Construction of 3-D model and its visualization of Road based on terrain

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Abstract: - This paper combines terrain with the feature of road engineering to set up the constraint Delaunay triangle net in division by terrain characteristic line, and then forming range constraint Delaunay triangle net. With the data of road midcourt line, the road slope toe line and the point of intersection of road slope toe line could be calculated. Terrain characteristic line can be used to construct the model of road and the whole digital terrain. Based on the WINDOWS platform, blend VC++ with OpenGL to build a simple and easy operation on 3-D visualization system of terrain and road. This system consists of four subsystems, namely, data input subsystem, the terrain subsystem, road subsystem and inquiry system. This paper has applied the method to a mountain highway road design from Chengdu to Shenzhen. The method realizes the visualization, which provides a vivid analysing method for the designer to improve the efficiency and quality and has a certain of engineering application value. Case study shows that this proposed model can directly be seen by the 3-D scene, and can be used to optimize the road design plan.

Key-Words: - terrain, constraint Delaunay triangle net, terrain character line, road, visual simulation

1 Introduction

Nowadays, roads have become an essential part of human daily life [1]. The design of road three-dimensional (3D) visualization is a method to transform the data produced in the road designing process and results into 3D graphics and images and then to interactive processing [2]. In this technology, the real scene can be obtained when road has been built during designing process. Thus, policy makers and designers could provide the decision for assessing road with the help of the intuitive 3D image [3-4]. In recent years, with the rapid development of China's highway construction, road and terrain overall visualization has been a hot research issue in road engineering. And the key technology is the combining method in digital road surface model (DRM) with digital terrain model (DTM). Many scholars have made useful explorations from different perspectives. Reference [5] investigates commonly-used processes for eliminating PSTs and puts forward a new algorithm for DTM, reference [6] present a survey of detected artefacts, evaluation of the Delaunay and greedy triangulations as to the number and kind of contour line artefacts, reference [7] discusses the method of applying triangulated irregular net to establish the DTM of open-pit，and constraint condition has been considered in the process of building model, reference [8] analysis how to obtain a sequence of approximations of the terrain where the difference between two consecutive approximations is only one curve. Especially the methods for building road route 3D integrated model presented in literature [9] should be pointed out here. In this method, roads design points (feature line) data and terrain points (feature line) data were merged together, and then to form constrained Delaunay triangular network. And it has achieved the integrity of design surface model and terrain model, so the calculation of combining two models can be concluded to the intersection of line and surface, surface and surface, surface and net and they can be treated respectively. Then discriminant validity of the calculated intersecting lines (points) can be achieved. But how to treat the invalid intersecting lines (points) and the triangle positioning before calculating the intersection and the method of treating the invalid intersecting lines are still not mentioned. Integrated building method based on CDT theory for road and terrain mentioned in literature [10].They studied on the calculation in combining digital surface model and terrain model. In their study, intersecting lines had been used as constraint lines to insert into the terrain model, then the triangulation in the range of intersecting lines influence domain was reconstructed. But in their method, it consumes a large amount of calculation when using blended Coons surface two or three times to describe the design surface. A method of feature and terrain matching in 3D scene modeling has been proposed by Yu Jiang [11]. According to the TIN model, they take terrain adaptation features ideas, and then combine ground objects with terrain. But they did not have a detailed discussion on the efficiency and robustness when the TIN has been constructed. In other words, they had built the roads (ground objects) and terrain model without taking full advantage of CDT algorithm to build the constrained Delaunay triangulation network. And in their analysis of road and terrain with combining method, they have basically to take the idea of terrain adaptation features. That is to say, when building the terrain model is completed, TIN would be partial reconstructed to combine design objects and terrain. However, they did not mention how to realize the seamless of combining road and terrain by using a plurality of terrain structure line to divide the terrain.

This paper has combined with the terrain and road engineering characteristics and proposed an improved CDT direction locating algorithm. And one of the differences from the conventional CDT algorithm is to use the idea of dividing and conquering algorithm, for all data were divided by the constraint conditions, and to put the constraint point to join in each sub-area around its field, and then generating triangle mesh. The other one is to establish each sub-region using point insertion method of CDT, based on the properties and definitions of Delaunay triangulation network and CDT for verification and adjustment of the constraint boundary.

