

3D Visualization of the VTK and Qt Based Mine Transient Electromagnetic Method

Based on the analysis of the advantages of VTK and Qt, we studied the mode and the internal principle to integrate them. Using simple and efficient C++ language, we combined the target-oriented visualized toolkit VTK with the cross-platform class library Qt towards the development of a 3D visualization software based on the mine transient electromagnetic method (MTEM, similarly hereinafter). The software was applied to the hydrological geophysical project in the 4300 track uphill, 4303 air-return gate and on-boundary return gateway of the Xinglongzhuang coal mine. With clear and straightforward mapping, the software renders the analysis of geophysical output more efficient. The validation result of the mining performance in the four marked water-rich anomaly zones has proved the applicability of 3D visualization achievements.

Keywords: 3D visualization, Qt, Transient electromagnetic method, VTK.

1. Introduction

With the depletion of shallow coal resources, major coal fields in eastern China gradually enter the stage of in-depth mining [1], which places the mining area into the threat of water burst. Transient electromagnetic method is a time-domain artificial electromagnetic detection approach founded on the principle of electromagnetic induction [2, 3]. MTEM has a good application prospect in the forecasting of water and gas outburst under the conditions of deep mining mined structure exploration, working face roof rock deformation observation and high permeability stress condition [4, 5].

As the basic traditional expression of the resistivity information in the detection area, 2D MTEM profile of real geophysical result is abstract and much difficult to understand. Until now, spatial visualization technology has become a tendency and must-to-be development of the

geophysical technologies, with the advantages of 3D objective display and multiple operations. Dai Guanghong [6] held that the visualization of scientific computing freed people from the time-consuming and tedious abstract analysis of massive data, and the working efficiency was improved accordingly. Chen Shaoqiang et al. [7] developed the visualization software of 3D regular data field by using Marc Levoy's light projection algorithm and applied it to the geophysical exploration of coal mines, achieving good results. Rashad, Mahmoud ed al. [8-10] have achieved some results in 3D algorism. Through corresponding analysis, Wang Peng [11] developed a Matlab 3D display software which operated in a triple of transient electromagnetic data visualization modes: "three-dimensional map", "slice map" and "contour plane map". By discussing the characteristics of mining geophysical data and OpenGL-VC++ programming, Gao Ji et al. [12, 13] developed the Windows-based mining seismic data 3D visualization system Sgy3D and the mine transient electromagnetic data processing/interpreting system Tem3D. Based on the Voxler 3D visualization software, Liang Qinghua et al. [14-16] studied with tests the 3D visualization of the underground transient electromagnetic field, and obtained an output map more intuitionistic and easier to analyze. Zhou Sihui et al. [17] used the method of natural neighbor interpolation to calculate the transient electromagnetic data, which realizes the 3D display of collapse columns in fully-mechanized coal mining face such that the development characteristics and water-bearing property of collapse column can be determined. Ulloa, Juan Carlos Díaz ed al. [18, 19] do some research in the field of 2D and 3D graphics engine. Su MaoXin ed al. [20-22] do some research in MTEM 3D visualization and 3D geologic structure modeling technique. In the medical field, Wei Na et al. [23-26] realized the three-dimensional visualization of medical images using techniques such as VTK, ITK, VC++, Qt, etc. The results also have certain reference value in geophysical field.

On the foundation of VTK and Qt, we developed a 3D visualization software in terms of geophysical results. The software was applied to the hydrological geophysical project in the 4300 track uphill, 4303 air-return gate and on-boundary return gateway of the Xinglongzhuang coal mine, which

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generates clear and straightforward 3D images. The validation result of the mining performance in the four marked water-rich anomaly zones has proved the applicability of 3D visualization achievements.

2. The fundamental theory of mtem

2.1 FUNDAMENTAL PRINCIPLE

Mine transient electromagnetic method is employed to indirectly judge the hydrological geology and the structural geology based on the geological structure or the physical properties of the geological body itself. It is a time-domain artificial geophysical electromagnetic induction detection method, because the method result is derived from the time-varying change of the secondary field induced by the detected objective that is stimulated by strong pulse currents as the field source. The rich geoelectric information is contained in the electromagnetic diffusion field

In the underground diffusion process, the information of the earth's electricity is rich. By extracting and interpreting these information, The purpose of sexual media.

