A STUDY OF THREE-DIMENSIONAL SPATIAL ENTITY MODELING

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ABSTRACT:

In order to really reflect the objective world on which the mankind depends by computers, this article first gives analysis on various kinds of terrain models such as contour line, TIN and RSG by choosing the methods integrating TIN data model with RSG, and smoothing the intersection to make a lifelike reconstruction of real terrain characteristics; secondly it gives analysis on the method of building modeling, ways of data acquisition; and then introduces the integrating method of terrain and building model by using triangle construct algorithms. Finally the author reconstructs the large scale three-dimension entity model of a residential block in Poyang Lake region by using three-dimensional spatial entity modeling method mentioned in this article.

1. FOREWORDS

Objective world is the foundation on which human being depends for living and for practical activities. In the process of human being development, the understanding of one's own living environment can be embodied on topographical map (LI Zhilin, ZHU Qing, 2000).

The traditional two-dimensional ichnography can offer abundant geographical information and a large amount of analysis functions based on geographical information to support decision-making. But due to the limitations of data models, two-dimensional system has its insurmountable defects. First of all, two-dimensional system adopt plane figure such as point, line and plane to describe real entity. But since the objective world is three-dimensional, traditional two-dimensional system results in the incompleteness of description and non-utilizable multi-dimensional spatial information. Meanwhile, since two-dimensional system is based on symbols, the virtual reality view it describes is very abstract and lacks of effective means to translate the geographical data and analysis result into information that is plainly understandable by the users, hence the application of two-dimensional system in many industries is greatly limited.

It undoubtedly is a constructive and revolutionary job that establishing real and measurable three-dimensional spatial entity model and realizing the lifelike reproduction of three-dimensional terrain by dint of the knowledge of geographic information system and computer science.

There are varied space entities such as mountainous region, plain, water system, road, building and vegetation etc. in the true world on which human being depends for existence. For lifelike reconstructing the objective world in computer, three-dimensional simulation to these varied spatial entities one by one is indispensable. There are many kinds of mature three-dimensional data models now, for instance volumetric model and surface model etc. But it is difficult for each single model to reconstruct all of varied space entities, and it is not easy to set up a brand-new data model to satisfy different system demand. Combined with the experiences of predecessors, the author firstly probes into the modeling methods of terrain and building, and then realizes three-dimensional spatial entity modeling by means of the model integration of many kinds of data.

2. THREE-DIMENSIONAL TERRAIN MODELING

In three-dimensional GIS, terrain reconstruction is realized by digital elevation model (DEM) which includes mainly three forms: contour line model, Regular Square Grid and Triangulated Irregular Network. DEM token modes of those three different data models different on data memory, spatial relations and so on (detailed in table 1). (ZHOU Xue-mei, 2003)

	Contour	RSG	TIN
Memory space	Little（relative coordinate）	Relying on the intervals of grid	Large（absolute coordinate）
Data origin	Digitalization of the relief map	Original data insert	Set up network by using discrete spots
Topology relationship	Bad	Good	Excellent
Insertion of any point	Indirectly and slowly	Directly and quickly	Directly and quickly
Suitable terrain	Plain or mildly changing	Plain or mildly changing	Random intricate terrain

Table 1. Comparison between the different DEM data models

Because contour model cannot show the user intuitionistic terrain characteristics, so TIN and RSG are popularly adopted as the method of three-dimensional modeling.

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Compared with TIN, RSG has its self-evident advantages such as simple data structure, apt to construct network, smaller memory space, convenient and effective analysis and calculation, direct modelling method and so on. On the other hand, RSG has its shortcoming, such as bigger data redundancies especially in flat region, inconsistency between irregular terrain characteristic and regular data.

TIN can fully reflect terrain characteristics. It has alterable resolution, that is, TIN can include more elevation point when the terrain surface is coarse or waves violently, while TIN only needs the least elevation point when the terrain surface is flat or waves gently. TIN also considers the ability of counting the stronghold of important surface, which will be convenient for simplifying terrain model. Certainly, these advantages have caused the complexity of the data store and operation too, for example, the complicated topological relationship, difficult to analyze the topography of TIN and the bigger memory space etc.