Based on the improved CDT direction locating algorithm, how to divide wide range terrain data in a reasonable way with the use of terrain features line has been studied. At first, establishing constrained Delaunay triangulation partition, and then the entire area is formed with the combined constraining Delaunay triangulation network. Finally, with the help of several terrain structure lines, the terrain has been divided for the second, to make the road and terrain seamlessly being put together, and then the whole digital terrain model has been built.

Based on the WINDOWS operating platform, using the MFC framework of VC++ and OpenGL to set up a 3D visualization system of terrain and road, and realize the whole 3D display which can be provided more intuitive decision basis for designers.

2 The development of the whole 3-D visualization system of terrain and road

The system is a whole 3-D visual simulation system of terrain and road based on the WINDOWS operating platform, using the MFC framework of VC++ and OpenGL. This system consists of four subsystems, which are respectively data input subsystem, the terrain, road and inquiry one. The composition diagram of the system shows in Figure 1, and the achievable steps of the system show in Figure 2.

This system has the function of hereinafter several aspects:

(1) Read document data files. Read and store the whole terrain 3-D data of the points, the points of character line and road middle line.

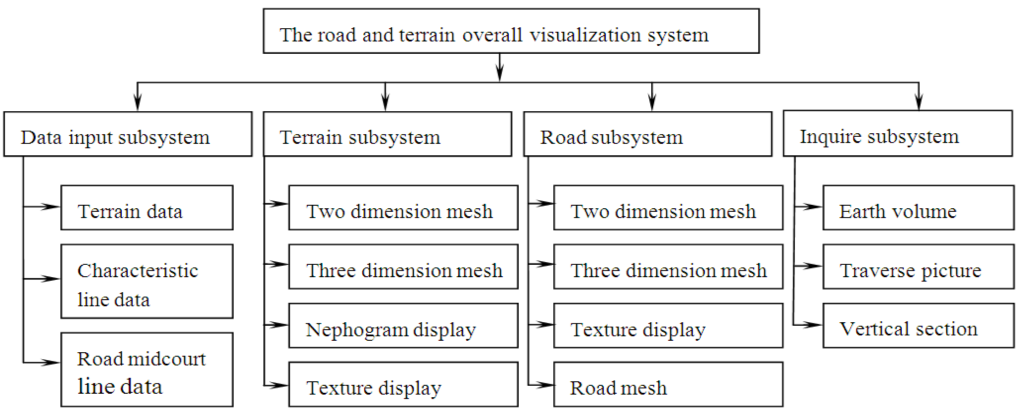

Figure 1 *Segment of the system*

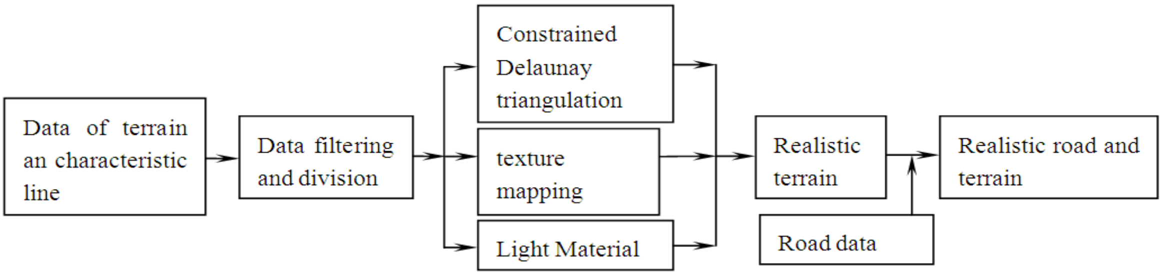

Figure 2 *Achievable steps of the system*

(2) The planar and 3-D display of the whole restrictive Delaunay triangle-net, the display of reflecting terrain gurgitation of nephogram and texture drape of by using OpenGL texture technique to paste texture picture.

