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ULTRASONIC TIME OF FLIGHT COMPUTED TOMOGRAPHY FOR CONCRETE INSPECTION

[1, 2] HONGHUI FAN, [1]HONGJIN ZHU

[1]School of Computer Engineering, Jiangsu Teachers University of Technology, Changzhou, 213001, China

[2]Key Laboratory of Cloud Computing & Intelligent Information Processing of Changzhou City, Jiangsu Teachers University of Technology, Changzhou, 213001, China

ABSTRACT

This research aims to evaluate the internal structure of concrete material configuration using an immersed ultrasonic computed tomography imaging technique. We propose a relative difference method of time of flight data to remove distortions in imaging process of concrete. Time of flight data for 306 paths were measured in total by manual scanning for one computer tomography image, we examined interpolation of time of flight data as the density which has a considerable effect on image quality in Filtered Back Projection (FPB) method. The relative difference of time of flight and interpolation is examined in detail using concrete phantoms. The accuracy of defect detection in concrete was significantly improved by the proposed technique.

Keywords: *Ultrasonic Computed Tomography, Time Of Flight, Concrete, Reconstruction Image*

1 INTRODUCTION

Ultrasonic computed tomography which has been used as the object's internal-structure imaging technique is able to map the physical quantity distribution within the object non-destructively (non destructive testing). It is an alternative way for quality inspection of many materials. The ultrasonic wave for nondestructive testing of concrete was repeatedly identified as being of high priority. The application of this reconstruction concept is then employed by some experts, such as Bracewell to reconstruct images of microwave emission from the solar surface[1], Imoto et al. studied image reconstruction using low-frequency for ultrasonic testing of concrete[2].

The research on the application of computed tomography for quality inspection of concrete is being done， it will be very appropriate for regular testing and in situnondestructive testing during concrete construction exists. The ultrasonic wave for nondestructive testing of concrete was repeatedly identified as being of high priority. Currently, the content of concrete inspection is cracked and holes. He-Ning proposed geometric active contour model for concrete computed tomography image[3]，Chai used attenuation of ultrasonic for concrete tomography reconstruction[4]. However, these methods cannot achieve the real internal structure visualization. Ultrasonic time of flight use ultrasonic signal which through the interior of measured object to reconstruct ultrasonic images. At the ultrasonic time of flight computed tomography, the spatial distribution of sound velocity is estimated, so using ultrasonic time of flight we can get concrete structure images.

Filtered Back Projection (FPB) method is an image reconstruction method for ultrasonic time of flight CT. It was modified to reconstruct CT images from incomplete time of flight profiles of wood by Yanagida and of concrete by Suryono et al[5, 6, 7, 8]. Concrete has an anisotropic property for sound velocity as wood [9, 10], it is difficult to accurately find the position of the holes in reconstruction images. So we proposed an approach to concrete inspection by ultrasonic CT on the basis of the FBP method. The relative difference method of time of flight data was proposed to remove distortions in imaging process of concrete. Furthermore, interpolation of time of flight data was applied to enhance image quality in FBP imaging process. The effects of image quality and the number of interpolations in the time of flight data are examined in detail using a numerical phantom and concrete phantom.

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2 IMAGING PROCESS

2.1 Image Reconstruction Using Fbp Algorithm

The Filtered Back Projection algorithm uses Fourier theory to arrive at a closed form solution to the problem of finding the linear attenuation coefficient at various points in the cross-section of an object [11]. A fundamental result linking Fourier transforms to cross-sectional images of an object is the Fourier Slice Theorem [12, 13], in this paper we concerned only with parallel beam projection data. The Fourier Slice Theorem for the parallel beam projection data is given here. The same justifications can be made for fan beam and cone beam projection data.

$$F(\rho\cos\theta, \rho\sin\theta) = \int_{-\infty}^{\infty}\left[\int_{-\infty}^{\infty} f\left(f(r\cos\theta - s\sin\theta, r\sin\theta + s\cos\theta\right)ds\right]\exp(-j2\pi\rho r)\,dr = \int_{-\infty}^{\infty} p(r,\theta)\exp(-j2\pi\rho r)\,dr \qquad (1)$$

In the Equine (1) above, the terms inside the square brackets (the operation indicated by the inner integral) represents a filtering operation and evaluate the filtered projections. The operation being performed by the outer integral evaluate the back-projections, which basically represents a smearing of the filtered projections back onto the object and then finding the mean over all the angles.

The process of reconstruction image based on FBP method in our system was shown in Figure 1.

