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Total Calibration of Position, Response, and Directivity of Transducer Elements for Precise Imaging with Plane-Wave Based Ultrasound Computed Tomography

Takahide Terada[1‡], Kazuhiro Yamanaka[1], Atsuro Suzuki[1], Yushi Tsubota[1], Wenjing Wu[1], and Ken-ichi Kawabata[1]
([1]Hitachi, Ltd., Research & Development Group)

1. Introduction

Breast cancer is the most common cancer in women worldwide. For decreasing the mortality rate from cancer, cancer detection in early stages with screening is important. A screening system with non-invasiveness, operator independence and high sensitivity is required together with low cost of manufacturing and maintenance.

X-ray mammography and ultrasound echography with hand-held probes are the current standard screening methods for breast cancer. Both have drawbacks. Mammography uses X-rays and the sensitivity is low for dense breast tissues. Ultrasound echography with a hand-held probe provides operator dependent results. A candidate for breast screening is the ultrasound computed tomography (USCT) system, which is typically equipped with a ring-shaped transducer array that scans breast tissues operator-independently. The USCT system can operate without using X-rays.

The USCT system has been investigated since the 1970s[1)]. Recently, studies on its practicality have been extensive due to advances in computer technology[2)]. We developed a prototype USCT system, as shown in **Fig. 1**. The system has 1024 piezoelectric elements in a ring-shaped transducer array. The array is in a water tank to couple with breast tissues placed inside the array. A synthetic wave, such as a plane wave, using multiple elements is used for pricise imaging in our prototype. This is because the received signal intensity of the plane wave is much larger than a fan beam using one element generaly used.

Assembly error, production tolerance and aging degradation variation of the array may hamper cost effectiveness, precise imaging and robust operation. Therefore, a calibration methods play an important role. A calibration method for the transducer element's position has been investigated [3)]. With this method, the center region of a B-mode image has high resolution, but the peripheral region of the image has degraded resolution. This is because timing error appears in not only the element's position but also its response time in transmitter and receiver modes (T_{TX} and T_{RX}, respectively) and directivity of propagation delay (T_{DIREC}). Therefore, we propose a total calibration method for these timing components and the position.

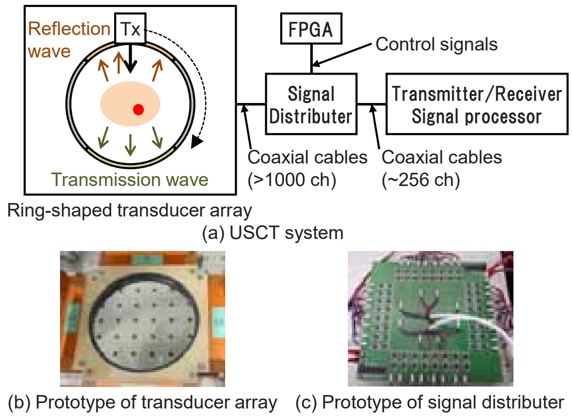

Fig. 1 USCT system; (a) block diagram and prototype of (b) transducer array and (c) signal distributer.

The plane wave is transmitted and received in all directions by changing the activated elements. Reflection and transmission waves can be received by the elements used for transmittng, and is located on the opposite side of the transmitter. The images of B-mode, speed of sound, and attenuation can be reconstructed using these waves. For calculating speed of sound and attenuation, the timing and amplitude of the received transmission wave are detected. The cancer is detected with high sensitivity using these indices.

2. Proposed calibration method

Figure 2 depicts the timing components in our prototype USCT system. T_{TX}, T_{RX}, propagation delay according to position of elements (T_{PROP}) and T_{DIREC} are required to compensate for errors for precise imaging. To expand the diameter of the field of view (FOV) to 70% of the diameter of the array, the signal that propagates ±45 degrees is required to use reconstructing images. The T_{DIREC} is mainly caused by the acoustic lens. The speed of sound and the thickness of the acoustic lens are about 1000 m/s and 1.5 mm, respectively. Therefore, the propagation delay at 45 degrees is 0.22 μs longer than that at 0 degrees. On the other hand, speed of sound of cancer tissue (5 mm) is about 30 m/s higher than that of the glandular tissues in breast[4)].