(3) According to the road width of enactment, calculate the road boundary and the road sloping lines, form the 3-D whole model of road and terrain, and glue texture graphics of road and slope.

(4) Graphics transforming operation. Operate the generated graphics to translate, rotate and scale.

(5) Inquiry function. Inquire earthwork quantity, road transect, vertical section, and check the actual effect of the joint of road and terrain by transforming operation.

3 The design and implementation of the system

3.1 Build the realistic 3-D terrain model

3.1.1 The method to build Delaunay TIN

Nowadays, the usual method to build constraint Delaunay triangle- net is as follows: first to build Delaunay triangle- net, then to insert constraint line. Through perfect and complex topology information, those methods build fast constraint Delaunay triangle- net. However, those methods need lots of information and then increase the complexity of the net-construction, so it can not optimize the modeling calculation of Delaunay triangle-net in the large region.

On the basis of other scholars' research on Delaunay TIN, this paper develops the method to build Delaunay TIN in part of improvement. In our project 2-D topographic drawings are made on AutoCAD platform, and the subsequent tasks are carried out as Reference [12].

(1) Read and cut data

First define the following data structure in the head file:

Point data structure—struct VERTEX{
float x,y,z; // 3-D coordinates
int item; //serial number of the point
int tt[100]; // the triangles sharing of this point
};
Edge data structure-struct EDGE{
int item; // serial number of the edge
int bb1,bb2; // the anticlockwise vertices number

int LTri,RTri; // the anticlockwise left and right triangle number
Triangle data structure-struct TRIANGLE{
int item; // serial number of the triangle
int vv0,vv1,vv2; // the anticlockwise vertices number
int RelaTri[3]; // the anticlockwise neighboring triangle numbers according to anti-clockwise.
EDGE edge [3]; // the anticlockwise edges number
};

Use subroutine Read Data() to read the needed original data. Next, use distribute Point() to separate the data.

(2) Apply point by point insertion to complete the constrained Delaunay triangulation of each sub-region.

The points on the constraining edges have been inserted into the left and right adjacent sub-region. Use subdivision algorithm to convert the feature line points into DTM vertices by subdividing the original DTM triangle into smaller triangles, and employ the subroutine Build Delaunay Triangle (int n, int nvert) to revise the triangulation of each sub-region.

(3) Delete the useless triangles

Through the following cyclic function delete the useless triangles;

```
{
    if(TP[n][i].vv0>n||TP[n][i].vv1>n||TP[n][i].vv2 > n)
    { ……
    }
}

while (ntri>i++);
```

(4) Clean up the constraining edges

Fig. 3 shows the tessellated mesh distributed along both sides of the constraining edges after completing the above three steps. Obviously there exist lots of unreasonable triangles, which need cleaning up. Triangles with the center of gravity lying outside bounding edge are useless and being deleted automatically.

Suppose the coordinates of the triangle vertices are (X_1,Y_1), (X_2,Y_2), (X_3,Y_3), and the center of gravity of the triangle is (X_0,Y_0), comparison shows the center of gravity lying between the boundary points (X_p,Y_p), (X_q,Y_q), The formulas for calculation are as follows.

$$X_0=\frac{(X_1+X_2+X_3)}{3}, \quad Y_0=\frac{(Y_1+Y_2+Y_3)}{3} \tag{1}$$

$$n=(Y_0-Y_P)\times(X_q-X_p)-(Y_q-Y_p)\times(X_0-X_p) \tag{2}$$

Through checking the sign of n value to judge whether is positive or negative, whether the triangle should be deleted or not. Fig. 4 shows the boundary after cleaning up.

The presented approach needn't build complex topological structure and deals with relatively fewer points, so it is simple and fast in running.

3.1.2 The 3-D display of terrain

According to the above method, taking the mountain highway from Chengdu to Guangzhou as an example, TIN configuration can be carried out and build topological relationship. Then conduct the texture mapping and realistic graphics display. Figure 5 is the constrained 3-D mesh. Figure 6 is 3-D nephogram, and Figure 7 is 3-D texture terrain.

