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Fusion of Vibro-acoustography Images and X-ray Mammography

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Abstract— **Image fusion, or combination of two images obtained by different techniques, has been widely used in medical imaging. Vibro-acoustography (VA) is a new imaging modality that has been applied to both medical and industrial imaging. Combining unique diagnostic information of VA with other medical imaging is one of our research interests. In this work, we studied the VA and x-ray image pairs and adopted two methods for fusing the registered VA and x-ray image. In the first method, the fused image is defined as a linear combination of the VA and x-ray images. Moreover, a color-based fusion technique was employed to combine the images for better visualization of structural information. By combining the information from x-ray mammogram and VA modalities into a single image, the accuracy of mammography interpretation which is important for women's health can be increased.**

I. INTRODUCTION

TO DATE various breast-imaging technologies have been proposed ranging from standard techniques, such as x-ray mammography, to highly experimental ideas, such as confocal microwave imaging [1]. **Vibro-acoustography (VA)** is one of the newest imaging modality based on ultrasound-stimulated acoustic emission.

In VA technology, the acoustic field in response to vibration of an object due to an applied cyclic force at each point is detected by a hydrophone and used to form the image of the object [2]. Vibro-acoustography has been tested as a noninvasive imaging tool to image excised human tissues, such as liver [3], breast [4-5], and prostate [6]. Vibro-acoustography has also used as a nondestructive imaging tool to identify the structural flaws of materials by measuring changes in the mechanical response to vibration at a point of interest [7].

Recently we have developed a VA system for in vivo breast imaging [3]. This system is integrated with a clinical stereotactic mammogram machine. The combined system is designed to produce matching VA and mammography images of the breast. The dual modality system can serve two purposes. The mammogram is used as a reference image to evaluate and optimize VA performance. Secondly, it is anticipated that the VA and mammography image would provide complimentary information of the breast. Thus, by comparing the two images, the diagnostic value of the two-modality image would be more than the individual images.

Mammography is considered as an extremely important diagnostic tool, particularly for screening micro calcification clusters and detecting malignancy [8-10]. There are some shortcomings associated with x-ray mammography however. For example, the efficacy of this modality heavily decreases in dense breast imaging [11]. Moreover, x-ray mammography does not contain information about the **depth and thickness** of the objects. Vibro-acoustography, on the other hand, is not hampered by tissue density [3]. This argument further justifies combining VA and mammography.

Fusing images of the same target generated with different modalities has been investigated for various clinical images [12-14]. In a study published by Behrenbruch et al. [12], fusion of the high-resolution structural information available from mammography with the functional data acquired from MRI imaging is proposed to offer a better pathological indicator such as calcifications. It has been reported that some tissue details that are not visible in contrast-enhanced MRI can be recognized in the fused images [12].

Prior to fusion process, it is important to apply a **robust registration** technique to align images, from a single or from different modalities [5 and 13-14]. By image registration the correspondences between the images can be seen more easily and the clinicians can get maximum amount of information from the images [14].

This paper proposes principles of combining VA and x-ray images after performing a reliable registration. Assuming that these two completely different modalities should provide relatively independent information about the breast tissues, the ultimate aim of this research is to generate more diagnostic and clinical value by fusing the images.

II. METHODS AND MATERIALS

A. *Experiment Setup*

A schematic of combined vibro-acoustography mammography system used for image generation is shown in Figure 1. X-ray images are generated by Mammovision system while immobilizing the target (breast). The sensitive part of the x-ray detector panel is a 50x50 mm square CCD screen. The stereotactic mammography system has target-focusing interface that can be used for measuring the distance of the target from the CCD screen.

A VA transducer is mounted in a water tank attached to the mammography system (Fig. 1). A window (104-by-80 mm) covered by a flexible membrane is mounted on water tank wall to allow both x-ray and the ultrasound beams pass through to the target. The imaging window for either imaging method is a 50-by-50 mm square. Within this area, the VA collects 256-by-256 points of the scanned target.

