

Study on 3D Mine Tunnel Modeling

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Abstract: Based on the discussion of the topological relations of 3D geometric elements, data structure and its organization method of 3D tunnel modeling were put forth. Modeling adopted the wire frame method, and used half circle and sin-function to simulate the section of tunnel. Modeling steps and formula of circulation were put forward. With Microsoft Visual C++ 6.0 as the developing tool and OpenGL as the major graphic-manipulating tool, the visualization system of 3D tunnel model is developed. And the trial system is tested with the example of Yin Mu-si Lead and Zincs Mine. The results show that the modeling for 3D tunnel is applicable.

Key-Words: Tunnel; Modeling; Wire Frame; Visualization; OpenGL; Visual C++

1 Introduction

Currently, 3D mine tunnel simulation is the one of most important contents in 3D GIS and Digital Mine(DM) theory and technology. Some data structure and methods of 3D tunnel modeling and showing was put foreword by the pioneer [1-5], but, there are some disadvantages in 3D tunnel geometry, full expression of attribute elements, automatization of modeling and spatial analysis, etc. Thus, the study of mine tunnel simulation method can perfect the DM modeling methods, promote the development in the theory and method of MGIS (Mine GIS), and provide theoretical and technological basis for commercialization software. This paper will discuss the topological relations of 3D tunnel elements, the data structure of 3D tunnel modeling and its methods.

2 Topological Relations of 3D Tunnel Geometric Elements

As for the whole mine region, every tunnel can be abstracted as a tunnel line. Spatial net is composed of tunnel lines which linked together. As far as the working face or a tunnel is concerned, tunnel can be regarded as 3D spatial entity [1]. Different methods were put forward by different scholars on tunnel entity's expression.

The method to stimulate 3D tunnel is using cylinder [6] and its expression precision is so-so; Some scholars [7] utilize the section object and Quasi cylinder to stimulate tunnel; Tunnel arc, the basis of tunnel line, is abstract from tunnel entity which can be show by bottom distance, up distance, right distance and left distance [3]; It is perfect method that Quasi Tri-Prism Volume is used to stimulate the tunnel directly [5].

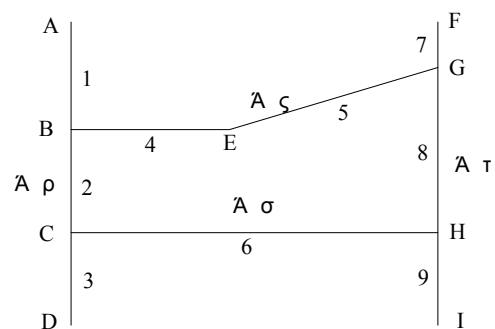


Fig.1 The topological relations of tunnel elements

In order to build the 3D tunnel modeling on computer, the tunnel can be decomposed into several basis elements: node, joint, arc and tunnel line. In Fig.1, English letters A, B, C, etc. represent nodes; The number 1,2,3 ,etc represent arc; Grecian letters I,II,III, etc represent tunnel lines.

Topological relations of above elements are shown in Tab.1

3 Data Structure and Methods of 3D Tunnel Modeling

Currently, the research on 3D spatial modeling methods is a hot topic in the field of 3D GIS. Many scholars and experts have done a lot of research in

3D GIS field. With further study on 3D GIS spatial data modeling, altogether 24 methods appeared in 3D spatial modeling, which can be divided into 3 classes (facial model, volumetric model and mixed model). This paper will choose Wire Frame to build 3D spatial modeling on the basis of 3D tunnel characteristics.

Table 1 The topological relations of tunnel geometric elements

Nodes ID	Arc ID	Tunnel ID	Coordinates	Connection Nodes	Type
A	1	□	...	B	end point
B	1,2	□,II	...	A,C,E	node, end point
C	2,3,6	□,III	...	B,D,H	node, end point
D	3	□	...	C	end point
E	4,5	□	...	B,G	node
F	7	□	...	G	end point
G	7,8	II,□	...	E,F,H	node, end point
H	6,8,9	□,□	...	C,G,I	node, end point
I	9	□	...	H	end point

3.1 Data Structure of 3D Tunnel Modeling

3.1.1 Data Structure of 3D Tunnel Elements

Each basic element is defined as a structure with C++ language and each element can be analyzed in program. Thus, the topological relations of those elements are established.