3.2 Data reading of road central line

Using computer for road aided design, firstly to give a road midline data. The obtained data of road midline have roughly two ways [13], the first one is given through on-the-spot investigation, and the second one is by the existing digital terrain 3-D plane. Along with the development of the graphic imaging technology and digital technology, in this paper, the second kind is adopted.

According to the design program reading, give road midcourt line data and terrain data; according to the road midcourt line data, calculate the coordinate corresponding road pavement edge and the shoulder edge mainly based on the road level and the number of lanes. Assuming that half range width of road pavement is w, road shoulder width is wj not considering local widened and heightening, then roads cross fall is 0.01.

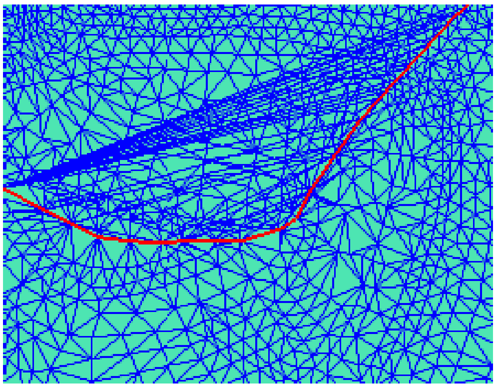

Figure 3 *Constraining edges before cleaning up*

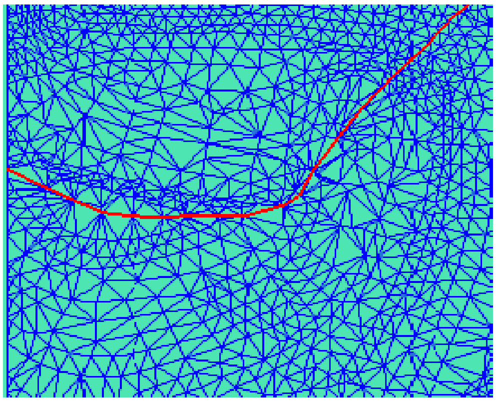

Figure 4 *Constraining edges after cleaning up*

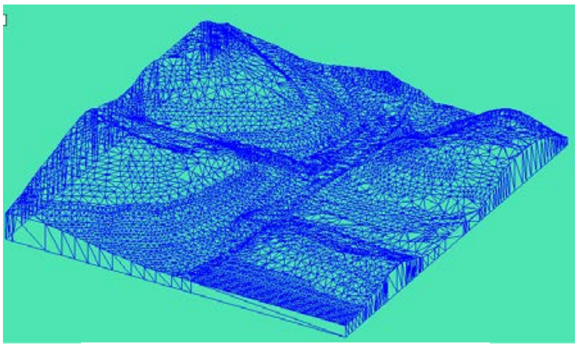

Figure 5 *Constrained 3-D mesh*

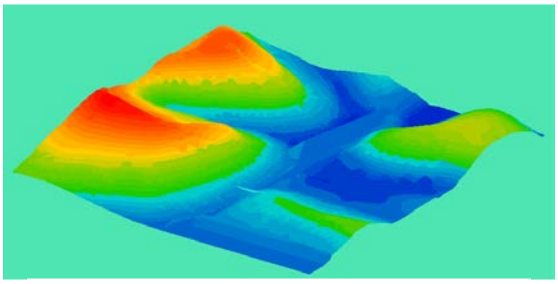

Figure 6 *Terrain 3-D nephogram*

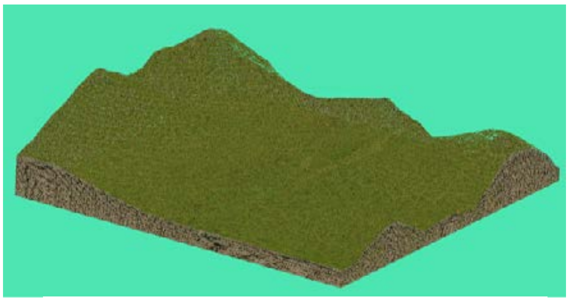

Figure 7 *3-D texture terrain*

3.3 Calculate road slope toe line

Process is as follows:

(1) Use Reference [14], modify directional search method to search the triangle. Calculate the actual terrain elevation of that point according to the triangle insert algorithm, then, compared with the protocol elevation of that point. If the difference value is in the allowable value range, then end the search, otherwise, continue to search value according to the comparison result, determine whether to increase or reduce the certain elevation value.