2.2 TRANSIENT ELECTROMAGNETIC DATA PROCESSING

2.2.1 Calculation of apparent resistivity

As the late conditions are more suitable for the detection of electrical anomalies in the deep, the general calculation of apparent resistivity used in the formula for the late formula [4, 27]:

$$\rho_{\tau}(\partial B_z / \partial t) = \frac{\mu_0}{4\pi} \left[\frac{2n\pi I_0 a^2 \mu_0}{5t \partial B_z / \partial t} \right]^{2/3} \quad \dots 1$$

μ_0 is the permeability. Generally, $\mu_0 = 4\pi \times 10^{-7} H/m$

The induction potential generated by the eddy current field in the receiver loop is:

$$V = -S_r \frac{\partial B_z}{\partial t} \quad \dots 2$$

S_r (m^2) is the effective area of the return loop, S_r (m^2) is the effective area of the receiving coil, I (A) is the supply current intensity, V (V) is the induced electromotive force of the receiver coil.

So the late apparent resistivity is calculated as:

$$\rho_{\tau} = \frac{\mu_0}{4\pi} \left[\frac{2\mu_0 S_r S_r}{5t(V/I)} \right]^{2/3} = 6.32 \times 10^{-12} \times (S_r S_r)^{2/3} \times (V/I)^{-2/3} \times t^{-2/3} \quad \dots 3$$

2.2.2 Depth calculation

In the geophysical exploration for the mining area, the coal-bearing strata are generally layered. Such being the case, the following method can be used for time-depth conversion. According to "smoke ring effect" in the electromagnetic field proposed by Misak Nabiqian, when the underground half-

space is a non-uniformly distributed conductive medium or an arbitrary conductive medium, the propagation of electromagnetic waves satisfies the Maxwell equations. At a certain moment, the rate of diffusion of electromagnetic fields in subsurface media is [3]:

$$V_s = \alpha \frac{\sqrt{\gamma}}{\sigma_i \mu a} \left[C_1 + (C_1^2 + 2)^{1/2} + \left(1 + \frac{C_1}{(C_1^2 + 2)^{1/2}} \right) \gamma C_2 \right] \quad \dots 4$$

where,

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

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

$$\gamma = \sigma_i \mu a^2 / 4t_i$$

σ_i is the apparent resistivity at the moment t_i ; is the coefficient. Then, D is:

$$D = V_i \times t_i \quad \dots (5)$$

3. The mine transient electromagnetic 3d visualization technology

3D visualization is a display tool that is used in the field of geology and geophysics to display features that describe and interpret many geological phenomena underground and on the ground. At the same time, 3D visualization is also an interpretation tool and an expression tool, which can supplement traditional methods of section interpretation. 3D visualization is a direct interpretation of different transparency parameters in 3D space that target physical properties of geological body within the range of underground detection. The function of this 3D scanning and tracing technology helps interpreters to determine objectives rapidly and describe all kinds of complex geological phenomena clearly.

Until now, spatial visualization technology has become a tendency and must-to-be development of the geophysical technologies, with the advantages of 3D objective display and multiple operations. Therefore, based on our research conducted on VTK and Qt, we realized the display of 3D MTEM results.

3.1 VTK TECHNOLOGY

VTK [28] (Visualization Toolkit) is a set of OpenGL-based 3D visualization tool developed by Kitware Corporation. All the functions of the commonly used algorithms in the field of graphics and visualization are encapsulated in several hundred class libraries by using object-oriented technology. 3D visualization development can be undertaken efficiently and rapidly with the help of the class libraries called by Java, Python or Tcl, whose code execution efficiency is higher than Matlab.

3.2 QT TECHNOLOGY

Qt [29] is a C++ toolkit with all the functions necessary for application program developers to establish a cross-platform graphical user interface. Completely object-oriented and easily extensible, Qt has become the foundation of thousands of successful applications worldwide.

The Qt functionality is built on the underlying API of the supported platform, rendering Qt flexible and efficient. It is different from traditional “layered” cross-platform toolkits in that it uses a single source code tree so convenient as to convert Qt into an executable program by recompiling on the target platform.

3.3 THE PRINCIPLE OF VTK-QT COMBINATION

With a large number of their own merits, VTK and Qt can supplement each other in developing design programs with greater advantages. We studied their way of combination as well as the corresponding internal principle. VTK provides QVTKWidget to manage the VTK subjects embedded in the Qt window interface. With new QVTKWidget (this), we can generate QVTKWidget cases,. The Widget function setCentralWidget (mainView) of Qt can be employed to integrate QVTKWidget into the major framework.

All the categories of VTK is stored in vtkRenderer. We instantiated a vtkRenderer and assigned it to QVTKWidget to manage GetRenderWindow()->AddRenderer (m_render)°Finally, VTK and Qt were combined together.

