acquisition (at 50 us) for which the maximum displacement is obtained at the focal point. Correlation parameters were 5 mm length-window with 0.4 mm overlap and 0.25 mm lag. Then, displacement images from five pushing locations were combined into a single image, taking the maximum displacement value for each pixel location.

![Image](image_url)

Fig. 2 Beam sequence for each line of an ARFI image.
Finally, images acquired at different angular positions are added together over a common rectangular grid by nearest-neighbor interpolation. Fig. 3 shows a scheme of the composition algorithm. For each pixel of the output image, its distance to the array is obtained by calculating the intersection between the perpendicular line containing the pixel and the array direction. Knowing the distance between the intersection and the center of the acquired image, the index to the nearest 4 sample is determined and its value is assigned to the pixel. Although a more precise algorithm like bilinear interpolation could be used, it was found that the averaging process inherent to the spatial compounding, process softens the artifacts of the nearest-neighbor interpolation, giving equivalent results in practice.

3. Results

3.1. ARFI image formation

An unexpected spatial modulation of the force in the lateral direction was obtained in all images, which is especially noticeable in the positions where a homogeneous region of the phantom is imaged. Fig. 5.a shows the final displacement image at $\theta=36^\circ$, in a homogeneous region. The amplitude modulation in the lateral direction is evident, and it could be produced by the element sensitive pattern of the array. To correct this artifact an equalization curve was obtained, from the average of the axial displacements between 10 and 30 mm for this angular position (Fig. 5.b). Each angular image was multiplied row by row, by the inverse of this curve. The resulting image at the same angular position is shown in Fig. 5.c where a more homogeneous displacement is observed.
3.2. Spatial Image compounding

The final step of the process was to combine the ten displacement images into a single compounded image. Because of the elevation focus position of the array at 20 mm, image range was restricted to 35 mm depth, which does not allow imaging the center region of the phantom, where all images overlap. Instead, we acquired a portion of an annular area near the surface, in which 6 of the 10 images, at most, are superimposed. Fig. 6 shows a spatial scheme of the number of images that are superimposed on each output pixel.

Fig. 7.a and 7.b show the displacement images, for angular positions of 8° and 24° respectively, where part of the rigid mass is distinguishable. Fig. 7.c shows the spatial compounded image, where the field of view is considerably enlarged in the lateral direction and the cyst is more clearly seen. In addition, the reflectivity compounded image was obtained by combining individual B-scans, taken from the same angular positions (Fig. 7.d). It already shown that in the case of reflectivity B-scans, the resolution and CNR improve by spatial compounding with this
experimental set-up (Camacho et al., 2012)). It is seen in Fig. 7.d that the speckle is slightly reduced in those regions where more images are superimposed, resulting in a more homogeneous area. However, in ARFI images there is no speckle noise, so the compounded image does not differ with regard to their components in this parameter. Therefore, the proposed spatial compounded method significantly expands the field of view of the ARFI images, which improves lesions detection and evaluation.

Fig. 7 Angular displacement images at (a) $\theta=8^\circ$ and (b) $\theta=24^\circ$; (c) Compounding of the 10 displacement images; (d) Compounding of the reflectivity B-scans (Dynamic range 40 dB).

4. Conclusions

Results presented in this work validate the concept of spatial compounding of ARFI images in a circular ultrasound imaging system, to be used as part of a new multi-modal approach for breast cancer detection. Combining ARFI images acquired from different angular positions, allows expanding the region of interest, which gives a realistic picture of the inside of the phantom and improves lesion visibility and evaluation. It was verified that similar displacement values are obtained between successive images and amplitude artifacts due to the array element sensitivity pattern were successfully corrected. As the whole process is done automatically, these images are repeatable and independent of the operator, which allows monitoring the patient evolution in long term.

The main limitation of the current system is its low penetration depth, and hence the small number of images that overlap in each pixel. Future work includes lower frequency arrays to increase penetration and obtaining a larger overlap region. Furthermore, other scanning modes like angular scans will be tested.

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References