Research on 3D−Image Reconstruction Based on TEM Inversion Image

Zhang Faquan

School of Information and Communication, Guilin
University of Electronic Technology
Guilin, China
zhangfq@guet.edu.cn

Li Zongmin

School of Information and Communication, Guilin
University of Electronic Technology
Guilin, China

Abstract—**TEM inversion image is a two-dimensional image, in which stratum structure does not reflect the image of the whole space, so that non-professionals can not accurately determine the exact location and shape of abnormal body. To solve this problem, two-dimensional inversion images are processed by the way of median filtering, threshold segmentation and linear interpolation, and so on. Then the method of marching cubes to surface rendering is used. It can reconstruct a three-dimensional image with good intuition. The method accurately demonstrates the spatial location and distribution of water, making detection more intuitive and easier to analyze the outcome. The results show that the method is also good at the safety of coal mine production.**

Keywords—TEM; Median filtering; Threshold segmentation; Linear interpolation

I. INTRODUCTION

Transient Electromagnetic technique is of simple operation, fast detection capabilities, high spatial resolution and other characteristics[1-4]. In recent years, the transient electromagnetic detection methods have rapidly developed. As the study on the technology is gradually going deeper and mature, the technology has been widely applied in underwater detection. Currently, the mine transient electromagnetic inversion images are two-dimensional plane, which reflects the distribution of the lateral extension of the surface of apparent. For resistivity of the vertical extension of the surface of apparent resistivity variation, it is not obvious. Because the three-dimensional imaging can improve transient electromagnetic geological prediction accuracy of interpretation, and it can be more intuitive in explanation and get more abundant amount of information, study on three-dimensional reconstruction TEM becomes very meaningful. [5-9]

II. A CROSS SECTIONAL VIEW OF THE INVERSION

After processing the data obtained by transient electromagnetic exploration method, drawing more measured channel cross sectional view of the raw data collected can reflect electrical parameters variation in the transverse more intuitively and qualitatively. Actual observation data is first converted into apparent resistivity curve by special software. Then according to the actual situation, it will be processed by filtering and one-dimensional inversion processing. Then we carries out time-depth conversion and apparent resistivity values to draw a cross sectional view, also named the inversion profile view.

In short, the basic processing steps for the transient electromagnetic exploration data are as follows: data preprocessing, data calculation and conversion, apparent resistivity conversion, time-depth conversion and drawing profile view.

An important step in the data processing is apparent resistivity depth conversion and scaling. Two ways are briefly introduced.

A. Apparent resistivity conversion

Region half-space apparent resistivity formula is given by

$$\rho_H = 6.32 \times 10^{-12} \cdot S_T^{\frac{2}{3}} \left(\frac{\varepsilon^c(t)}{I} \right)^{-\frac{2}{3}} t^{-\frac{5}{3}}, \tag{1}$$

where ρ_H is half-space apparent resistivity. $\varepsilon^c(t)$ is induced electromotive force. $S_T = 4Na^2$ is the equivalent area of the transmitter loop, which is often made some adjustment based on the actual ground conditions in reality.

According to multiple relationships, the apparent resistivity of whole space is easily computed by

$$\rho_W = \rho_H \cdot G. \tag{2}$$

Apparent resistivity of the whole space is defined by

$$\rho_W = G \cdot 6.32 \times 10^{-12} \cdot S_T^{\frac{2}{3}} \left(\frac{\varepsilon^c(t)}{I} \right)^{-\frac{2}{3}} t^{-\frac{5}{3}}, \tag{3}$$

where ρ_W is apparent resistivity of the whole space. G is the whole space apparent resistivity multiple relationships, which value in theory is $(2.5)^{\frac{2}{3}}$.

B. Time-depth conversion

In any conductive medium and conditions, under being excited by multi-turn rectangular loop source, the rate of diffusion of apparent electromagnetic fields at a certain time is given by

$$v_s(t_i) = \lambda \frac{\rho_s(t_i)\sqrt{\pi v}}{2\mu_0 a}\left\{c_1(v) + \sqrt{c^2(v)+2} + \left[1 + \frac{c_1(v)}{\sqrt{c^2(v)+2}}\right]vc_2(v)\right\} \quad (4)$$

where a is half of the loop side. v_s is the diffusion rate of apparent electromagnetic field. λ is conversion factor, which value is related with the electrical distribution of the rock detected front, usually between 0.6 to 1.8.