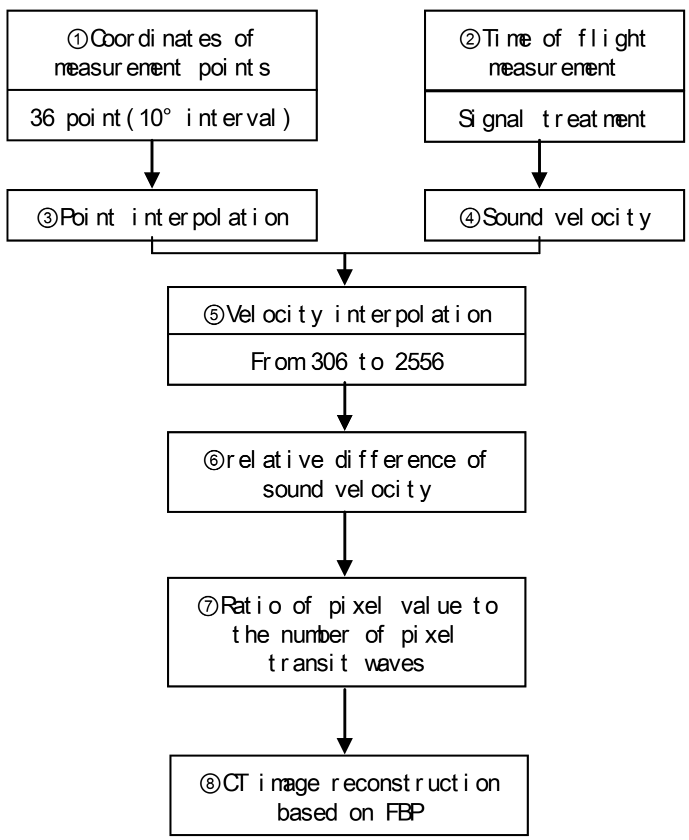

Figure 1: Flowchart For Reconstruction Image Based On FBP

2.2 Measurement And Materials

The materials which used in our system were produced by the Atati Laboratory and YastakaYanagida Laboratory of Yamagata University. All of the data used in this paper were from the same experimental system which was explained by Yanagida et al[5].

2.3relative Difference Method Of Time Of Flight

Because of anisotropic property for sound velocity, Yanagida et al. performed the "0 or 1

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imaging method" to reduce the artifacts of reconstruction images based on FBP method for wood CT image reconstruction. In our system, the CT image was reconstructed based on the assumption that an ultrasonic wave was transferred along the straight line. However, an ultrasonic wave in the interior of the object wave propagation. To consider the ultrasonic characteristics, the relative time of flight method was performed. According our measurement method, all ultrasonic time of flight data grouped with a gap angle θ_c of the transmitter and the receiver (measuring angles from 20 to 180 with 20 intervals).

The average sound velocity of the same gap $v_{ave}{}^{(gap)}$ was calculated using

$$v_{ave}^{(gap)} = \frac{1}{36}\sum_{i=0}^{35} v_i^{(gap)} \qquad (2)$$

L was the length of measurement path, *T* was the time of flight of with the same measurement path L. So the sound velocity of the measurement path was calculated using

$$v = \frac{T_{(TOF)}}{L_{(Dis)}} \qquad (3)$$

$$Q_i^{(gap)} = \begin{cases} Q1_i \ \ for \ \ v_i^{(gap)} \geq v_{ave}^{(gap)} \\ Q2_i \ \ for \ \ v_i^{(gap)} > v_{ave}^{(gap)} \end{cases} = \begin{cases} Q1_i \ \ for \ \ \dfrac{T_{(i)}}{L_{(i)}}^{(gap)} \geq \dfrac{T_{(i)}}{L_{(ave)}}^{(gap)} \\ Q2_i \ \ for \ \ \dfrac{T_{(i)}}{L_{(i)}}^{(gap)} \geq \dfrac{T_{(i)}}{L_{(ave)}}^{(gap)} \end{cases} \qquad (4)$$

The sound velocity $v_i{}^{(gap)}$ must be almost the same for one same gap pathways if the sample is normal (no defect). If $v_i{}^{(gap)}$ was considerably slower than the $v_{ave}^{(gap)}$ (average velocity of the gap), some defect should be on the *i*-th pathway. So $Q1_i{}^{(gap)} = v_{th}^{(gap)}$ was used for the clear pathway instead of the time of flight value, and $Q2_i{}^{(gap)} = v_i^{(gap)}$ was used to for the defect in the Equine (4).

Nine $Q_i^{(gap)}$ groups after relative time of flight method were used to reconstruct one CT image. As the influence of the anisotropic acoustic property was reduced, the artifact level of the reconstructed image decreased.

