SMALL CALCIFICATION DETECTION FOR ULTRASONOGRAPHY USING DECORRELATION BETWEEN RAW ULTRASONOGRAPHIC DATA

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ABSTRACT

For the improvement of the calcification detectability in ultrasonography we propose and experimentally investigate a calcification detection method using decorrelation between raw ultrasonographic data. The waveform of a transmit wave changes significantly at a calcification position, and thus the correlation between echoes of adjacent scan lines suppressed severely behind the calcification position. Therefore, the existence of a calcification is predictable using the waveform difference between adjacent echoes by calculating cross-correlation coefficients, similar to the calcification detection using acoustic shadowing. The proposed method selects high-intensity-echo positions with posterior low-correlation-echo regions. 11 out of 15 wire targets 0.2 - 0.4 mm in diameter were detected using this method with a certain threshold set, yielding a sensitivity of 73.3% and a specificity of 100%, which are difficult to detect under clinical inspection of ultrasound B-mode images.

1. INTRODUCTION

Ultrasonography (US) has an excellent ability to depict soft tissues without ionizing radiation; however, the calcification detectability in US is insufficient compared with X-ray computed tomography (CT) and other X-ray imaging techniques [1-4]. The detection of calcification is one of the important factors to diagnose malignancy of masses, and thus the improvement of calcification detectability in US is strongly desired.

Since the echo from a calcification is supposed to have high echo intensity, several calcification detection methods are reported using the extraction of high-echo-intensity regions. For the extraction of high-echo-intensity regions, many researchers have employed a constant false alarm rate (CFAR) technique [5, 6]. A CFAR detector extracts targets in non-stationary noise and clutter while maintaining a constant probability of a false alarm [7]. Therefore a small calcification with low echo intensity is hardly detected using CFAR detectors. In addition the specular echo scattered beside a calcification severely interferes the detection of calcifications.

For the detection of a small calcification with low echo intensity we have proposed a calcification detection strategy using cross-correlation between echoes of adjacent scan lines [8, 9]. Since the acoustic impedance of a calcification is much larger than those of other tissues, the waveform of a transmit wave changes significantly at the calcification position, as shown in Fig. 1. This causes the decorrelation between echoes of adjacent scan lines behind the calcification position. Therefore, the existence of a calcification is predictable using the waveform difference between adjacent echoes by calculating cross-correlation coefficients, similar to the calcification detection using acoustic shadowing. In this study we propose a calcification depiction technique

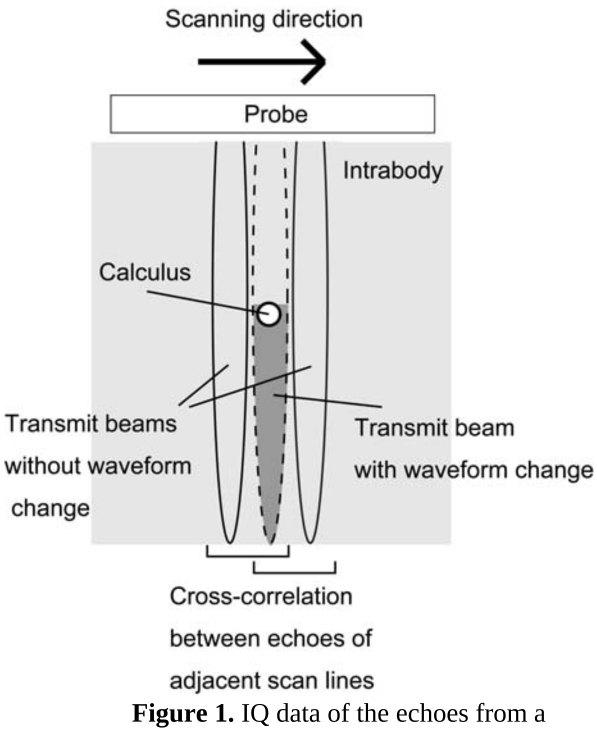

Figure 1. IQ data of the echoes from a boundary between gelatin and agar in two scan lines.

using the cross-correlation between adjacent scan lines. The proposed method presumes the existence of calcifications by selecting high-intensity-echo positions with posterior low-correlation-echo regions. We investigate the efficiency of the proposed method experimentally using a commercial ultrasonographic device and a calcification phantom.

2. METHODS

The presented method employs the cross-correlation coefficients between adjacent scan lines of raw ultrasound in-phase and quadrature (IQ) data. Section 2.1 presents the equations used in the proposed method. Section 2.2 explains the experimental setup to evaluate the efficiency of the proposed method.