Class QVTKWidget is investigated:

Class QVTKWidget: public QWidget

```
{
// member variable
vtkRenderWindow* mRenWin;
}
```

We had a member of vtkRenderWindow that was a class in VTK. The member was in the charge of QVTKWidget. Then, in the realization file, there is

```
this->mRenWin->SetWindowId(this->winId());
```

Nothing but this sentence is related to the actual window. By referring to Qt Assistant:

```
//WinId QWidget::winId () const
//Returns the window system identifier of the widget
```

We understand how Qt is integrated with Windows apparent window system.

Through the above analysis, we naturally find the way to combine VTK with other cross-platform interface class libraries in Windows.

3.4 REALIZATION OF THE VISUALIZATION SYSTEM

In this paper, the simple and efficient C++ language is used as the preferred language for development. The

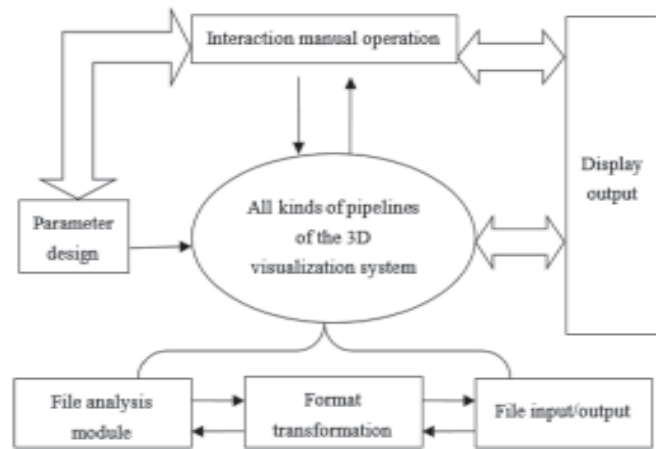


Fig.1 System architecture

development environment of the program is Visual Studio.Net 2005, but the interface development class library is the cross-platform class library Qt in combination with the target-oriented visualization toolkit VTK. The program has realized part of commonly-seen 3D visualization algorithms, which can be classified into two types: plane mapping, which includes contour plane extraction, display of three perpendicular planes and arbitrary slice display of interactive Widget data volume, and volume mapping, which mainly realizes the combination method and the contour plane method in the ray-tracing method.

By our analysis of the requirements of MTEM data processing, the system architecture is designed properly according to the proposed functions, as shown in Fig.1.

Developed software should have the following main functions:

1. Reading of three-dimensional transient results of data volume and relevant data. Analysis of all kinds of file formats for the data to be inputted into the system. Mutual conversion between file formats, capable of saving converted files for future use.
2. A variety of display modes, such as frame display (Outline), slice display, extraction of isosurface, volume visualization (VR), interactive widget display, and box display.
3. Interactive operations of 3D scenes, including rotation, translation, zoom.
4. Control of all kinds of display like lights, scene color and transparency.

The overall design of the program is shown in Fig.2. Fig.3 shows the main interface of the developed software.

4. Working examples

4.1 OVERVIEW OF THE PROSPECTING AREA

Xinglongzhuang coal mine, under Yanzhou coal field, is in the vicinity of the syncline axis of Yanzhou coal field. It



Fig.2 The overall design scheme of the 3D visualization system

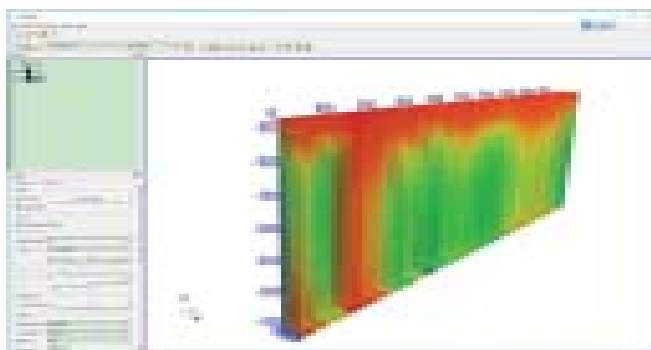


Fig.3 the main interface of the software

has deep depth of Ordovician ash, high artesian head, good local water enrichment, and a serious risk of Ordovician water in sublevel coal mining. To reveal the condition of water enrichment in Ordovician ash such that ensuring safety operation, we undertake the hydrological geophysical project in the 4300 track uphill, 4303 air-return gate and on-boundary return gateway. As a result, the water-rich zones are determined.

In this survey, we measured a total of three transient electromagnetic survey lines, at the overall length of 3,024 m and the measure point interval of 8 m. There are all together 380 measure points.

The measured data are denoised, filtered, and inverted before being inputted to the proposed MTEM 3D visualization software. Then, the 3D isoline map of apparent resistivity is plotted in the coordinate system in Fig.4, whose vertical coordinate is horizontal distance (unit: m), and horizontal coordinate is the detection distance in the detection direction (unit: m).