$$v = \frac{\mu a^2}{\pi \rho_s(t_i)t_i}. \quad (5)$$

$$C_1(v) = \frac{3}{4}\sqrt{\pi}\left[1 - \frac{v}{4} - \sum_{k=2}^{\infty}\frac{(2k-3)!!}{k!(k+1)!}\left(\frac{v}{2}\right)^k\right]. \quad (6)$$

$$C_2(v) = \frac{3}{4}\sqrt{\pi}\sum_{k=0}^{\infty}\frac{(2k-1)!!}{k!(k+2)!}\left(\frac{v}{2}\right)^k. \quad (7)$$

The apparent depth is calculated as

$$D_s(t_i) = v_s(t_i) \times t_i. \quad (8)$$

C. Sectional view of the inversion

The actual probe will take a number of survey lines and plot multiple profiles of survey lines, thus rendering 3D image. In the one survey line, the induced voltage value of every measuring point in the same time was connected with each other. When the same measuring points maintain a continuous trend, it can generally be determined that there are anomalies at this point. Apparent resistivity contour maps can be obtained by analyzing the potential distribution which can provide a vision where anomaly is. Aquifer displayed in apparent resistivity region is black. The profile drew according to the basic approach to transient electromagnetic exploration data is shown in Figure 1.
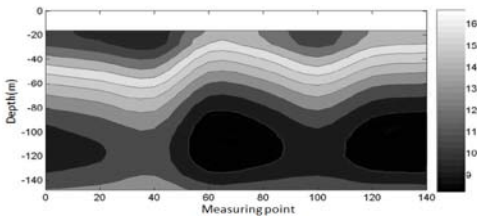

Fig. 1. Sectional view of the inversion

III. IMAGE PREPROCESSING

A. Median filtering

The disturb massage that received in the sampling process will lower SNR, furthering influence the density of the image resolution, graphics fuzzy and distortion, to make the image distortion. In order to make images mixed with noisy be applied, image filtering must be done to remove noise and to enhance image features, and then there will be a better subsequent process. Median filter overcomes the linear filter under certain condition, such as the detail fuzzy in image which comes from minimum mean square filtering or average filtering. In addition, it is especially effective to suppress the impulse noise and salt pepper noise image. Median filtering generally uses a sliding window containing an odd number of points and arranges the pixel gray level within the sliding window, then uses the mid-value instead of window center pixel of the original grey value, or uses local values instead of local average[10,11]. Specifically, assuming that there is a N–dimensional odd discrete sequences a_1, a_2, $\cdots a_n$, its median is m which can be used to replace corresponding pixel gray in window center.

In general, the median of a window with N numbers is defined by

$$median(x_1, x_2, \cdots x_N) = m. \quad (9)$$

If N is even, then take the average of two median as the median.

B. Threshold segmentation

Threshold segmentation is an important link in the 3D image reconstruction, it not only can compress a large amount of data and reduce the storage capacity, but also can greatly simplify the subsequent analysis and processing. It takes advantage of the difference of the extracted target and background on the gray characteristic, and then puts the image as the combination of two regions of different gray level of target and background, after which it selects a suitable threshold in order to determine each pixel point of image should belong to the background or the target area, thus separate the background area pixel and the target area pixel and reduce the interference of background factors on the reconstruction of the target. This paper uses semi-threshold value method which sets the threshold t to realize the threshold segmentation. Its principle can be represented as

$$G(x, y) = \begin{cases} F(x, y) & F(x, y) > t \\ 0 & \text{other} \end{cases}. \quad (10)$$

Among them, $G(x, y)$ is the gray value after threshold segmentation, $F(x, y)$ is the original gray value, it is the average gray value for the image.

In figure2, the original image after filtering and threshold segmenting, obviously, compared with figure 1, figure2, is

clean with abnormal area image and only keep the anomalous areas of interest target image left, which reduces the interference of background factors in the process of reconstruction.

C. Linear interpolating

In the 3D reconstruction process of transient electromagnetic inversion image, the position of each section has determined and a interlayer spacing between each section exists. If the images are superimposed directly, there will be obvious ladder shape at the edge of the reconstruction image which will seriously affect the quality of reconstruction of 3D image. Therefore interpolation method must be applied in ct image. There are many interpolation methods for interpolation. When it comes to the gray level interpolation, linear interpolation can be used. Linear interpolation is the most widely applied interpolation algorithm. For new images

$$f(p_{k+d}) = (1-d)f(p_k) + d \bullet f(p_{k+1}). \qquad (11)$$

where p_k , p_{k+1} are the corresponding points of picture S_k , S_{k+1}. $f(p_k)$, $f(p_{k+1})$ are corresponding picture gray value. $f(p_{k+d})$ is the new picture gray value.
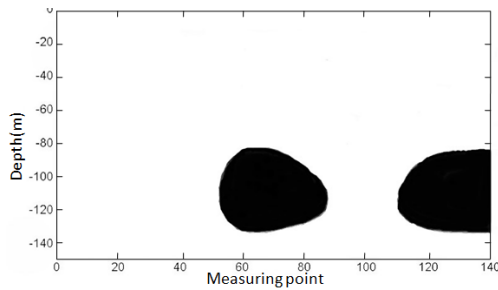