(1)The definition of universal point structure
typedef struct

```
{
    double m_x;//x coordinate
    double m_y; // y oordinate
    double m_z; // z coordinate, namely altitude
    CString m_Dname; //point name
} TUNNELPOINT;
```

(2)The data structure of nodes

typedef struct

```
{
    TUNNELPOINT m_xdpoint;
    int m_nodeAttribute;//Attribute,if it is
    //equal to 0, it represents for joint; if it
    //is equal to 1, it represents for start
    //node; if it is equal to -1, it represents
    //for end node
    CString m_TunnelID;//Tunnel ID
} NODE;
```

(3) The data structure of tunnel line

typedef struct

```
{
    NODE m_node;
```

```
double l_bang;//left side distance
double r_bang;//right side distance
}PointStr;
class CNodeLine
```

```
{
public:
    PointStr m_pointstr;
    CArray<double,double> YR;
    //coordinate y on the right side
    CArray<double,double> XR;
    //coordinate x on the right side
    CArray<double,double> XL;
    //coordinate x on the left side
    CArray<double,double> YL;
    //coordinate y on the left side
    .....//other number variables and
    //functions
}
```

3.1.2 Data Structure of Tunnel Section

The attribute data of tunnel section, such as height, width, will describe with C++ as follows:

typedef struct //the data structure of adding section

```
{
    TUNNELPOINT Point[11];
    //a point on the arch every 15 degree
```

```

TUNNELPOINT m_special[2];
    //2 special points on the arch
TUNNELPOINT m_base[2];
    //2 base points on the two sides
double height;//height of tunnel
double width;//width of tunnel
} TUNNEL;
    
```

The data structure of section is the representation of every point in tunnel line model and will be useful in showing 3D tunnel.

3.2 Method of 3D Tunnel Modeling

This paper will mainly adopt methods of Wire Frame to create 3D tunnel modeling.

Wire frame[8]: The main idea of this method is that two neighboring sample point or special point on the object spatial outline are joined by lines, so, a series of polygons will be formed; then, the grid, which can be used to stimulate geologic boundary or dig boundary, will be shaped by putting the polygons together.

$$\left. \begin{aligned}
 X_{iR} &= X_i + r_i \times \cos(\alpha_i - \pi/2) \\
 Y_{iR} &= Y_i + r_i \times \sin(\alpha_i - \pi/2) \\
 X_{iL} &= X_i + l_i \times \cos(\alpha_i + \pi/2) \\
 Y_{iL} &= Y_i + l_i \times \sin(\alpha_i + \pi/2) \\
 Z_{iR} &= Z_{iL} = Z_i
 \end{aligned} \right\} \quad (1)$$

In the equation, i is the sequential number of lead point such as d_{x1} , d_{x2} etc. X_{iR} , Y_{iR} , Z_{iR} and X_{iL} , Y_{iL} , Z_{iL} are coordinate of right-side and left-side which are accordance with lead point (In fig.2, A_1 and A_2 is the right-side and left-side respectively). X_i , Y_i and Z_i represent coordinates x , y , z , l_i and r_i represent left-side distance and right-side distance and α_i represent the backsight azimuth of the lead point correspondingly.

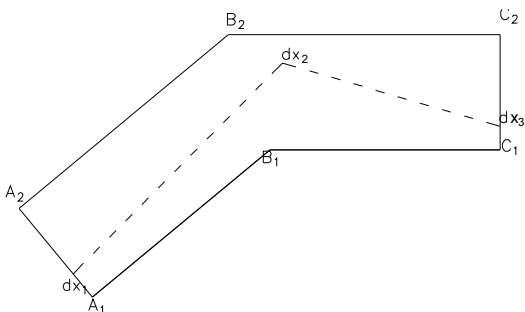


Fig.2 The original tunnel boundary & layout of surveying lead.