2.1. Calcification Detection Using Decorrelation between Adjacent Scan Lines

A cross-correlation coefficient between adjacent scan lines of IQ data is suppressed by not only the existence of a calcification, but also the noise intensities of the scan lines. In this study we employed an echo intensity constraint to suppress the influence of noise. The cross-correlation coefficient with a constraint is

$$r(x+\frac{\Delta X}{2},z)=\frac{\left|\sum_{z'=z}^{z+m\Delta Z} g(x,z')g(x+\Delta X,z'+L\Delta Z)^{*}\right|}{\sqrt{\sum_{z'=z}^{z+m\Delta Z}\left|g(x,z')\right|^{2}\sum_{z'=z}^{z+m\Delta Z}\left|g(x+\Delta X,z'+L\Delta Z)\right|^{2}}}, \quad (1)$$

subject to

$$\sqrt{\sum_{z'=z}^{z+m\Delta Z}\left|g(x,z')\right|^{2}\sum_{z'=z}^{z+m\Delta Z}\left|g(x+\Delta X,z'+L\Delta Z)\right|^{2}} \geq \alpha m I_{t}, \quad (2)$$

where x and z are respectively the lateral and vertical components of a measurement point on a B-mode image, $g(x,z)$ is the IQ datum at a pixel in a B-mode image, $g(x,z)^*$ is the complex conjugate of $g(x,z)$, ΔX is the scan line interval, ΔZ is the range interval, $m\Delta Z$ is the correlation window width, α is a real number employed for the echo intensity threshold, and I_t is the intensity of a pixel at 1% from the maximum. The variable L is employed to acquire the maximum of the correlation coefficients.

Since the echo from a calcification is supposed to have high echo intensity, the proposed method first picks up candidates for calcifications. The method presumes the calcification positions by selecting the high-echo-intensity positions with posterior low-correlation-echo regions.

2.2. Experimental Setup

US was performed with a Hitachi EUB-8500 (Hitachi, Tokyo, Japan) US device with 7.5 MHz linear array probe, which has the function to export raw IQ data. The scan line interval of the device ΔX is about 0.13 mm, and the range sampling interval ΔZ is 0.05 mm. We prepared a calcification phantom with layered structure interference, as shown in Fig. 2. Three copper wires 0.2, 0.29, and 0.4 mm were embedded in an agar block at the depth of 2 cm, where the wire interval is 1 cm. A polyethylene sheet 0.1 mm thick was placed closely behind the wires. The agar gel contains 0.5% Tech Polymer particles, spherical polymer particles 7 μm in diameter (Sekisui Plastic Co., LTD). Fig. 3 shows the B-mode image of the calcification phantom, showing the difficulty to detect wire targets that mimic calcifications, where white arrows point at wire targets simulating calcifications. Five B-mode images were acquired to evaluate the proposed method.

Figure 2. Calcification phantom with a swine fat layer utilized in this study.

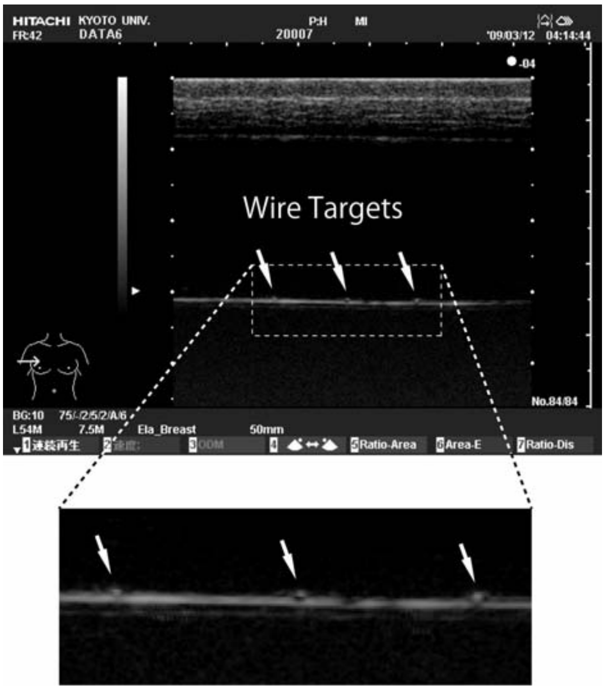

Figure 3. B-mode image of the calcification phantom with a swine fat layer. The diameters of wires are 0.2, 0.29 and 0.4 mm in left to right order.

3. RESULTS

All the positions with high echo intensities in the top 1% were picked up as the candidates for wire targets, as shown in Fig. 4. Almost all specular echoes with high echo intensity and echoes from wire targets were picked up by using the 1% intensity threshold.

We then surveyed the cross-correlation between adjacent scan lines of IQ data behind the candidates, where the correlation window width is 5 mm, i.e. m = 100, and the echo intensity thresholds for calculation of correlation α are 0.05 and 0.2. In cases of edges of correlation windows located around the boundary of the polyethylene sheet, correlation coefficients are temporarily suppressed; on the other hand, correlation coefficients are suppressed continuously along the range direction at and behind calcifications, as shown in Fig. 5 (a). Fig. 5 (b) shows the cross-correlation coefficient profile in the same section using the intensity threshold α of 0.2. When a higher echo intensity threshold is employed the isolated suppressions of correlation coefficients are inconspicuous because of the low echo intensity in the case that the edge of the correlation window is located at the boundary of the polyethylene sheet.