Fig. 2.   The image processed by filtering and dividing

IV.   THREE-DIMENSIONAL DATA RENDERING

A. Determine the way of isosurface subdivision

The basic assumption of MC algorithm is that along the edge data field of voxel show a continuous linear change. When each value of the two corners in one edge is greater than or less than the value of the isosurface, the side has only one point of intersection with the isosurface. When the eight corners are greater than or equal to the value of the isosurface, labeled 0. When the eight corners are less than the value of the isosurface, labeled 1. Each corner has two states, a total of 256 states. According to rotational symmetry, it can be reduced to 15 kinds. Firstly, establish a lookup table which has 256 index entries, each index entry by the index, rotation and split mode components. Eight corner values are composed as 0 and 1 string to form an index entry, then use index entry look for in the lookup table to determine one of fifteen kinds of split mode[12,13]. Parts of fifteen kinds of the form show in Figure 2.
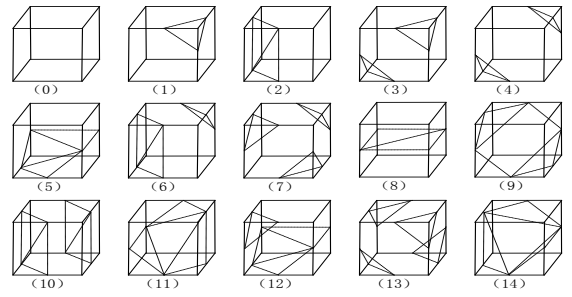

Fig. 3.   Fifteen kinds of split mode

B. Determine the intersection of isosurface and edge

When the two corner of the edge is 0 and 1, isosurface necessarily intersects with edges, the position are given as following.

(1) When the X-axis is parallel with the edge, two corner points of the edge is provided for $v_1(i, j, k)$, $v_2(i+1, j, k)$, so that the intersection is $v(x, j, k)$:

$$x = i + \frac{c - f(v_1)}{f(v_2) - f(v_1)}. \qquad (12)$$

(2) When the Y-axis is parallel with the edge, two corner points of the edge is provided for $v_1(i, j, k)$, $v_2(i, j+1, k)$, so that the intersection is $v(i, y, k)$:

$$y = j + \frac{c - f(v_1)}{f(v_2) - f(v_1)}. \qquad (13)$$

(3) When the Y-axis is parallel with the edge, two corner points of the edge is provided for $v_1(i, j, k)$, $v_2(x, j, k+1)$, so that the intersection is $v(i, j, z)$:

$$z = k + \frac{c - f(v_1)}{f(v_2) - f(v_1)}. \qquad (14)$$

C. Determine the isosurface normal vector

To take advantage of graphics hardware to display isosurface image, must be given the equivalent surface normal vectors, select the appropriate lighting model calculating, generate more realistic image reconstruction. Because direct calculation of the normal vector of triangular facets is time-consuming, actually, center difference method is used to calculate the gradient of each corner point. Then calculate the intersection of the gradient by linear interpolation, i.e. the normal vector of the vertex of triangular facets. The pixel value of space coordinates (i, j, k) is expressed as $f(i, j, k)$, then the gradient value of the data point is (g_x, g_y, g_z). So that the corner central difference formula are given by

$$\begin{cases} g_x = \dfrac{f(x_{i+1}, y_j, z_k) - f(x_{i-1}, y_j, z_k)}{2\Delta x} \\ g_y = \dfrac{f(x_i, y_{j+1}, z_k) - f(x_i, y_{j-1}, z_k)}{2\Delta y} \\ g_z = \dfrac{f(x_i, y_j, z_{k+1}) - f(x_i, y_j, z_{k-1})}{2\Delta z} \end{cases} \cdot \qquad (15)$$

where Δx, Δy, Δz are side length of cube, respectively.

Marching cubes algorithm implementation process is as follows:

(1) Read into the three-dimensional medical volume data, and constitute a voxel with eight data points of vertically adjacent layers image.

(2) According to the size relationship between the pixel value of each the data point in the voxel and a given threshold, structure state table of the voxel data points, and thus obtained with the side that has intersection with the isosurface;

(3) Using a linear interpolation method, and according to the pixel values of voxel edge endpoints and given off value to calculate the specific location of the intersection isosurface with voxel edge.

