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Small calcification depiction in ultrasonography using correlation technique for breast cancer screening

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In breast cancer screening mammography plays the primary role to depict small calcifications that accompany cancers; however, it involves exposure to ionizing radiation, and it is not effective in younger women for detecting cancers in the pre-menopausal breast. In order to realize the breast cancer screening without radiation exposure for all people including young women, we have proposed an ultrasound calcification depiction method employing correlation technique. Since a calcification has a large acoustic impedance mismatch to soft tissue, it is supposed that the waveform of an ultrasound pulse changes at the position of the calcification. The method utilizes the deterioration in the cross-correlation between adjacent scan lines caused by the waveform change. In this study, we investigate the performance of the method in the condition close to a clinical environment. The result shows that the method has the potential to depict small calcifications without acoustic shadowing, indicating the capability of the method to improve the sensitivity of ultrasonography in small calcification detection.

1 Introduction

In breast cancer screening, mammography plays the primary role in depicting small calcifications that accompany cancers; however, it involves exposure to ionizing radiation [1-3], and the presence of the mammary glands reduces its performance in calcification detection. Therefore, mammography is not effective in detecting breast cancer in younger pre-menopausal women. In general, breast cancer screening using mammography is undertaken in women younger than 40 years of age [4,5]. Mammary glands have little effect on the image quality in ultrasonography (US), and it is therefore expected that this modality will be developed for the non-invasive screening of breast cancer in young women, owing to its improved performance in calcification detection.

Since the acoustic impedance of a calcification is much higher than that of soft tissue, the echo returned from a calcification surface has a high echo-intensity, and the blocking effect of the calcification suppresses the echo returned from the region behind the calcification. The conventional calcification detection method using a B-mode image thus selects a high echo-intensity region that is associated with posterior acoustic shadowing [6]. However, a small calcification has an insufficient blocking effect for the appearance of acoustic shadowing, and its echo intensity is low. Therefore, US B-mode imaging has low sensitivity in calcification detection.

Several techniques have been reported for breast ultrasound imaging. While tissue harmonic imaging is utilized to improve contrast resolution in US, its performance in calcification detection is considerably lower than that of CT [7]. The use of spatial compound improves US image quality with regard to mass margins and internal architectures; however, it also decreases the frame rate and suppresses acoustic shadowing [8]. An operator typically cannot detect small calcifications without acoustic shadowing, and as a consequence compound imaging is not effective in detecting calcifications. For calcification detection, another group employed a cell-averaging constant false alarm rate detector that selects regions with high echo-intensity [9]; however, the method is unsuitable for small calcification detection because the echo intensity from a small calcification is low.

In order to realize breast cancer screening without radiation exposure for all age groups including young women, we have reported an ultrasound calcification depiction method employing a correlation technique [10-12]. Since a calcification has a large acoustic impedance mismatch to soft tissue, it is supposed that the waveform of an ultrasound pulse changes at the position of the calcification. The method utilizes the deterioration in the cross-correlation between adjacent scan lines caused by the waveform change. The reported method successfully depicts 0.2 mm cylindrical copper rods embedded in a homogeneous agar gel block, indicating its potential to detect small calcifications in the gallbladder. In contrast, the method fails to depict small rods embedded in a swine breast tissue model, illustrating the difficulty involved in detecting small calcification in the breast [12].

In the present study, we employ the variance of the correlation coefficients between adjacent scan lines to determine the existence of calcifications in a region of interest (ROI). Since the existence of calcifications in heterogeneous medium also suppresses the correlation between adjacent scan lines, the variance of the correlation coefficient in heterogeneous medium is expected to increase when the ROI includes small calcifications. We experimentally investigate the effect of small glass beads in heterogeneous medium on the variance of the correlation coefficients between adjacent scan lines.

2 Methods

2.1 Decrease in correlation between adjacent scan lines caused by calcifications

We have employed the decrease in cross-correlation coefficients between adjacent scan lines, as shown in Figure 1. Since the radiation regions of two adjacent ultrasound beams overlap, the signal received from the two adjacent scan lines correlate with each other. When a radiation region of an ultrasound beam includes a small calcification, the waveform of the ultrasound pulse changes considerably at the calcification position. This change in waveform suppresses the cross-correlation between adjacent scan lines.