(2) If the actual elevation is more than the protocol elevation, for the road left boundary point: $X = X - \Delta X$, $Y = Y$, $Z = Z + \Delta Z$; for the right boundary point: $X = X + \Delta X$, $Y = Y$, $Z = Z + \Delta Z$; Instead, for the road left boundary point: $X = X - \Delta X$, $Y = Y$, $Z = Z - \Delta Z$; for the right boundary point: $X = X + \Delta X$, $Y = Y$, $Z = Z - \Delta Z$.

(3) According to the second introduced method, search and calculate the actual elevation after changing, and then compared with setting elevation to find the difference value between actual and setting elevation value in the allowable value range, then get the corresponding side slope point of road boundary point.

(4)According to the above three steps, continually search and calculate the other corresponding side slope point of road boundary point, and then linearly connect these side slope points to get the road slope toe line.

3.4 The whole 3-D display of terrain and road

Add the calculated intersection points of slope toe line and terrain line to the point range of terrain line as the constraint points in the field of constitutive nets. Respectively make the texture mapping of the pavement, roadbed, road slope. Visualization result shows in Figure 8 and 9 below.

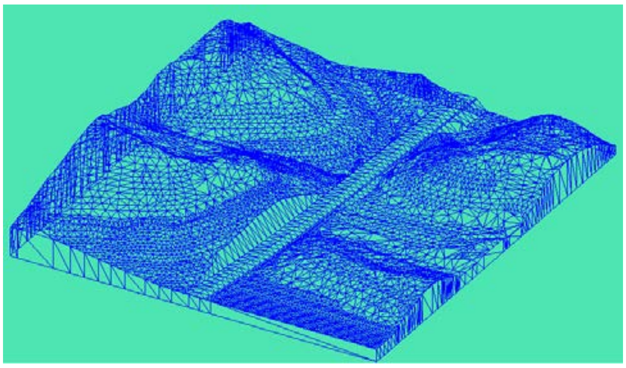

Figure 8 *The whole 3-D mesh of road and terrain*

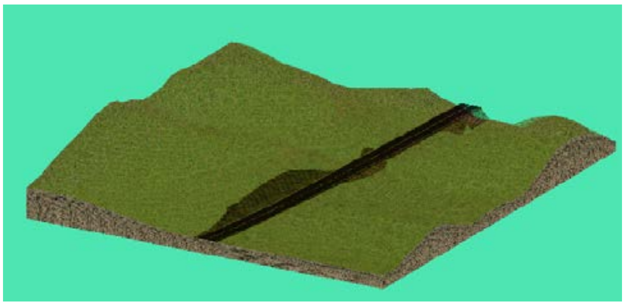

Figure 9 *The whole texture display of road and terrain*

4 Conclusion

Based on the road and terrain model, a CDT direction locating algorithm has been proposed, combining the characteristics of the terrain and road projects, roads and terrain entirety digital terrain model could been built. First, to establish constrained Delaunay triangulation network partition by using terrain structure lines and then merge them to form the entire area constrained Delaunay triangulation network. Using terrain structure line to divide terrain again, and then combining with the road centerline data, the road toe line would be automatically got. This method solves the problem that road model and land surface model can be put together automatically, and triangulation can be generated in an easy way.

Based on VC++ and OpenGL, we can easier implement 3D visualization. By using the visualization system, the concept and outcomes of designers can express in 3D place than in 2D drawings. The proposed method has been applied to a section of mountainous road design of Chengdu to Shenzhen Expressway. It proves that road and terrain overall 3D modeling and visualization method presented in this paper has a more rapid speed of network construction, simplifying the programming complexity and improving the accuracy of the network construct. So this method has certain of engineering application value.

In addition, in order to expanding its scope of application, we should do some further researches about its interface with other software. With the constant development of engineering design theory and computer technology, CAD used in road design has an even broader prospect.

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