(4) First, calculate the normal vector of each data point in the voxel. Then calculate normal vector of each vertex in the triangular facets of constituted isosurface by linear interpolation. Finally, take advantage of the normal vector of each vertex of triangular facets to calculate the normal vector of triangular facets.

(5) According to the vertex coordinates of various triangle facets and normal vector, draw the local isosurface.

(6) Repeat step (2) to (5), until processing all voxels which intersect with isosurface.
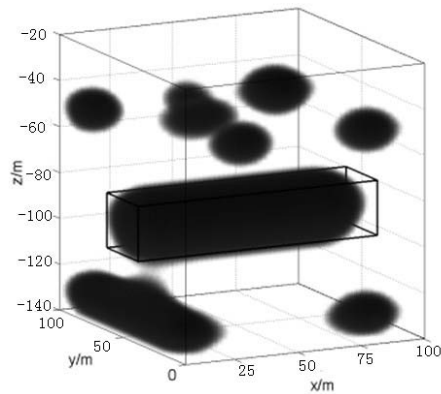

Fig. 4. 3D-reconstruction renderings image

V. Conclusion

By drawing the multiple plane reconstruction technology, proposed a three-dimensional image reconstruction algorithm base on TEM inversion image method, which combine threshold segmentation, linear interpolation, Marching Cubes

and other methods to get a better quality of 3D images. Not only retains the details inside the object, but also avoid the massive data processing. After reconstruction the three-dimensional image can be rotated, section selected and other treatment. It can observe abnormal body function from different angles and positions. The three-dimensional image can be demonstrated the spatial location and distribution of the anomalies accurately and visually, making detection result more intuitive and easier to analyze. It can better guide the coal mine production safety.

References

[1] Guillemoteau J, Sailhac P, Béhaegel M. Regularization strategy for the layered inversion of airborne transient electromagnetic data: application to in‐loop data acquired over the basin of Franceville (Gabon)[J]. Geophysical Prospecting, 2011, 59(6): 1132-1143.

[2] Dumin O M, Dumina O O, Katrich V A. Evolution of transient electromagnetic fields in radially inhomogeneous nonstationary medium[J]. Progress In Electromagnetics Research, 2010, 103: 403-418.

[3] Tanaka Y, Kunisada E. Study on meshless method using RPIM for transient electromagnetic field[J]. Magnetics, IEEE Transactions on, 2011, 47(5): 1178-1181.

[4] Pieper S,Halle M,Kikinis R. 3D Slicer[C]//Biomedical Imaging: Nano to Macro,2004. IEEE International Symposium on. IEEE, 2004: 632-635.

[5] Pickhardt P J. Three-dimensional endoluminal CT colonography (virtual colonoscopy): comparison of three commercially available systems[J]. American Journal of Roentgenology, 2003,181(6): 1599-1606.

[6] Jonker PP. Skeletons in n dimensions using shape primitives[J]. Pattern Recognition letters, 2002, 23(4): 677-686.

[7] Gregory M. Nielson, On Marching Cubes[J], IEEE Transaction on Visualization and Computer Graphics, 2003: 281-287.

[8] Weaver A A, Loftis K L, Tan J C, et al. CT based three-dimensional measurement of orbit and eye anthropometry [J]. Investigative ophthalmology & visual science,2010,51(10):4892-4897.

[9] De La Haza Aldo O, Samokrutov Andrey A, Samokrutov Pavel A. Assessment of concrete structures using the Mira and Eyecon ultrasonic shear wave devices and the SAFT-C image reconstruction technique[J]. Construction and Building Materials,2013,38: 1276-1291.

[10] Yamasaki S, Mitsuhara M, Ikeda K. 3D visualization of dislocation arrangement using scanning electron microscope serial sectioning method[J]. Scripta Materialia[J]. 2015,101:80-83.

[11] Horie Masafumi, Muneta Takeshi, Yamazaki Junya. A modified quadrant method for describing the femoral tunnel aperture positions in ACL reconstruction using two-view plain radiographs[J]. Knee Surgery Sports Traumatology Arthroscopy[J]. 2015,23(4): 954-960.

[12] Cabrera Javier, Diaz-Manzano Fernando E, Barcala Marta. Phenotyping nematode feeding sites: three-dimensional reconstruction and volumetric measurements of giant cells induced by root-knot nematodes in Arabidopsis[J]. 2015,206(2): 868-880.

[13] Jiao Chunhai, Zhang Yali, Zhang Junwei. 3D reconstruction research of medical image based on improved MC algorithm [J]. Microcomputer Application, 2011, 30(3): 39-41, 45.