The cross-correlation between adjacent scan lines can be suppressed not only by a calcification but also by noise. To suppress the noise effect on the correlation coefficients, we have proposed a method that employs an echo-intensity threshold and a modified Wiener filter [12]. An echo intensity threshold eliminates the signals with low SNR. The method calculates cross-correlations when both the adjacent signals cut out by correlation windows exceed an intensity threshold given by:

$$I_{\mathrm{T}} = \alpha n I_0, \tag{1}$$

where α is a positive number and I_0 is the average pixel intensity in a ROI. After the employment of the intensity

threshold, we calculated the cross-correlation coefficients between adjacent scan lines according to:

$$r\left(x+\frac{\Delta X}{2}, z\right) = \max_{l} \frac{\sum_{z'=z-n\Delta Z}^{z} g(x,z')g(x+\Delta X, z'+l\Delta Z_S) + \beta n I_0}{\sqrt{\sum_{z'=z-n\Delta Z}^{z}\left|g(x,z')\right|^2 \sum_{z'=z-n\Delta Z}^{z}\left|g(x+\Delta X, z'+l\Delta Z_S)\right|^2} + \beta n I_0}, \quad (2)$$

where x and z are the lateral and vertical components, respectively, of a measurement point on a B-mode image, $g(x, z)$ is the RF datum at a pixel in a B-mode image, ΔX is the interval of scan lines, ΔZ is the range interval, ΔZ_S is the scan interval for the maximization of the correlation coefficient, $n\Delta Z$ is the correlation window width, and β is a positive number [12]. $\beta n I_0$ added to both the numerator and dominator of the formula works as a modified Wiener filter to suppress the influence of the noise on the cross-correlation coefficients. In this study, we employed the parameters $\alpha = 1$ and $\beta = 0.1$.

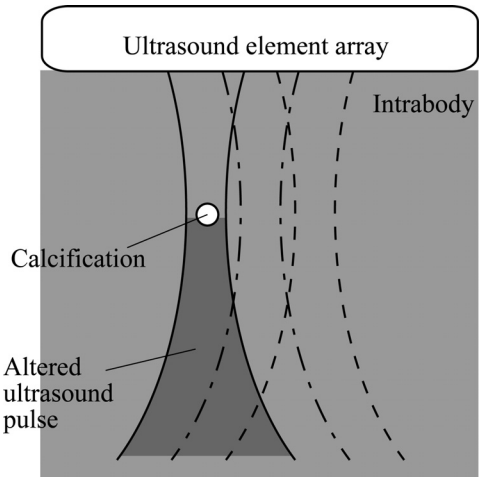


Figure 1: Waveform change of an ultrasound pulse caused by a calcification.

2.2 Calcification detection using distribution of correlation coefficients

A previous study indicated that the decrease in cross-correlation coefficients between adjacent scan lines caused by a small calcification is inconspicuous when it is located in heterogeneous medium such as a breast tissue [12]. One of the reasons for this is the larger variance of correlation coefficients in heterogeneous medium compared with that in homogeneous medium. The large variance of correlation coefficients in heterogeneous medium conceals the decrease in correlation caused by a small calcification. However, it is expected that many small calcifications in heterogeneous medium influence the variance of correlation coefficients.

Since the existence of small calcifications in heterogeneous medium is also supposed to suppress the correlation between adjacent scan lines, the increase in the region of low correlation coefficients may indicate the existence of small calcifications in heterogeneous medium. In the present study, we use a swine breast tissue model to investigate the change in the distribution of correlation coefficients between adjacent scan lines caused by small glass beads distributed in the tissue.

