CORRECTION OF ACOUSTIC LENS ERROR IN SPATIAL COMPOUNDING OF ULTRASONIC DIAGNOSTIC IMAGES

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Abstract: Spatial compounding has been used in ultrasonic imaging for suppressing speckle noise. The technique generally involves electronically steering the ultrasonic beams. The steering angle of the ultrasonic beam is distorted by the acoustic lens structure of the probe that is used to focus the beam mechanically. These errors introduced by the lens structure cause misalignment of the ultrasonic images received at different steering angles, and consequently results in the blurred image after spatial compounding. In this paper, a solution is proposed that corrects the lens error by using image registration. The lens error was compensated by registering the wire target images before spatial compounding. An efficient registration algorithm was developed to compute the transformation matrix required for the registration. The images were registered by the transformation matrix before spatial compounding.

1 INTRODUCTION

Ultrasonic images show a characteristic granular structure commonly known as speckle (Burckhardt, 1978, Wells and Halliwell, 1981). Speckle is one of the fundamental problems of ultrasound imaging, and it is a cause of major limitation on image quality. Speckle in ultrasonic images arises from the presence of closely spaced and randomly distributed microscopic scatterers (Ahbott, 1979, Wagner, 1983). The coherence of the ultrasound sources and the interference pattern caused by these tiny targets result in fluctuations in the amplitude of the echo called speckle. Although speckle noise carries some information about the nature of the imaging object, the speckle reduces the detection capability of ultrasonic imaging systems, and makes it difficult to identify specific target regions on the image.

Spatial compounding has been used to reduce speckle brightness variations. The compounded image is formed by, for example, averaging the component images that have been acquired by steering ultrasound beams in several different directions. In the component images, the structural targets show consistently strong echoes while speckles show random variations. Consequently, the structural targets in compounded images are enhanced and variations in the soft tissues due to speckle noise are averaged out (Shankar, 1986). As a result, image contrast is improved, and electronic noise is reduced and artifacts such as shadowing and reverberation are suppressed. Examples in (Entrekin, 2001, Huber, 2002) show improvements in visualization of breast lesions. These results indicate that spatial compounding can enhance the delineation of the boundaries and internal structure of lesions. The improvement, however, is usually gained at the price of spatial resolution. The misalignment of the legions caused by aberration and the loss of spatial resolution can degrade the effectiveness of spatial compounding (Krücker, 2002, Meuwly, 2003).

Steering of electronic beam is accomplished electronically by controlling the excitation of the individual elements in the ultrasonic transducer array. One of the errors introduced by the electronic steering of the ultrasonic beam is caused by the acoustic lens structure that is used to mechanically focus the ultrasonic beam, such as the thickness and acoustic speed of the lens. In Figure 1, ideal case is compared with the real case. In an ideal case, the ultrasound echo data reflected off the target is received along a simple straight line. In a real situation, the ultrasound echo data path is changed at the interface between the lens and the tissue. The steering angle is changed from θ_1 to ϕ_1 by the ratio of the acoustic speed of the lens and the tissue. These errors introduced by the lens structure cause

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misalignment of the ultrasonic images received at different steering angles, and consequently results in the blurred image during the spatial compounding.

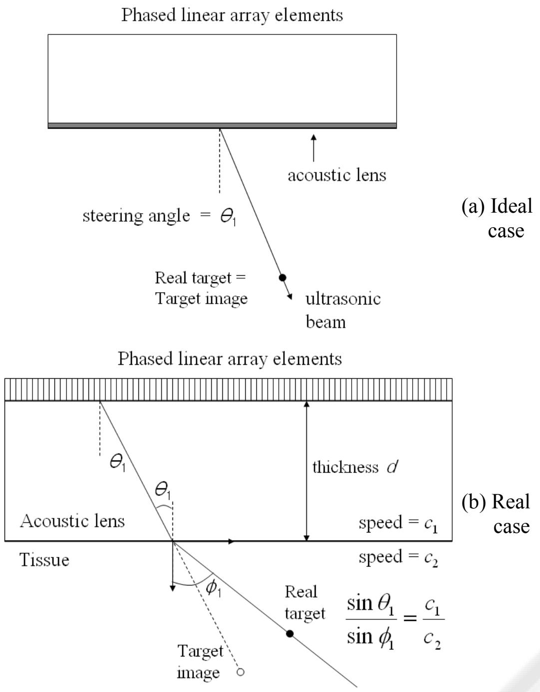


Figure 1: Acoustic lens error in the steering of ultrasound beam.

The conventional solution to correct the errors introduced by the lens structure involve manual fine tuning of the lens thickness and the steering angles. These parameters are used in the resampling process which geometrically transforms the image data from the probe coordinates to the patient coordinates as shown in Figure 3(a). In ultrasound imaging systems, this kind of manual fine tuning can be difficult and time consuming as many different kinds of probes are used interchangeably for different diagnostic applications.

In this work, a systematic solution is proposed that corrects the lens error by using image registration. The lens error was compensated by registering the wire target images before spatial compounding. An efficient registration algorithm was developed to compute the transformation matrix required for the registration. The images were registered by the transformation matrix before spatial compounding.