As is shown in fig.2, A_1, A_2, B_1, B_2, C_1 and C_2 are original side point on the tunnel while d_{x1}, d_{x2} and d_{x3} are the surveying point of lead. The arithmetic

step to construct the tunnel modeling can be divided to 4 steps:

Step1: Through 3D coordinate of surveying point of lead and the left-side distance and right-side distance, 3D coordinate of two side point (such as $A_1, A_2, B_{11}, B_{12}, B_{21}, B_{22}$ etc) can be calculated by using formula (1), and the picture can be shaped by joining a series of sequential two side point coordinates as is shown in Fig 2. Simultaneously, the coordinate of intersected points (such B_1, B_2 etc) must be calculated by using line equation of A_2B_{21} and C_2B_{22} . As Fig.3 shows.

$$\left. \begin{aligned}
 x_o &= \frac{x_{A1} + x_{A2}}{2} \\
 y_o &= \frac{y_{A1} + y_{A2}}{2}
 \end{aligned} \right\} \quad (2)$$

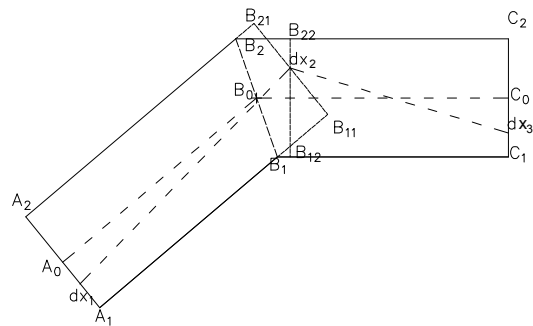


Fig.3 The figure of calculation

Step2: We can calculate the coordinates of central line point in correspond with lead point (such as A_0, B_0 from Fig.3). Thus, we can obtain the central line of tunnel.

Step3: On the basis of Fig.3, we can add the tunnel section according to the points of central line and two side points, as Fig.4 shows:

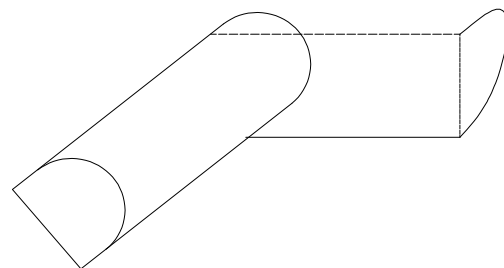


Fig.4 The addition of tunnel section

Step4: As for the section arch, we need to scatter the section arch curve; generally, section arch is set as half circle that can be divided by 15 degree. This resolution can approach the tunnel factually. In terms of formulas (2), (3), (4), the coordinates of scatter point can be calculated, and then link the scatter points correspondingly on the tunnel section according to method of wire frame, finally, link the scatter points between the two neighboring

sections. Namely, a lot of rectangles are shaping and neighboring, like the Fig.5 and Fig.6 shows.

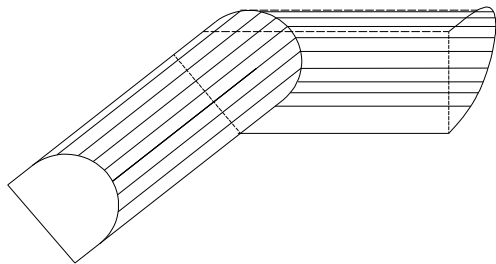


Fig.5 Scattering the section arch

$$\left. \begin{aligned} d_{ok} &= \frac{l+r}{2} \cos(j \times \pi / 12) \\ d_{pk} &= \frac{l+r}{2} \sin(j \times \pi / 12) \end{aligned} \right\} (j=1 \square 2 \square \dots \square 11) \quad (3)$$

$$\left. \begin{aligned} x_p &= x_o + d_{ok} \cos(\alpha_1 + \pi / 2) \\ y_p &= y_o + d_{pk} \sin(\alpha_1 + \pi / 2) \\ z_p &= z_{A1} + h + d_{pk} \end{aligned} \right\} \quad (4)$$