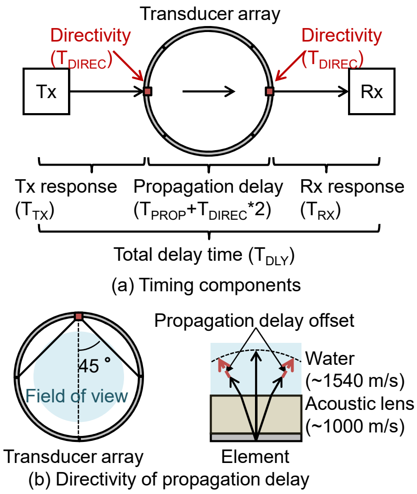

Fig. 2 Timing components; (a) overall and (b) directivity of propagation delay.

The signal through the cancer tissue is 0.07 µs faster than that not through the cancer tissue. This means the T_{DIREC} cannot be ignored.

The procedure of the proposed calibration method is as follows. First, the total delay time of the signal (T_{DLY}) between each element is measured. One element transmits the signal, and the elements located in a half circle on the opposite side of the transmitter receive the signal. Next, the differences between measured and typically configured T_{DLY} are calculated. Finally, the position of the elements, T_{TX}, T_{RX} and T_{DIREC} are optimized iteratively for minimizing the square sum of the differences. The calibrated parameters are used for generating synthetic waves and reconstructing images.

3. Experimental results

We evaluated the proposed calibration method with the developed prototype of USCT system, as shown in Fig. 1. The 100-mm-diameter transducer array has 1024 piezoelectric elements and its signal center frequency is 1.7 MHz. The array was assembled from four sub arrays. The signal distributer connects the array and 256 channels of the transmitter and receiver unit and activates elements in the array.

The transmission plane wave is measured using 256 elements for transmitting and receiving for evaluation of generating the synthetic waves is shown in **Fig. 3**. By using calibrated parameters, no significant shifted values or curve was observed in the received plane wave. The standard deviation of the plane-wave timing on each element with the proposed calibration method was 0.018 µs, a reduction of 88% from that without calibration.

Figure 4 presents measured the full width at half maximum (FWHM) of a 4-wire phantom by using the reflected plane wave. The diameter of wires was 0.27 mm. thirty-two B-mode images

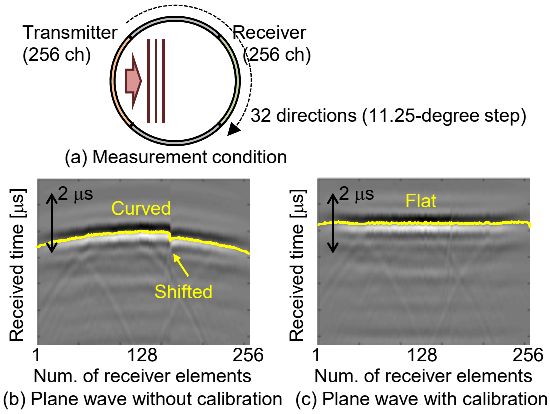

Fig. 3 Measured plane-wave flatness. (a) Condition. Received wave with (b) no calibration and (c) proposed calibration.

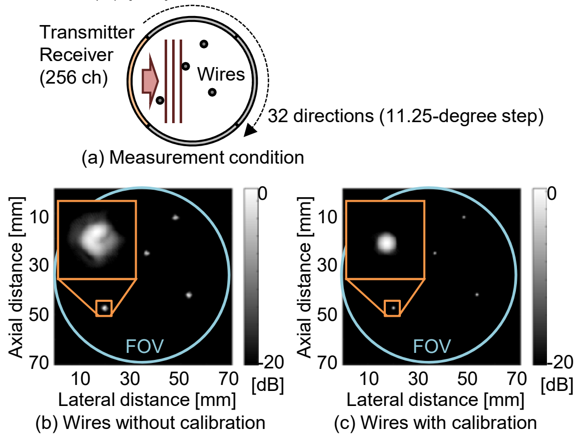

Fig. 4 Measured B-mode images of wire phantom with; (a) no calibration, (c) proposed calibration.

were compounded. The average FWHM with the proposed calibration method was 0.76 mm, half of that without calibration.

4. Conclusion

We proposed the total calibration method. The position of the elements, T_{TX}, T_{RX}, T_{DIREC} are calibrated iteratively. We evaluated the proposed calibration method with our developed prototype of USCT system. By applying calibrated parameters, the performances of generating synthetic waves and reconstructing images improved. The USCT system with the proposed calibration method can operate robustly against assembly error, for production tolerance, and against aging degradation variation of the transducer array.

References

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