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Ultrasonic Tomography of Core Plug Using Fresnel Volume Approach

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Abstract. Tomography was a non-destructive method for investigating the internal structure of an object, usually used to find internal anomalies caused by differences in the physical parameters. The fresnel volume tomography method was an alternative method for reconstructing the image of an object using travel times, whereas this method did not use a ray path in its calculations. In calculating the fresnel zone, the finite difference method which was the solution to the equation of wave propagation was used. The frequency of the waves was also considered, here we used ultrasonic waves with a frequency of 1 Mhz for the inverse modelling process. The reconstruction algorithm we used was Modified Simultaneous Iterative Reconstruction Technique for Fresnel volume. The application of the inversion of synthetic data resulted in an estimation of a velocity model that has good imaging quality and similarity with the synthetic model.

1. Introduction

Tomography is a reconstruction of a geometric object from the observed physical parameters representing the propagation effect of radiation through the observed object. McMehan [1] succeeded in developing an inversion method with an iterative approach for cross-hole reconstruction tomography, which was further developed by Sanny [2]. Travel time tomography generally uses a raytracing approach which is the arrival time or the first break based on Fermat's principle. Vidale [3] formulated a solution to the Eikonal's equation of the wave using a finite-difference approach to reduce the time consumption in ray-tracing. In this study, we focused to get the inversion result using Eikonal's solver and Fresnel volume approach. We used Modified Simultaneous Iterative Reconstruction Technique which was developed by Sanny [2].

2. Fresnel Volume Inversion

To calculate the travel time of the synthetic model, we need to forward model the synthetic model. We used a finite difference method proposed by Vidale [3] to calculate the travel time of waves in a medium. The basis of this method is the solution of Eikonal's equation of wave propagation in the three-dimensional case.

$$\left(\frac{\delta t}{\delta x}\right)^2 + \left(\frac{\delta t}{\delta y}\right)^2 + \left(\frac{\delta t}{\delta z}\right)^2 = s(x,y,z)^2 \tag{1}$$

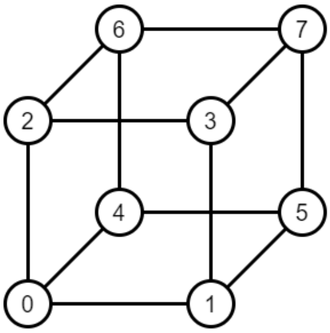

Figure 1. Wave propagation scheme using the finite-difference travel time method [3]

$$t_1 = t_0 + \left(\frac{s_0 + s_1}{2}\right) h \quad (2)$$

$$t_3 = t_0 + \sqrt{2(hs)^2 - (t_2 - t_1)^2} \quad (3)$$

$$t_7 = t_0 + \frac{1}{\sqrt{2}} \sqrt{\begin{matrix} 6(hs)^2 - (t_1 - t_2)^2 - (t_2 - t_4)^2 - \\ (t_4 - t_1)^2 - (t_3 - t_5)^2 - \\ (t_5 - t_6)^2 - (t_6 - t_3)^2 \end{matrix}} \quad (4)$$

Fresnel volume tomography is one of many tomographic method in which the fresnel zone approach is used to represent wave propagation compared to conventional wave rays [4]. Fresnel volume is defined as a set of arriving waves delayed after the first wave arrived by a difference of less than half a period.

$$\tau_{SP} + \tau_{PR} - \tau_{SR} \leq \frac{1}{2f} \quad (5)$$

Where (τ_{SP}) is travel time from source to point P, (τ_{PR}) is travel time from point P to certain receiver, and (τ_{SR}) is the travel time from the source (S) to the receiver (R) while (f) is the frequency of the wave.