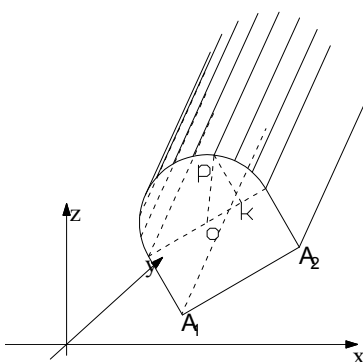


Fig.6 The figure of 3D wire frame of tunnel

Another method can also be used to obtain the section arch curve, which is to utilize sin-function curve to approach the arch curve. Firstly, we can divide the projection A_1A_2 , which section arch mapped onto xy plane, into 12 segments; then 3D coordinate of scatter points can be obtained by calculating from formula (5). The addition of

section like above addition, so we will not discuss it in more details.

$$\left. \begin{aligned} x_p &= x_{A1} + j \times (x_{A2} - x_{A1}) / 12 \\ y_p &= y_{A1} + j \times (y_{A2} - y_{A1}) / 12 \\ z_p &= z_{A1} + h + \frac{d_{A1A2}}{2} \sin(j \times \pi / 12) \end{aligned} \right\} (j=1,2,\dots,11) \quad (5)$$

In the equation, x_o, y_o represent the coordinate of central line, x_p, y_p and z_p represent 3D coordinate of point p, d_{ok} and d_{pk} represent the distance of ok and pk respectively, d_{A1A2} represent the distance between A_1 and A_2 , h represent the height of tunnel.

From the above stated, the main idea of 3D tunnel modeling is as follows: create the boundary of tunnel, obtain the central line, add the section, build the 3D wire frame model of tunnel.

3.3 Visualization Methods of 3D Tunnel Modeling

The data to make the 3D tunnel model comes from surveying point mainly. The main methods are wire frame. Visualization is realized through OpenGL. The setting of basic parameters in OpenGL include position of light, mode of lighting, mode of color, (mode of light and shade, mode of texture mapping etc. At the same time, the initial value of viewpoint and observed direction need enactment. Then, model transformation, projection transformation, viewport transformation need to be done before transforming survey 3D coordinates to screen coordinates on the monitor. Finally, 3D tunnel model will be created by using the function which Z-buffer can be culling automatically, 3D tunnel model is shown in Fig.7. Fig.8 is the flow chart of tunnel model creation [9]

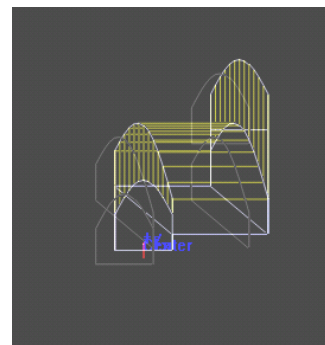
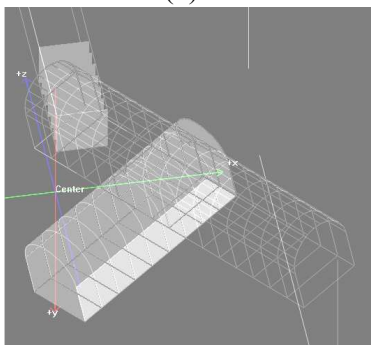


Fig.7 3D tunnel wire frame simulated by half circle & sin-function

4 Test of Trial System

Based on the data structure and modeling methods mentioned above, with Windows XP as the platform , MS Visual C++6.0 as the tool of software development and OpenGL as the main graphics manipulating tool, 3D visualization system of tunnel

model is developed. The system has many functions, such as adding text, zooming out/in, moving, and rotating, etc. And the trial system is tested with the example of Yin Mu-si Lead and Zinc Mine. The result shows that the method of 3D tunnel modeling put forward in this paper is applicable.