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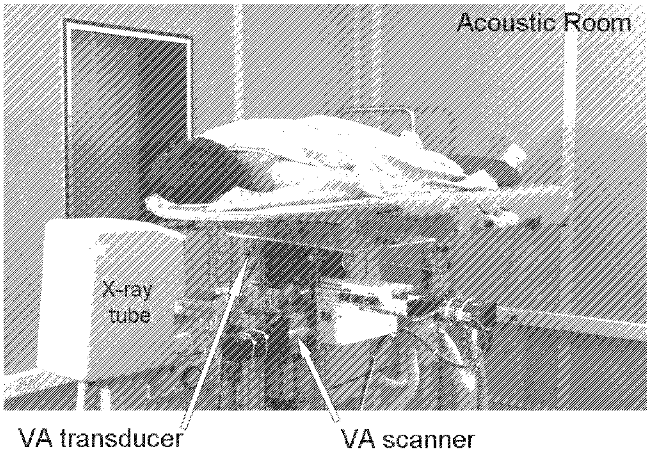


Fig. 1. Schematic of combined vibro-acoustography mammography system.

Speckle is the snowy pattern which results from random interference of the scattered ultrasound field. Speckles reduce the contrasts of conventional ultrasound images and often limit detection of small structures, such as breast micro calcifications in tissue. Vibro-acoustography on the other hand uses the acoustic emission signal, which is at a low frequency, thus the resulting images are speckle free and have high contrast. This feature makes vibro-acoustography suitable for detection of breast micro calcifications [3].

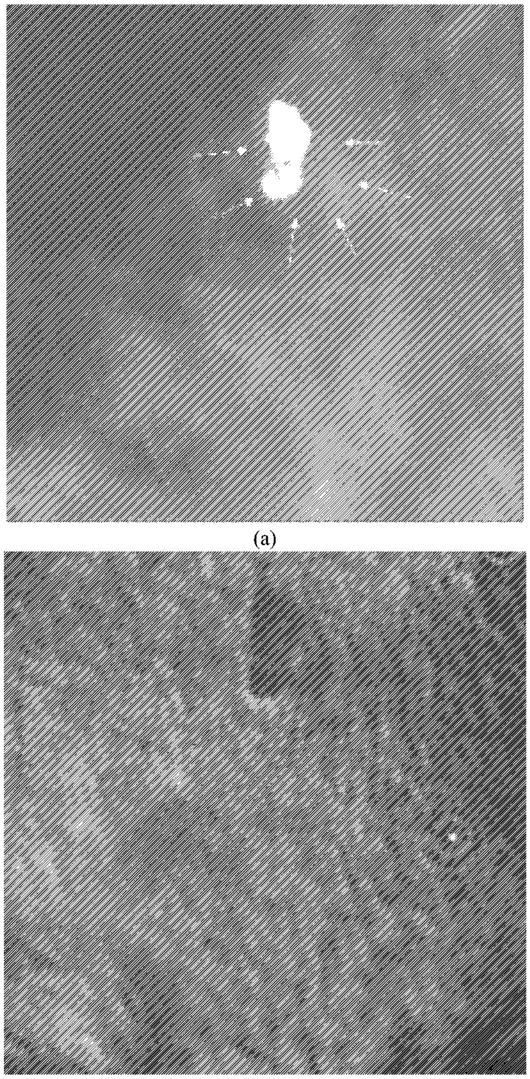
B. Registration of VA breast images and x-ray mammography

The VA beams stay parallel as the object is scanned and can be used to generate 3D images of an object by combining its image slices acquired at different depths. The VA beams scan across the object while focusing at a fixed depth. On the other hand, x-ray beams are canonical and generate a 2D projection image of the object without any depth/thickness information. Due to the dissimilarity of VA/x-ray mammography technology, a precise image registration is required prior to fusion. Figure 2(a) shows the coronal view x-ray mammography of a patient with a large calcification and a fibro adenoma marked with white arrows according to a radiologist diagnosis. The VA breast image obtained by scanning the same subject with focal point positioned at 4 cm from the skin (20 mm from the CCD screen) is shown in Fig. 2(b).

The x-ray images are rescaled from resolution of 1024-by-1024 to 256-by-256 to match the number of pixels with the VA pixels. However, the positions of similar pixels are still different in the two images. The VA frames have been shifted and they need to be adjusted for maximizing the common coverage area by two modalities. In addition, due to different magnifications of these two methods still registration is required.

Ideally, by registration, the size and position of VA images should be geometrically transformed to match exactly with mammography images pixel-by-pixel. In this work, we adopted an algorithm based on control points (CPs) to register the VA images [5, 15]. An initial study of x-ray and VA images of a phantom was conducted to create a universal matrix of CPs. The CPs in x-ray of the phantom image are selected as base-points and similar points in the corresponding VA image are called input-points. Eight CPs that can be clearly located in both images were selected to generate two 8-by-2 matrixes of base-points and input-points. The number of CPs and their locations are flexible and can be optimized empirically. The matrix of CPs are contained the X and Y coordinates of the selected CPs in the x-ray and the corresponding VA images.