To calculate the fresnel volume, a weighting function is used, (ω), where (Δt) is the residual of the travel time (τ_{SR}) to the sum travel time from the source point (τ_{SP}) and receiver (τ_{PR}).

$$\omega = \begin{cases} 1 - 2f\Delta t, & (0 \leq \Delta t \leq {}^{1}/_{2f}) \\ 0, & ({}^{1}/_{2f} \leq \Delta t) \end{cases} \quad (6)$$

We used the fresnel volume MSIRT inversion method, which was developed by Hardi and Sanny [5] to calculate the slowness correction factor (ΔS_i).

$$S_i^{k+1} = S_i^k + \Delta S_i \quad (7)$$

$$\Delta S_i = \frac{\sum_{j=1}^{M} \Delta t_{ij}}{\sum_{j=1}^{M} l_{ij}} \quad (8)$$

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$$\Delta S_i = \frac{\sum_{j=1}^{M} \frac{\omega_{ij} \, . \, S_i^k \, . \, \Delta T_j^k}{T_{calj}^k}}{\sum_{j=1}^{M} \omega_{ij}} \tag{9}$$

3. Synthetic Modelling

In this study, we applied the Fresnel volume tomography with several synthetic modeled after a core filled with minerals, an oil-filled shear fracture, a cornered structure, and a lamination structure. We used small-sized square cells of 0.2 mm and to cover the area of the core plug with a diameter of 2 cm and set the sensor around it by 360 degrees. The area of the image was 100 x 100 grid points. The frequency of the wave is set depend on the size of the object, we used a frequency of 1 MHz for the inversion process using equation 9. The first model of the iteration technique is a homogenous model.

Figures 2, 3, 4 and 5 show the result of the synthetic study using Fresnel volume tomography. By rescaling the color scale to minimize smoothing effects, we can see that various anomalies on the core plug are well imaged. The oil-filled shear fractures model on Figure 3 was well displayed. The mineral model on Figure 2 has a very high velocity contrast, resulting in a smoothing effect. The cornered model and the laminated model on Figure 3 and 4 can be reconstructed well, although there are still artifacts around the source/receiver points. Further techniques are needed to reduce artifacts and smooth effects. Alternatively, you can use a constraint model.

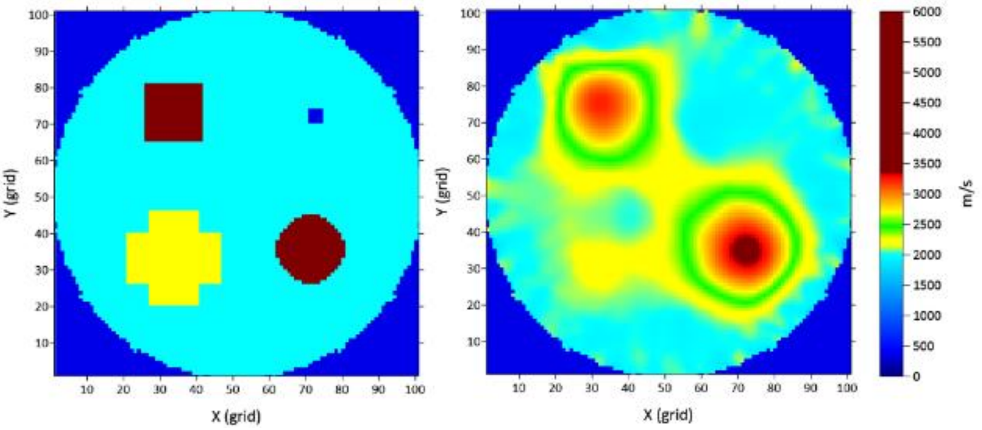

Figure 2. The mineral synthetic model (left) and its reconstruction (right)