The method selects the high-echo-intensity positions with posterior low-correlation-echo regions to presume the calcification positions. In this study we calculated the cross-correlation coefficients located within 5 mm behind all candidates, and select the candidates where the ratios of significantly low correlation coefficients behind them are 50% or over. Estimated positions using the proposed method were located close to wire targets, as shown in Fig. 6. As a result, 11 of 15 wire targets included in the five B-mode images were depicted using the proposed method.

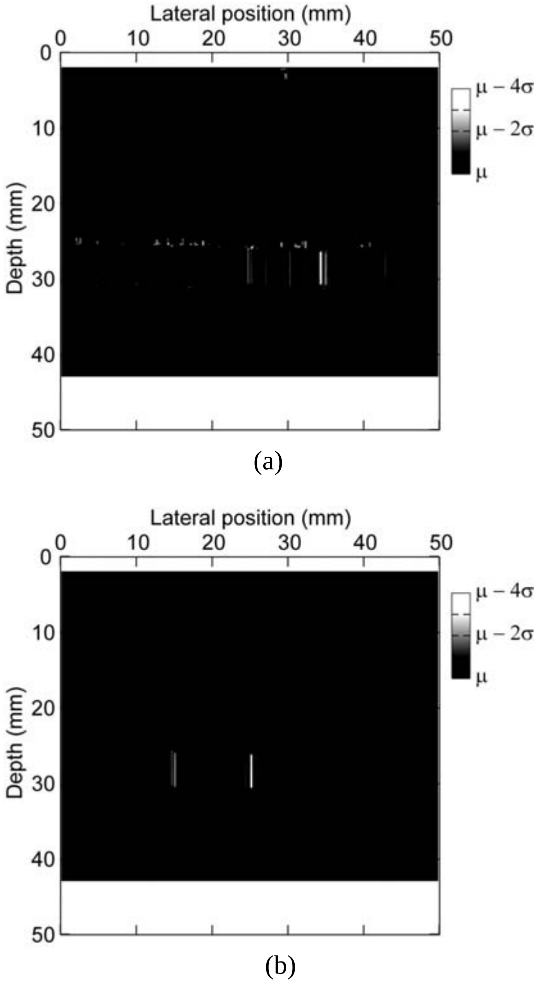

Figure 5. Correlation coefficients between echoes of adjacent scan lines when the echo intensity thresholds α are (a) 0.05 and (b) 0.2. μ and σ are respectively the average and standard deviation of correlation coefficients.

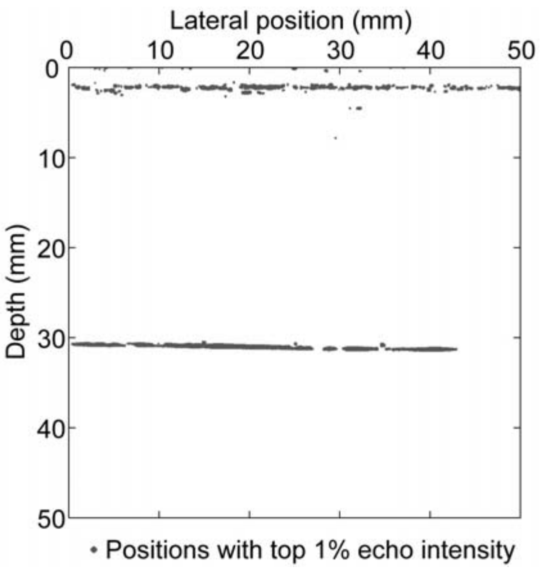

Figure 4. Candidates for wire target positions with the top 1% signal intensity.

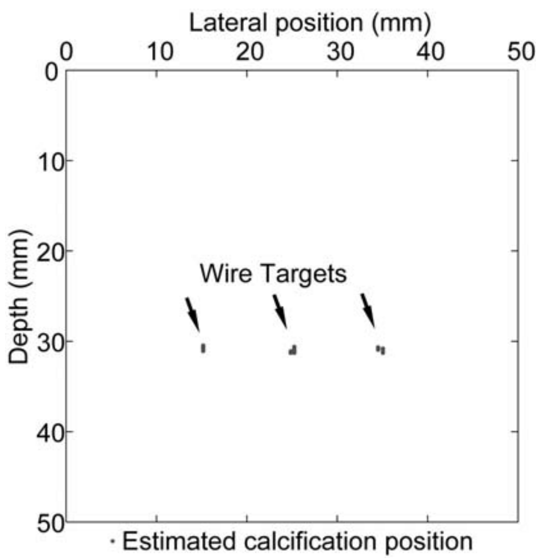

Figure 6. Estimated wire target positions selected using the proposed method.

4. CONCLUSION

In this paper we proposed a novel calcification method using the decorrelation of adjacent scan lines caused by the forward scattered wave originating at the calcification position. The proposed method detected 11 of 15 wire targets 0.2 - 0.4 mm in diameter using a certain threshold set, yielding a sensitivity of 73.3% and a specificity of 100%. This result indicates the high potential of the method in small calcification detection.

5. REFERENCES

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