2.3 Experimental setup

Figure 2 shows the swine breast tissue with small glass beads that we used in this study. A Hitachi EUB-8500 (Hitachi, Tokyo, Japan) US device with a 7.5 MHz linear element array was used, where it had the function to export raw IQ data. The RF data with a 30 MHz sampling frequency was reconstructed from the IQ data acquired by the device [13]. The scan line interval and range interval of the RF data were 0.13 and 0.025 mm, respectively. We used spherical glass beads that were 0.1, 0.2 and 0.3 mm in diameter to mimic small calcifications. We prepared four breast tissues; one contained no glass beads, and the others contained glass beads that were 0.1, 0.2 and 0.3 mm in diameter. Glass beads of each size were distributed in the swine breast tissue separately at a depth of 1 cm, where the distribution density was 100/cm^2. We measured five sections for each breast tissue.

3 Results

First, we selected one section from five sections of each breast tissue to suppress the influence of signal-to-noise ratio (SNR) on correlation coefficients. The average pixel intensity I_0 of the four selected sections ranged within 1.1 dB. Figure 3 shows the B-mode images of swine breast tissues with and without glass beads. Since the size of spherical glass beads used in this study is 0.3 mm and less, the commercial US device failed to depict the beads in B-mode images.

We investigated the cross-correlation coefficients between adjacent scan lines in the ROI, where the size of the ROI was 0.5 × 3 cm and its depth was from 1 to 1.5 cm. Figure 4 shows the profiles of cross-correlation coefficients between adjacent scan lines in the ROIs located in swine breast tissues with and without glass beads. Figure 5 shows the distributions of cross-correlation coefficients in the ROIs shown in Figure 4. The positions of small glass beads were unclear in the correlation profiles; however, the positions of correlation coefficients lower than 0.6 appeared almost only in the breast tissues with glass beads, as shown in Figure 6. This result indicates the possibility that the increase in the region of low correlation coefficients suggests the existence of small calcifications in the ROI that are 0.3 mm and over in size.

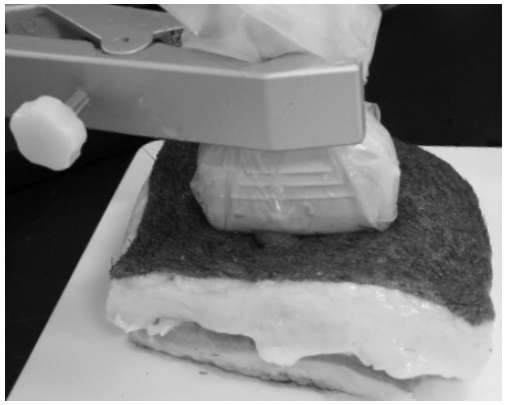
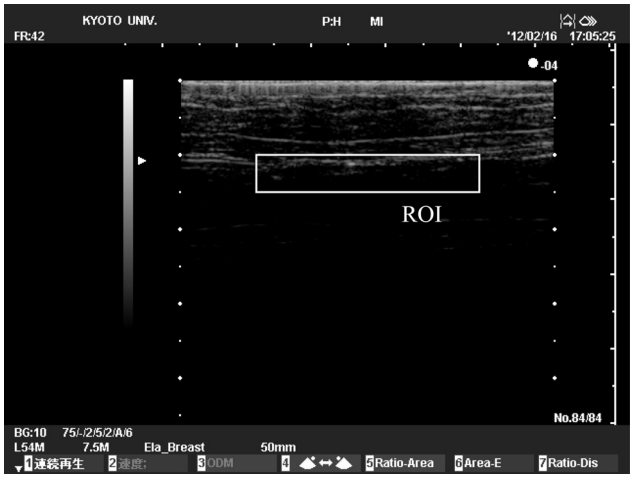
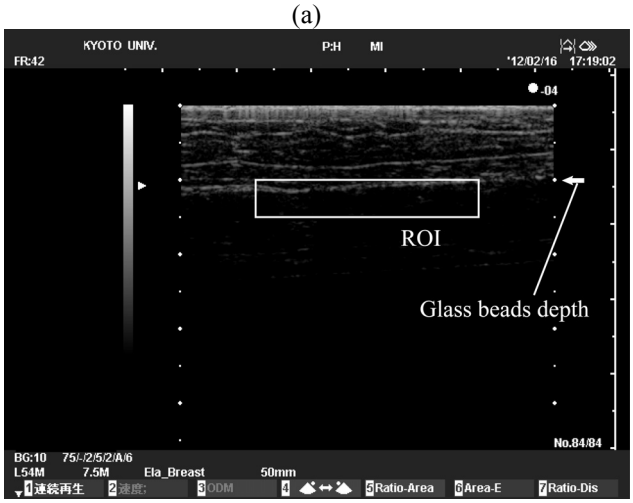


Figure 2: Swine breast tissue with small glass beads used in this study.