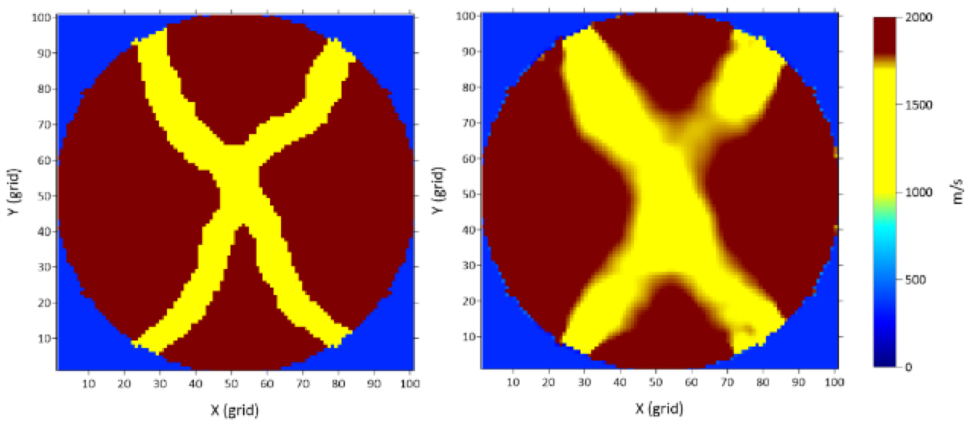

Figure 3. The oil-filled shear fracture synthetic model (left) and its reconstruction (right)

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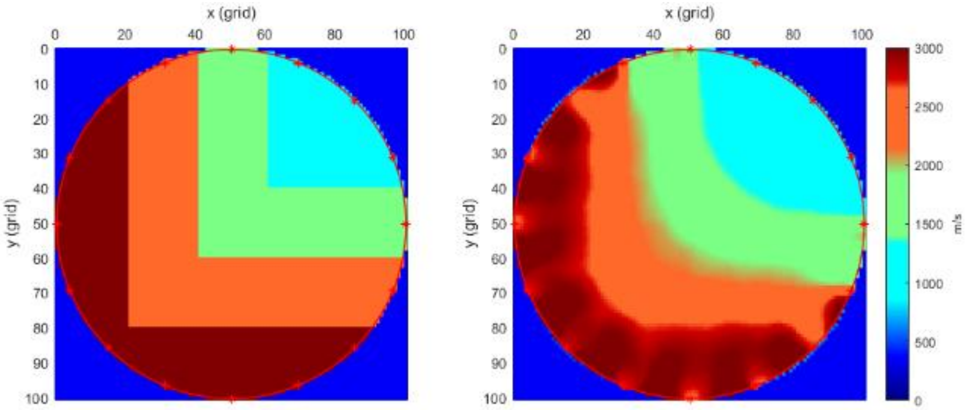

Figure 4. The cornered synthetic model (left) and its reconstruction (right)

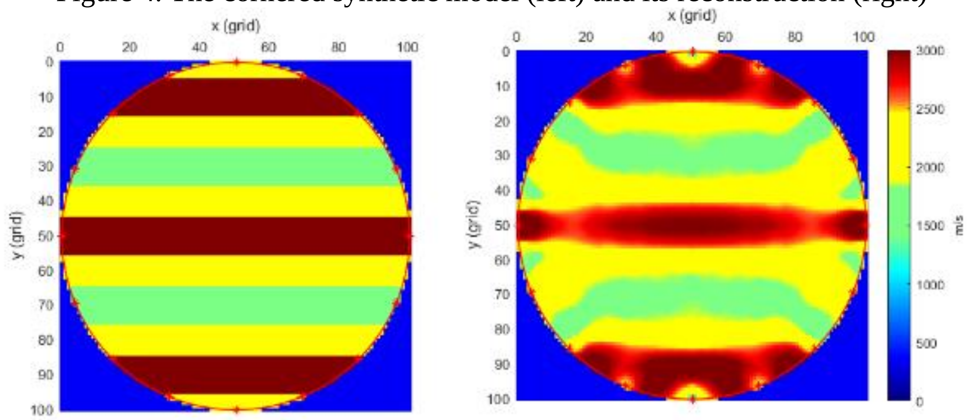

Figure 5. The lamination synthetic model (left) and its reconstruction (right)

4. Conclusion

We have presented a tomography method using ray substitution with the finite-width case. We also succeeded in applying the method of inversion by using Modified Simultaneous Iterative Reconstruction Techniques using Fresnel volume approach. The advantage of this method is that it considers the frequency used, as well as denser kernel matrix in the inversion, thereby minimizing ray distribution sparseness in cells. The synthetic modelling results shows that this method have good reconstruction image, resembling its original model.

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