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Noise reduction in ultrasonic computerized tomography by two-dimensional filtered projection data

投影データへの二次元フィルタ処理による超音波 CT 像におけるノイズ抑制

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1. Introduction

We have proposed a nondestructive inspection method for steel billets using computerized tomography (CT) based on time-of-flights (TOFs) of longitudinal waves.[1)] In this method, TOFs are measured by a transmittion method while a transmitter and a receiver are scanned all around the billet. When a defect exists on or near the measurement paths, the TOFs vary due to diffraction and scattering around the defect. We treat the TOF variation $\Delta\tau$ as the projection data in CT. The distribution of pseudo sound velocity inside the billet is reconstructed.In this method, a filtered back projection (FBP) with Shepp-Logan filter is employed for reconstruction. Therefore, low noise CT images is obtained by cutting high-frequency component. However, when the strong noise is included in $\Delta\tau$ data, the dapple noise remains on the CT image due to existence of the $\Delta\tau$ error. [2)] The strong noise in CT image disturbs detection of a defect. Therefore, in this study, we aim to reduce the noise in CT image by denoising on the projetion data. In scanning around the square billet, the transmitter and the receiver are not always face to face, therefore, the receiving sensitivities on those measurement paths become low.[3)] The projection data on those measeuremt paths have high tendency to include measurement errors. The measurement error results in low signal-to-noise ratio (SNR) of CT image, and defect detection difficult. Therefore, it is necessary to use more probable TOF data for back projection. As it is difficult to improve the experimental environment because of the limitation of equipments, we attempt to apply image processing to the projection data. In this study, we apply outlier rejection and moving average filtering as preprocessing filter to reduce the noise in CT image.

2. Preprocess algorithm

The procedure of FBP in this study is outlined as follows:

i) Obtaining TOF difference $\Delta\tau$ as projection data
ii) Arranging $\Delta\tau$ on r-θ plane
iii) Interpolating the $\Delta\tau$ data to be equally-spaced
iv) Back projection by inverse Radon transform, in which the $\Delta\tau$ data is interpolated with coordinate transform and is filtered on frequency space.

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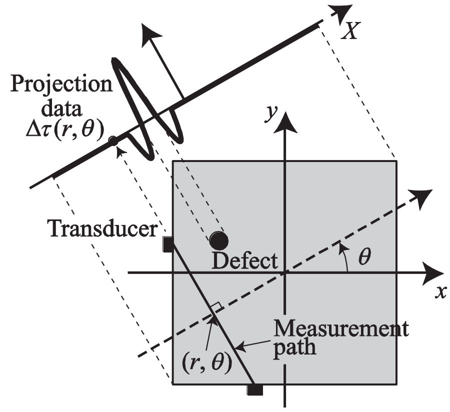

Fig. 1 Relation between x-y coordinate and r-θ coordinate.

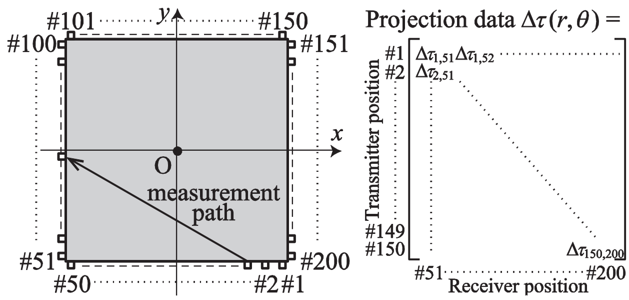

Fig. 2 TOF arrangement according to position of transmitter and receiver.

Figure 1 shows the relation of x-y coordinate and r-θ coordinate. Projection data are not regularly spaced on r-θ plane because of square scanning, therefore, interpolation (procedure iii) is necessary. The $\Delta\tau$ measurement error causes the noise on CT image. In our previous work, while these noise was reduced by weighted $\Delta\tau$ by the reliability of measurement path, the defect information was also lost.[2)] In this study, we manage to reduce the effect of the measurement error by following two ways:

1) Omitting outliers of $\Delta\tau$ from the projection data
2) Omitting $\Delta\tau$ next to the outliers of 1)
3) Moving average filtering on r-θ plane

First, the outlier is chosen by a threshold value, which is decided not to lose the defect information. However, after threshold processing, some $\Delta\tau$ errors are still remaining because the threshold value is set to have sufficient margin to the defect information. In the measurement, the errors possibly occur at some consecutive measurement points.[4)] Here, $\Delta\tau$ data are arranged in a matrix according to the position of the transmitter and the receiver, as shown in Fig. 2. Then, the neighboring values of outliers on the matrix are also omitted. Next, a moving average filter is applied on the projection data arranged on r-θ plane to cut off the high frequency component. While a prefilter is generally applied along r direction, in this case, the filter acts not only along r direction but also along θ direction. [4)] After above preprocessing, the projection data is used for FBP.