2 SPATIAL COMPOUNDING WITH LENS ERROR CORRECTION

A typical spatial compounding scheme that uses 5 component image frames from a linear probe to generate a compounded image is described in Figure 2. Each of the component images I_k corresponds to a steering angle of $k\Delta\theta$, where $\Delta\theta$ is the incremental angle and I_{0x} is the image corresponding to the zero rotation angle. Various methods were proposed to compute the compounded image from the consecutive frames which include linear averaging, median, mean-excluding- minimum, root mean square, etc (Wilhjelm,2004). In this work, a simple linear averaging scheme was used.

Let I_i, $i= -N,\ldots 0,\ldots N,$ denote the component images that will be used in the spatial compounding. The center image I_0 undergoes no rotation and thus is free from the influence of the lens errors. Hence, the center image I_0 is used as the reference frame with respect to which all other images will be transformed for registration. Let T_i, $i= -N,\ldots 0,\ldots N,$ denote the geometric transformation matrices that transforms images I_i such that $J_i = T_i\, I_i$ will be the image registered with respect to the reference frame. The alignment errors between the component images are removed by the registration process. The registered images J_i can be used to produce the compounded image by a spatial compounding algorithm as shown in Figure 3.

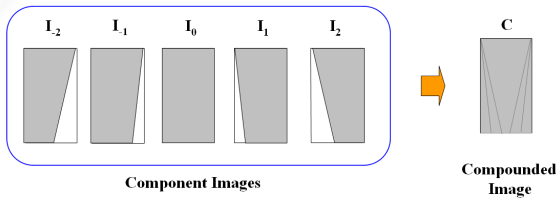


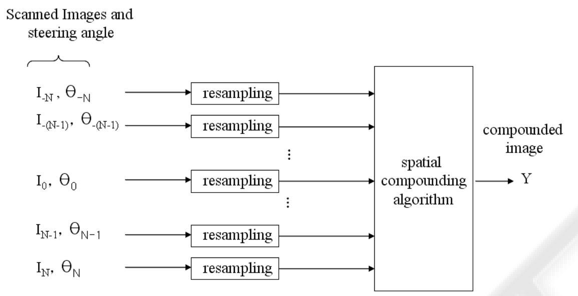
Figure 2: Concept of Spatial Compounding.

The transformation matrix T_i that registers the component image I_i with respect to the reference image I_0 is computed from the images of a wire phantom. The wire phantom images are converted to binary images by using a suitable gray level threshold. Threshold value is selected to generate clear binary images of wire targets. For each image I_k , position vector of the wire targets $u_{kj} = [x_{kj}, z_{kj}]^T$, $j=1,\ldots M,$ are obtained by computing the center of gravity of the wire targets, where M is the number of wire targets, x_{kj} and z_{kj} are the x and z coordinates of the position vector u_{kj} .The position vector of the same wire target in the reference image I_0 is denoted as $u_{0j} = [x_{0j}, z_{0j}]^T$, $j=1,\ldots M$.

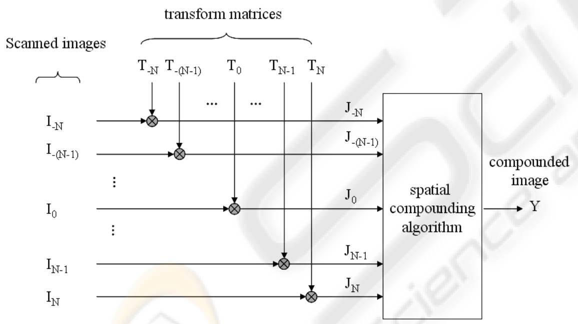
Let the position vectors be expressed in homogeneous coordinates (Fu,1987). Let H_k , $k= -N,\ldots 0,\ldots N,$ denote the 4x4 homogeneous transformation matrices that transform u_{kj} to u_{0j} . Then we can write

$$\begin{bmatrix} x_{0j} \\ 0 \\ z_{0j} \\ 1 \end{bmatrix} = H_k \begin{bmatrix} x_{kj} \\ 0 \\ z_{kj} \\ 1 \end{bmatrix}, \quad j=1,\ldots, M \tag{1}$$

$$H_k = \begin{bmatrix} {}^k h_{11} & {}^k h_{12} & {}^k h_{13} & {}^k h_{14} \\ {}^k h_{21} & {}^k h_{22} & {}^k h_{23} & {}^k h_{24} \\ {}^k h_{31} & {}^k h_{32} & {}^k h_{33} & {}^k h_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



(a) Conventional spatial compounding.



(b) Spatial compounding with image registration.

Figure 3: Comparison of spatial compounding schemes.