2.4 Interpolation

Measurement points were arranged at 10º intervals. It took about two hours to obtain 306 time of flight data from 20º intervals. So, the number of data that can be measured is thought that 306 were near the upper bound timely and spatially. The interval of measuring point and the number of time of flight path was determined by the size of specimens and the wavelength of ultrasonic. The interval of the measuring point should be smaller than the wavelength. So, start measuring from 20 º intervals, until end of the diameter of the measurement phantom. There was an exchange when transmitting and receiving on the same measurement point. Therefore, all the measurement paths should be 306 [= (transmitter 36 × receiver 18) /exchange 2- diameter 18], all measurement paths of one measurement point were shown in Figure 2(a). However, it is indicated that 306 data were not sufficient to obtain a clear CT image by the FBP method. Because of the lack of time of flight data, artifacts appeared in the FBP CT images [see Figure 3(b)].

To remove the artifact, angle interpolation was used in imaging process. Fan-beam was connected lines that arranged from the measurement point 0 to 35. When the intervals of transmitter and receiver were 10º intervals and 5º intervals, fan-beam of crossing paths would be made detailed. Because of all paths that could be calculated, so the interpolation data were increased. When the intervals of transmitter and the transducer were 5º intervals, 72 measurement points were assumed on the circumference of the test sample and labeled with numbers from 0 to 71. Figure 2(c) showed the paths and measurement points after interpolation. After 10 interpolation, the estimated time of flight data should be 630 [= (transmitter 36 × receiver 35) /exchange 2], and 2556 [= (transmitter 36 × receiver 71) /exchange 2] time of flight data were obtained by 5º intervals interpolation.

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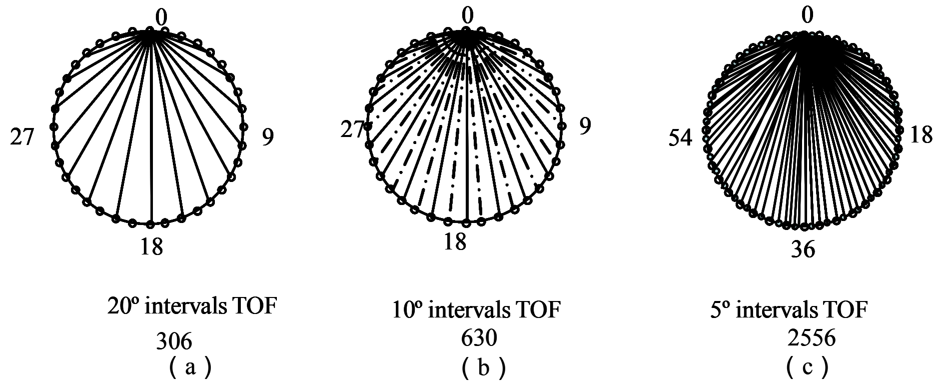

Figure 2: The Interpolation In The Case Of Fan Bean Geometry

3 RESULTS

3.1 Numerical Phantom

A numerical phantom containing a circle shaped defect was assumed which was composed of 128 x 128 square pixels of 1 mm size. The acoustic velocities were 5000 m/s for normal part, the acoustic velocities 2500 m/s for defect part. The diameter of specimen was 128. The defect was set of coordinates x=128, y=80, and radius r=15. The reconstruction images based on FBP method are shown in Figure 3.

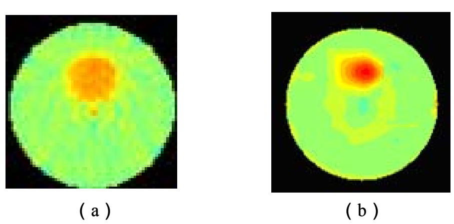

Figure 3: Reconstruction Images Of Numerical Phantom

From the reconstructed images which without interpolation, some artifacts were observed in the images and no clear defects were observed. The number of time of flight data after 5º intervals interpolation was 2556. When time of flight interpolation was used, better-quality images could be obtained. In our simulation, we did not consider the undulatory property. Furthermore, the time of flight data from the numerical phantom did not take into account the effect on the anisotropic acoustic property.

3.2 Cconcrete Phantom

Three pieces of concrete phantom were prepared as test specimens. The materials of test specimens were mortar and polystyrene foam. Test specimen (a) was no defect. Test specimen(b) had a defect which was set in the center, and the diameter was 8cm. Test specimen(c) had a defect which was set from the center 7cm, and the diameter was 4cm. All of the test specimen diameters were 25cm.