(a)



(b)

Figure 3: B-mode image of swine breast tissues (a) without glass bead and (b) with spherical glass beads 0.3 mm in diameter, where 100 glass beads per cm^2 are distributed at a depth of 1 cm. The white line is the boundary of a ROI 0.5 × 3 cm in size.

Figure 7 shows the average of I_0 and the average cumulative distribution of correlation coefficients of swine breast tissues with and without glass beads, where we averaged five data sets for each value. The proportion of cross-correlation coefficients lower than 0.5 ($p_{0.5}$) of the swine breast tissue with 0.3 mm beads were higher than that of the swine breast tissue without bead; however, the $p_{0.5}$ of the swine breast tissues with 0.1 and 0.2 mm beads were lower than that without bead. In contrast, the average pixel intensity I_0 of the tissue without bead was about half that with 0.1 mm beads, and one third that with 0.3 mm beads. This result indicates that the SNR of the received signal of the tissue without bead was considerably lower than that with beads, more strongly suppressing the correlation coefficients of the tissue without bead than that of the tissues with beads 0.1 and 0.2 mm in diameter.

The $p_{0.5}$ of the swine breast tissue with 0.3 mm beads was 1.6 times that of the tissue without bead. Under the condition that the SNR of the received signal of the tissue with 0.3 mm beads was almost equal to that without bead, the $p_{0.5}$ of the tissue with 0.3 mm beads was 4.6 times that without bead. These results suggest the possibility that the increase in the region of low correlation coefficients indicates the existence of small calcifications 0.3 mm in size in a ROI when the ROI contains sufficient number of small calcifications.

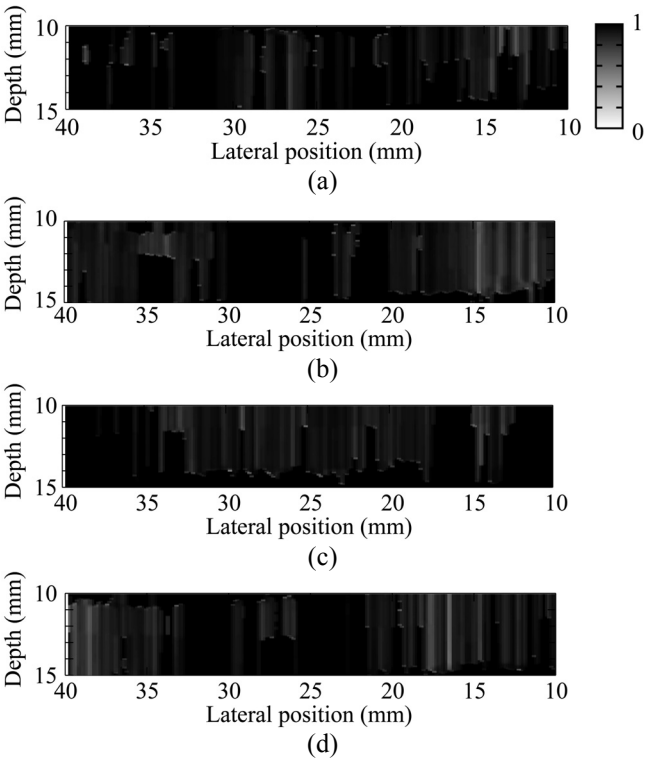


Figure 4: Cross-correlation profiles between adjacent scan lines of swine breast tissues (a) without glass bead, (b) with 0.1 mm glass beads, (c) with 0.2 mm glass beads and (d) with 0.3 mm glass beads.