We can remove the y component of the equation and rewrite (1) as below.

$$\begin{bmatrix} x_{0j} \\ z_{0j} \\ 1 \end{bmatrix} = \begin{bmatrix} {}^k h_{11} & {}^k h_{13} & {}^k h_{14} \\ {}^k h_{31} & {}^k h_{33} & {}^k h_{34} \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_{kj} \\ z_{kj} \\ 1 \end{bmatrix}, \quad j=1,\ldots, M \tag{2}$$

This equation can be expressed

$$\begin{bmatrix} x_{0j} \\ z_{0j} \\ 1 \end{bmatrix} = T_k \begin{bmatrix} x_{kj} \\ z_{kj} \\ 1 \end{bmatrix}, \quad j=1,\ldots, M \tag{3}$$

$$T_k = \begin{bmatrix} {}^k h_{11} & {}^k h_{13} & {}^k h_{14} \\ {}^k h_{31} & {}^k h_{33} & {}^k h_{34} \\ 0 & 0 & 1 \end{bmatrix}$$

Here, T_k is the transformation matrix that registers the wire targets of I_k with the reference image I_0. Since T_k applies to all the wire targets in the image I_k ,

$$\begin{bmatrix} x_{01} & x_{02} & \cdots & x_{0M} \\ z_{01} & z_{02} & \cdots & z_{0M} \\ 1 & 1 & \cdots & 1 \end{bmatrix} = T_k \begin{bmatrix} x_{k1} & x_{k2} & \cdots & x_{kM} \\ z_{k1} & z_{k2} & \cdots & z_{kM} \\ 1 & 1 & \cdots & 1 \end{bmatrix} \tag{4}$$

Let the equation (4) be written in a simplified form as

$$U_0 = T_k U_k \tag{5}$$

Then, the transformation matrix T_k can be computed by

$$T_k = U_0 U_k^T (U_k U_k^T)^{-1} \tag{6}$$

3 EXPERIMENTAL RESULTS

The images were denoted as I_i, $i=-3,\ldots,0,\ldots 3$, and hence images corresponding to 7 different view angles were used in the spatial compounding. Seven consecutive images were used in the compounding computation, each of 5232 x 256 RF sample data, and compounded images are shown after scan conversion into a 640 x 480 BW data.

The binary images of I_i were obtained by selecting a threshold. Six wire targets were used in the computation. The wire target positions $u_{kj} = [x_{kj}, z_{kj}]^T$, $j=1,\ldots 6$, $k= -3, \ldots, 0, \ldots, 3$ were obtained by computing the center of gravity of the binary images of wire targets. The transformation matrix T_k were computed using (6), and used to register the component images I_i to the reference image I_0 . The registered images are denoted by that $J_k = T_k I_k$. The position error between the wire target of the *k-th* image and that of the reference image were computed before and after the registration and their magnitudes are shown in Figure 4. Before the registration, the position error increases with the rotation angle, error increasing to over 110 pixels (RF data) in I_{-3} and I_3. After the registration, the position errors were reduced to less than or equal to one pixel with the exception of I_3 where the maximum error magnitude was three pixels.

The compounded image obtained by the conventional spatial compounding scheme is shown in Figure 5(a) and contain geometric errors caused by the lens error and the result of compounding these misaligned images is the blurry compounded image. The proposed spatial compounding with image registration was applied to the same image and the result is shown in Figure 5(b).

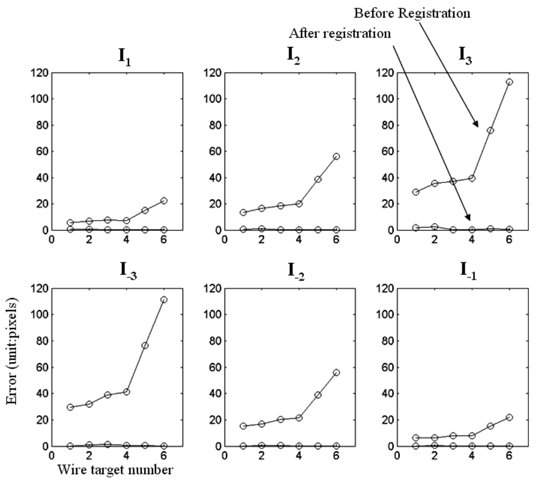
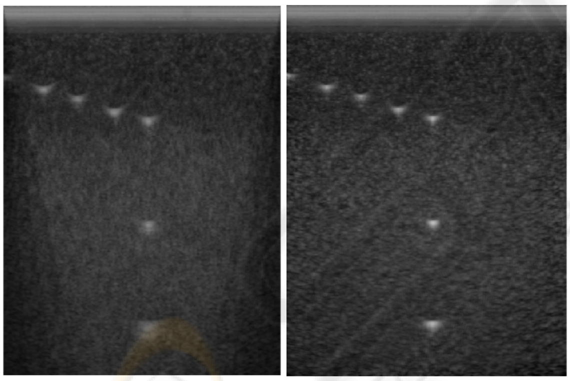


Figure 4: Registration error of wire targets before and after the registration.



(a) no lens error compensation (b) Proposed method

Figure 5: Spatial compounding results.

4 CONCLUSIONS

A lens error correction method for spatial compounding is proposed that uses image registration. The lens error was compensated by registering the wire target images before spatial compounding. An efficient registration algorithm was developed to compute the transformation matrix required for the registration. The images were registered by the transformation matrix before spatial compounding. It was shown that the registration error that causes the blurring of the spatially compounded images can be removed effectively.

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