The images in Figure 5 were reconstructed by the conventional FBP(a) method with interpolation time of flight data. In the FBP (b) method, the relative difference method of time of flight was taken into account before interpolation. The CT images were successfully reconstructed based on FBP(a) method. The defect position of (B) specimen and (C) specimen were observed, but, it was possible that some artifacts were recognized in Figure 5. It was difficult to accurately judge the position of the defect. The anisotropic acoustic property was considered in the reconstructed images by the FBP(b) method in Figure 6, in which the number of line artifacts was reduced considerably and the artifacts on the edge of the reconstructed images almost disappeared. We could clearly find the defect in the reconstructed images of Figure 5.

4 CONCLUSIONS

It was experimentally confirmed that an ultrasonic wave was nonlinear propagation in concrete by the anisotropy of the concrete structure. The defect of concrete was successfully reconstructed based on the FBP method which time of flight data interpolation and anisotropic acoustic property were considered. The methodology of the application of the relative time of flight method to process of CT reconstruction image was proposed and verified. However, the shape and the size of defect cannot be fully displayed in reconstruction CT images by this method. Furthermore, the steel also not been considered in our system.

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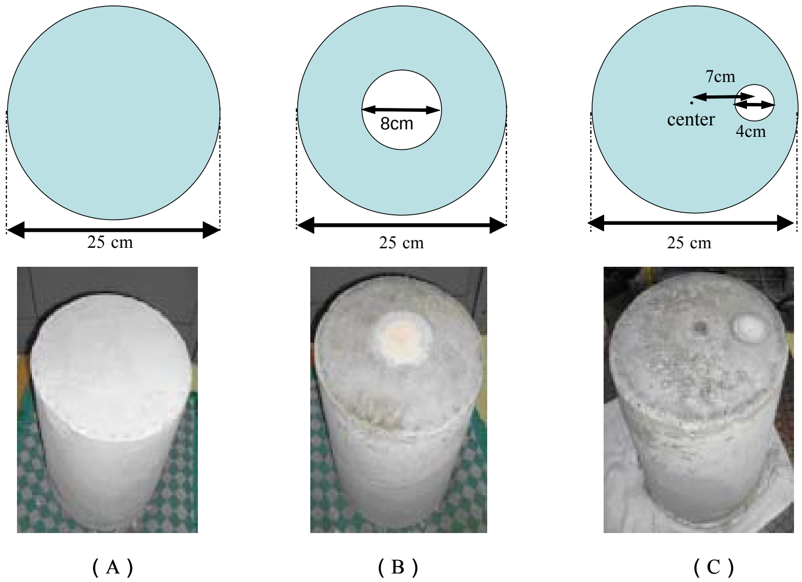

Figure 4: Inspection Object

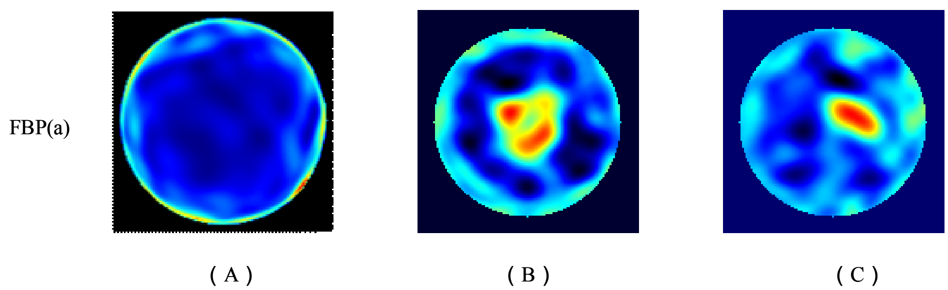

Figure 5: Image Reconstructed Based On Conventional FBP Method

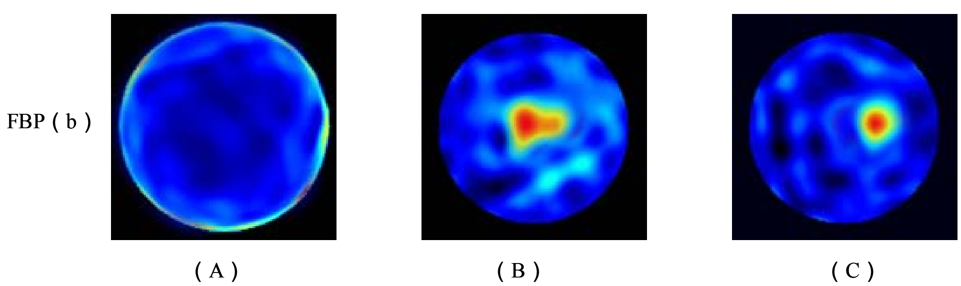

Figure 6: Image Reconstructed Considered Relative Difference Method Of Time Of Flight

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