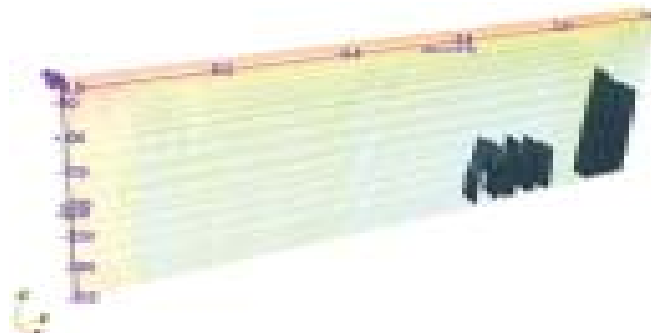


Fig.4 Three-dimensional contour map of apparent resistivity in 4300 track

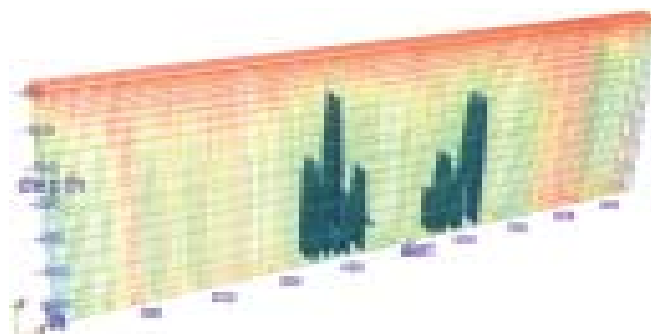


Fig.5 Three-dimensional isoline diagram of apparent resistivity on the 4303 air-return gate

As can be seen from the above figure, there are two low-resistive anomaly areas in respective 4300 track uphill and 4303 air-return gate. By using the slicing function of the software, we obtained the corresponding apparent resistivity contour map, as shown in Fig.6 and 7.

Accordingly, we are able to divide the 4300 track uphill and 4303 air-return gate into four water-rich areas:

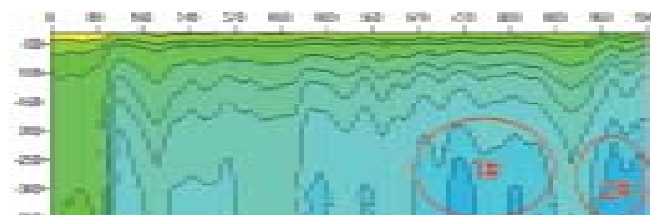


Fig.6 Sectional view of apparent resistivity contour in 4300 track

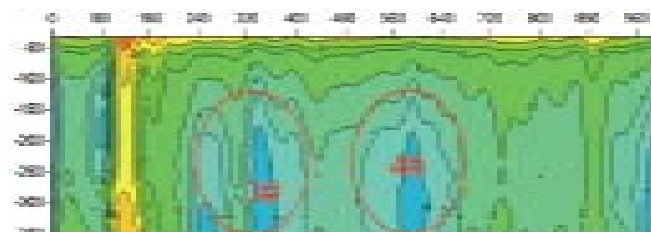


Fig.7 Sectional view of the apparent resistivity contour along the 4303 air-return gate

- 1# water-rich area: 4300 track uphill in the range of 640 ~ 880 m;
- 2# water-rich area: 4300 track uphill in the range of 960 ~ 1040 m;
- 3# water-rich area: 4303 air-return gate in the range of 240 ~ 400 m;
- 4# water-rich area: 4303 air-return gate in the range of 500 ~ 660 m.

According to the results of 3D visualized exploration of mine transient electromagnetics, for the drilling holes of FO₂-20 and FO₂-21 that are arranged in the respective 3# water-rich zone and the 4# water-rich area, the actual intake of Ordovician ashes are 150 m, and the water burst amount is 150 m³/h and 180 m³/h, respectively. The strong water enrichment verifies the reliability of the geophysical results and the applicability of the 3D visualization results.

4 Conclusion

Both VTK and Qt have the advantages of high code execution efficiency and easy access to cross-platform operation. By studying the principle of VTK-Qt combination, we developed the 3D visualization software of mine transient electromagnetic results. With clear and intuitive software imaging results, the efficiency of geophysical result analysis is enhanced.

In the hydrological geophysical project in the 4300 track uphill, 4303 air-return gate and on-boundary return gateway of the Xinglongzhuang coal mine, we validated the existence of four water-rich anomaly zones according to the 3D isoline of the apparent resistivity and other maps generated by the software. The result has proved the applicability of 3D visualization achievements.

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