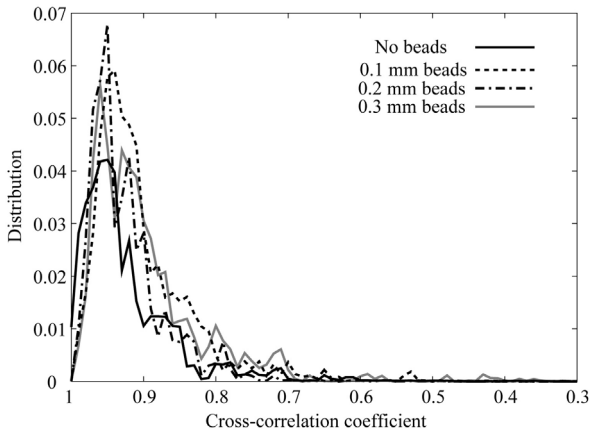


Figure 5: Distributions of cross-correlation coefficients between adjacent scan lines of swine breast tissues without glass bead, with glass beads that are 0.1, 0.2 and 0.3 mm in diameter.

4 Conclusion

In the present study, we experimentally investigated the effect of small spherical glass beads in a swine breast tissue on the distribution of the cross-correlation coefficients between adjacent scan lines of RF data, acquired by a commercial US device. The results suggest that the increase in the region of low correlation coefficients indicates the existence of small calcifications 0.3 mm in size in a ROI when the ROI contains 100 small calcifications per cm^2.

Since small calcifications distributed in breast tissue often accompany malignant breast cancers, the condition that a breast tissue contains 100 small calcifications per cm^2 may be not far from the clinical condition.

This study suggests that the low SNR of received signals suppresses the cross-correlation coefficients between adjacent scan lines after the employment of a modified Wiener filter. Future work should take into consideration the influence of the SNR on the distribution of correlation coefficients between adjacent scan lines.

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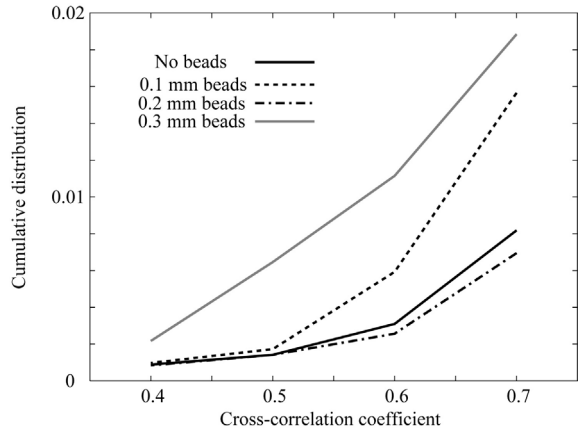

Figure 6: Cumulative distribution of cross-correlation coefficients between adjacent scan lines of swine breast tissues without glass bead, with glass beads that are 0.1, 0.2 and 0.3 mm in diameter.

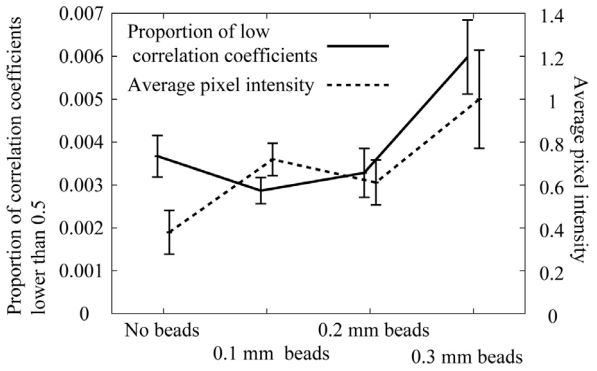

Figure 7: Proportion of cross-correlation coefficients lower than 0.5 and the average echo intensity of swine breast tissues without glass bead, with glass beads 0.1, 0.2 and 0.3 mm in diameter. We average five data sets for each value, and each error bar shows a quarter of the standard deviation. Average pixel intensities are normalized with that of the tissue with 0.3 mm glass beads.

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