One of the key components of the registration process is to find a mathematical transformation to map the input image to the base image. A second order polynomial, which is invariant to rotation and translation, was used to infer a spatial transformation of the X and Y pair of each pixel. For VA registration, this transformation can be applied to the base and input-points to map any new grayscale VA images into its corresponding x-ray.


(a)

(b)

Fig. 2. The breast image with fibro adenoma: (a) Marked x-ray by radiologist showing the fibro adenoma and the nearby calcification; (b) The VA image of the same subject.

The rotation and translation of VA images are mathematically assigned by the transformation, which is then used to create the fusion display of the original grayscale medical images.

The second order polynomial transformation maps X_b and Y_b of the base-point matrix to X_i and Y_i of the input-point matrix according to Eq. (1) [15]:

$$[X_i,\ Y_i] = [1,\ \mathrm{X_b},\ \mathrm{Y_b},\ \mathrm{X_b} * \mathrm{Y_b},\ \mathrm{X_b}^2,\ \mathrm{Y_b}^2] * \mathrm{InvT} \quad (1)$$

where * is the multiplication sign.

To specify all coefficients of InvT with the size of 6-by-2, at least 6 CPs are required to solve the inverse of the second-order polynomial, *InvT*. We chose eight CPs and used normalized cross-correlation to adjust each pair of CPs to solve the second order polynomial.

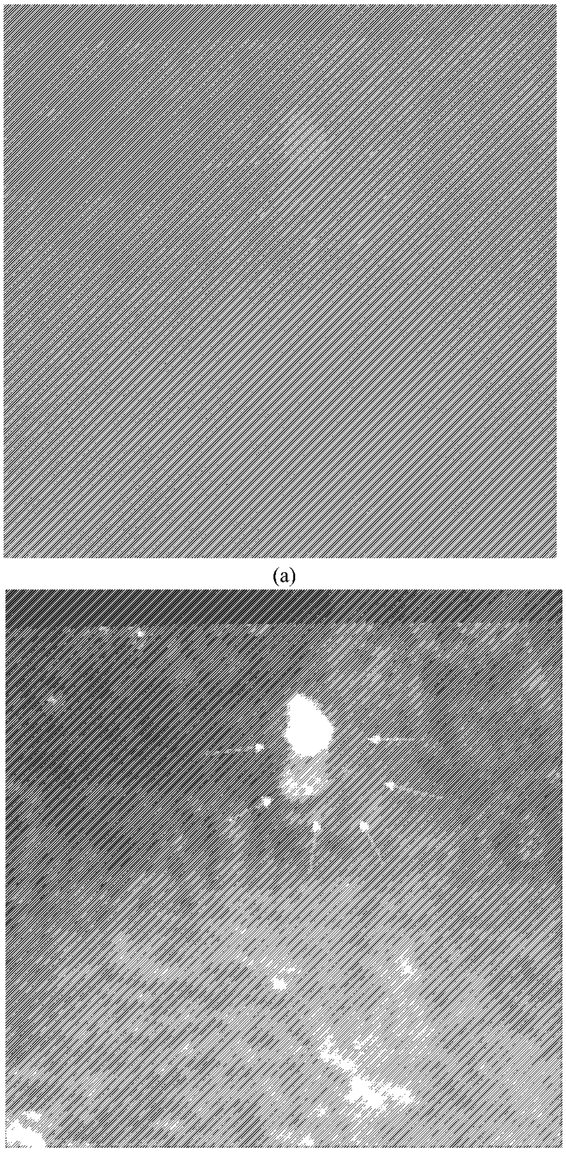
The results of registration of the **phantom images** including the matrixes of base-points and input-points were used to spatially transform **in vivo breast VA images** from volunteer.

C. *Image fusion*

Image fusion can be performed at three different levels; Pixel level, Feature level, and Decision level [16-17]. We used pixel level image fusion techniques and for better visualization of the structural information contained in both images, it is decided to adopt a color-based method for fusing the registered images. The registered VA and x-ray images are assigned as the blue and red components of an RGB image, respectively. A zero matrix is assigned as the green-component of the RGB image. Figure 3(a) shows the resultant image of color-based fusion of the two primary images. This method generates an image with color-code information of each image which may be useful for diagnostic purposes.