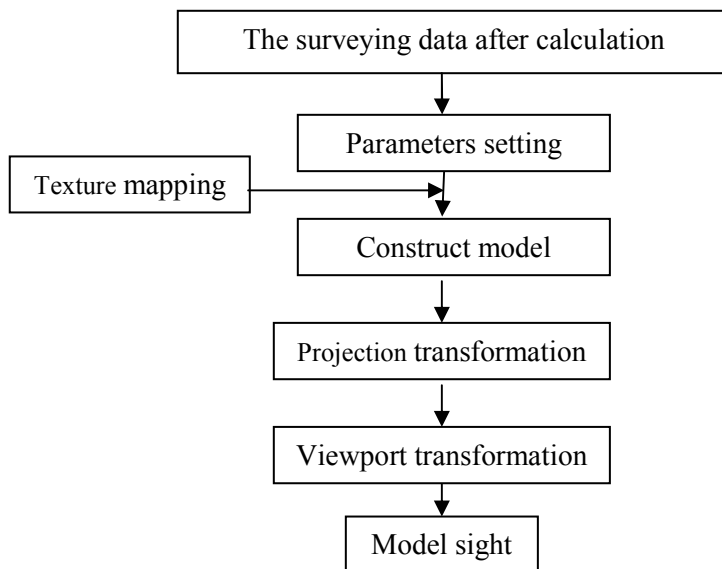


Fig.8 The flow chart of tunnel model creation based on OpenGL

5 Conclusion

This paper discusses the topological relations of 3D tunnel in brief. On the basis of the topological relations mentioned above, we obtain the data structure of 3D tunnel, based on which we design the methods of modeling and program and develop the trial system. The system can create the 3D tunnel model efficiently. Since time is limited, the spatial analysis of 3D tunnel is not discussed in much detail. We need to perfect the spatial analysis of 3D tunnel in future.

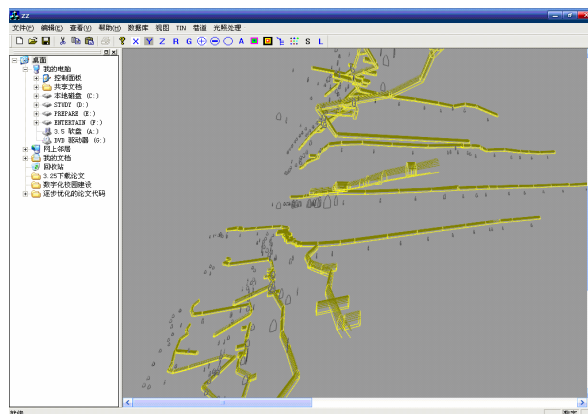


Fig.9 The figure of test system

References:

[1] Hai-xia Li, Jian-hua Jia, Shuo Yang, *The Study of 3D Data Structure in tunnel*, *Mine Surveying*, Vol.12, No4, 2000 :10-12
 [2] Kui-qi Yang, Hai-qiao Tan, *Roadway 3D Display and Inquiring System Model Facing to Different Objects*, *Coal Mine Modernization*, No.1 2004: 35-36

- [3] Rong-hua Ma, Xing-yuan Huang, Jian-hua Jia ,
etc. *Study of Laneway Modeling GIS for Mine*,
Acta Geodaetica et Cartographica Sinica,
Vol.29,No.4, 2000:355-359.
- [4] Zhan-ying Wei, Bao-shan Wang, Qing-yuan Li.
*Underground Laneway Modeling and
Realization by C++*, Geomatics and Information
Science of Wuhan University, Vol.30, No.7,
2005: 650-653
- [5] Peng-gen Cheng, Xue-bin Liu, Wen-zhong Shi,
etc. *A Method of 3D Modeling Based on QTPV in
Subsurface Rock Bedding*. Journal Of East China
Institute Of Technology Vol.27,No.1, 2004:
73-78
- [6] Kui-qi Yang, Zhen-lin Song, *The Application of
OpenGL in Three-dimensional Display of
Laneway*. Journal of Lanzhou Polytechnic
College, Vol.11,No.2, 2004:8-11
- [7] Jian-ya Gong, Zong-gu Xia, *An Integrated Data
Model in Three Dimensional GIS*. Journal of
Wuhan Technical University of Surveying and
Mapping, Vol.22,No.1, 1997:7-15
- [8] Li-xin Wu, Wen-zhong Shi, *Principles and
Algorithms of GIS*, Science Press, 2003.
- [9] Jian-jun Bai. *3D Graphics Design and Execution*,
Post & Telecom Press, 1999.