3. Experimental verification

3.1 Experimental condition

Figure 3 shows the experimental setup. The test piece is made of cast steel. The size of its cross-section is 100×100 (mm^2). The defect whose diameter is 2 mm is at $(x, y) = (0, 0)$ (mm). The center frequency of the transducer (Japan Probe IW B2C5I) is 2 MHz. The element size is 5 mm in diameter. The input signal is upchirp signal swept from 1 to 3 (MHz) in 5 μs. The scan pitch of the transducer is 2 mm. The threshold value of $\Delta\tau$ (in procedure 1 in §2) is set to be 0.02 μs. The moving average filter size is 3×3.

3.2 Experimental result and discussion

Figure 4 shows the experimental result. Figure 4(i) is the result using original $\Delta\tau$ data. Figure 4(ii) is the result with outlier rejection (procedure 1 in §2). Compared with Fig. 4(i), strong high-frequency noise of $\Delta\tau$ reduces, and the SNR of CT image improves. Figure 4(iii) shows the results with omitting $\Delta\tau$ next to the outliers (procedure 1 and 2 in §2). In this figure, the high-frequency noise on r-θ plane is diminished, and the noise in CT image is also diminished. The SNR is better in Fig. 4(iii) than in Fig. 4(ii). Therefore, it is preferable to remove the measurement error not only smoothing by Shepp-Logan filter. Figure 4(iv) shows the result using a moving average filtering on r-θ plane (procedure 1 to 3 in §2). From this result, $\Delta\tau$ data on r-θ plane is smoothed by filtering, and strong noise on r-θ plane disappeared. The noise in CT image are diminished, and this makes the detection easy. The SNR is the highest in the four results. Therefore, prefiltering along θ direction is efficient for noise reduction in CT image. Consequently, it is suggested that omitting unreliable data and applying the preprocess filter is useful for noise reduction in CT image by FBP.

4. Conclusions

We managed to reduce noise in CT images by preprocessed projection data. In addition to the procedure of FBP, the projection data is denoised by outlier rejection and moving average filtering before back projection. From the experimental result, the projection data before back projection became smooth and less noisy, and then the SNR of CT image improved. Consequently, it was found that omitting unreliable data and applying a preprocess filter for noise reduction in CT image by FBP.

References

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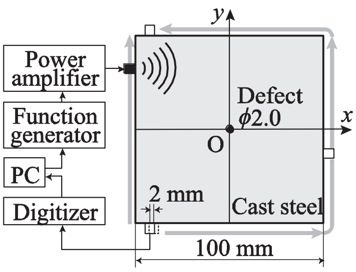

Fig. 3 Experimental setup.

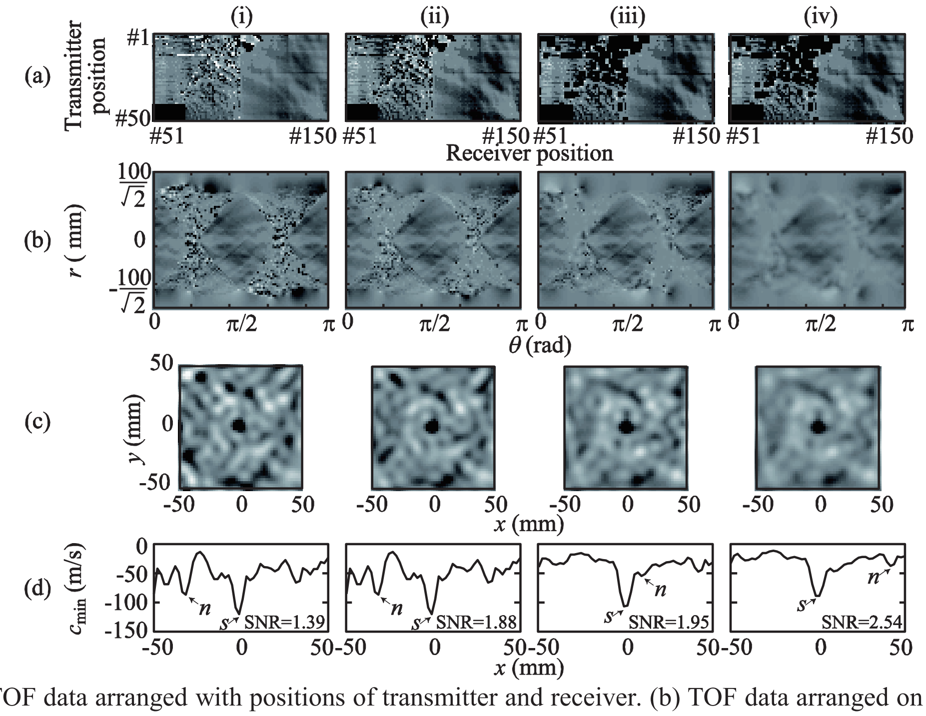

Fig. 4 Experimental results. (a) TOF data arranged with positions of transmitter and receiver. (b) TOF data arranged on r-θ plane. (c) CT image $c(x, y)$ reconstructed with (b). (d) Minimum values $c_m(x) = \mathrm{mic}(c(x,y))$. SNR is calculated by s/n, s and n is c at defect and at the strongest noise, respectively. (i) Using original TOF data. (ii) Using TOF data in which outliers are omitted. (iii) Using TOF data in which outliers and neighbors are omitted. (iv) Using TOF data in which outliers and neighbors are omitted, and moving average filtered on r-θ plane.