To improve the quality of fused images, we used pixel level fusion with different ratio (R) of pixel values. Figure 3(b) shows the resultant image of fusing the two images using 50% of each image pixel values. The combined image shows features of VA and x-ray in a single image. The calcification is seen in the VA and x-ray mammography match perfectly. The thick dark band at the top of fused VA image (Fig. 3(a or b)) is the area that was not covered by VA because the VA image frame did not match exactly. On the other hand, the bottom part of the target, which was scanned by VA, was not covered by x-ray. This error is caused due to misalignment of the x-ray and VA imaging windows.

To combine images from a single or two different modalities, a graphic user interface tool was designed and includes pre-processing (such as histogram equalization), image enhancement (brightness, contrast), registration, fusion (color-based/pixel-level ratio) and display of the images. Other features such as wavelet analysis of the input image are available for further processing. Image enhancement techniques such as adjustment of brightness and contrast can be employed before or after fusion. Other preprocessing techniques for eliminating background noise and histogram equalization are also available to improve the quality of the input images.

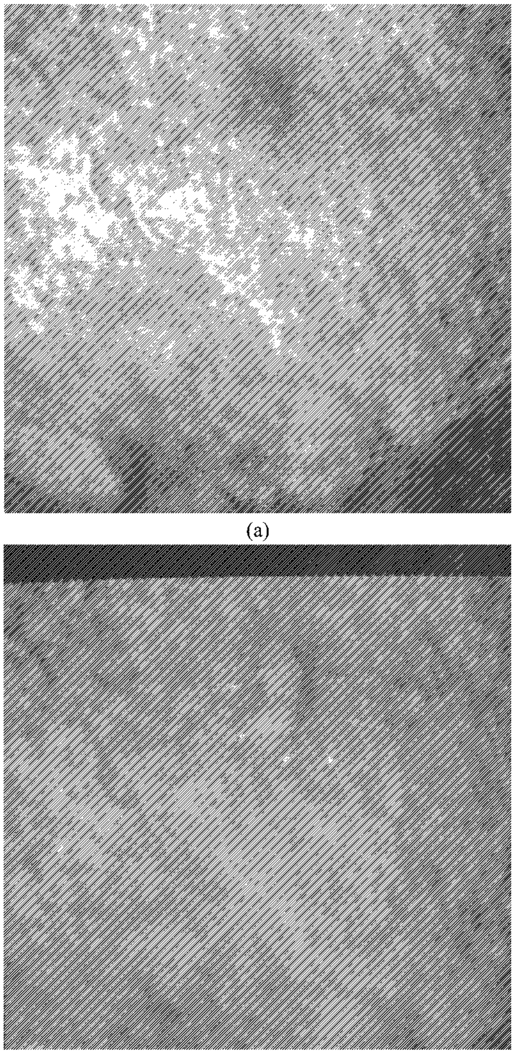

(a)

(b)

Fig. 3. The fused breast image using the primary images of Fig. 2 by: (a) color-based method; (b) pixel level method with R = 50%.

The proposed method for integrating of multimodality medical images allows extracting new information by fusing VA images at different depths with x-ray mammogram. User can select one VA image at a time from a file, containing VA images scanned at different depths of the object, and register it with a based mammogram. Finally, the registered VA image can be enhanced and fused with the base image of x-ray mammography.

Figure 4(a) shows another scanned VA image taken at the depth of 5 mm of the CCD screen and Fig. 4(b) shows the same image after fusing with the x-ray image which confirms the position of calcification. The VA image shows the fibro adenoma (marked by arrows) which is not clearly visible in the x-ray.



(a)

(b)

Fig. 4. (a) The original VA image; (b) The fusion of VA with marked mammogram.

III. Discussion And Conclusions

Combining images from two completely different modalities, VA and x-ray, using either color-based or pixel value fusion techniques may generate more structural and diagnostic information. A color-based fusion technique may be more suitable for visualization of the structural information. Here, we presented a method for combing VA and x-ray (mammography). It is shown that, because x-ray image magnification varies with target depth, the registration transformation must be applied to adjust the images of different target depths. In this work, we used a modified second order polynomial, which leads to a scale/rotation/translation invariant paradigm for image registration. To validate the proposed registration method, we fused VA images at different depths with the x-ray mammogram and demonstrated that the detected classification area is located at the same position in both modalities.

The fused image of two different modalities which is associated with an x-ray mammography, annotated by an expert radiologist, can be used to verify independent diagnostic information of the VA modality. Moreover, the aligned image would assist the users to gain maximum amount of information from x-ray mammogram and the VA modality.

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