From the contrast above, we can see that RSG and TIN has their advantages and disadvantages, but none can fully satisfy various kinds of project demands, so the author probes into the integration of the two methods to establish three-dimensional terrain model in order to meet the project's need and to make system operate efficiently. The method is detailed as follows:

Firstly, establishing TIN from discrete elevation points or contour, and then building RSG from TIN by interpolation. Considering that many operations are needed, we divide the big area where we want to model into many small areas according to the smoothness, making each small area contain only smooth plain or steep mountainous region, so as to optimize the precision of RSG formed by TIN. Modeling by means of TIN in the area where the terrain fluctuates greatly and modeling by means of regular square grid DEM drawn from TIN in the area where it is smooth, which makes good advantage of TIN and regular grid DEM to get a better description of the terrain and less data amounts.

Many operation methods can be adopted to establish TIN from discrete elevation points or contour, and most GIS software is functioned to do it, such as 3D extending module of ArcGIS. In order to simulate the terrain realistically, we adopt interpolation algorithm in which regular square grid DEM data is processed smoothly after drawing from TIN.

① Establish the topological relationship between every triangle and its neighbour ones.

② Confirm the lateral and longitudinal step size and smoothing width of square grid.

③Divide every triangle into three sub-triangles using its center of gravity data gets from TIN. This is to divide every triangle into three areas, and find out the sub-triangle which has a common border with another sub-triangle by topologic relationship in each area, and smooth the common border. Here we first calculate the data of all the nodes of the square grid that fall in the sub-triangle, and compute the elevation of square grid nodes viewing the triangle as a plane, then conduct smooth operation of the two triangles, and finally calculate the elevation value after smoothing.

④ Operate step 3 on every triangle, thus the smooth interpolation of TIN data into regular square grid data is finished.

After modeling by means of TIN or RSG in every small area, piece together the TIN or regular square grid DEM in each area, and then correlate the data smoothly.

3. BUILDING MODELING

3.1 Data model

The three-dimensional description of buildings on the ground is an important part in three-dimensional modeling of space data, and different scales should be considered when modeling.

Under small scales, buildings can be viewed as a group that lies in a plane. So this group can be rasterized and then superpose it on DEM, endowing it with the corresponding elevation, so the three-dimensional model of the group can be formed. It is easy to model in this way with a small amount of data, but it is only the silhouette of buildings that are reflected, not the details of the buildings.

While under large scales, detailed exteriors of individual building are needed. With no consideration on the in-house structure, many models can be used in three-dimensional reconstruction of buildings (Detailed in table 2). (LI Qing-quan, LI De-ren, 1996)

Regular Voxel	Irregular Voxel
CSG Voxel Octree Needle Regular Block	TEN Pyramid TP Geocellular Irregular Block Solid 3D Voronoi chart GTP

Table 2. Three-dimensional volumetric models of buildings

Volumetric model is the segmentation of voxel based on 3D space, and it's the description of real 3D entity. Since the characteristics of voxel can be described and memorized independently, 3D space operation and analysis can be conducted. Regular voxel which includes five models such as CSG-tree、Voxel、Octree、Needle and Regular Block, is often used in modeling water, pollution and environment issues. Voxel model and Octree model are a standard segmentation way aiming at continuous space of field substance (such as gravity field of magnet field) with no sampling limitation; while irregular voxel includes 8 models as TEN、Pyramid、TP、Geocelluar、Irregular Block、Solid、3D-Voronoi and GTP（Generalized Tri-Prism）. With sampling limitations, irregular voxel models are all 3D model that aims at entity based on stratum interface and geologic structure. Irregular voxel models realize the space description of 3D object by entity description. It has the advantage of easy space operation and analysis, but a big memory is needed and calculation, vision and refresh go slowly. The users can select the most suitable model according to their purpose and conditions.

3.2 Data acquisition

The three-dimensional spatial data needed by building modeling mainly include plane data, elevation data and the data about the building’s height. Plane data indicate the building’s plane location and the plane geometrical shape, and then combining with the elevation or the height of the building, we can establish the three-dimensional building model. In addition, in order to make the building model having third dimension, texture is necessary to building model. Following we discuss the methods of data acquisition separately.

The plane data of buildings mainly refers to the contour lines that the building cast on the ground in three-dimensional plan form. Nowadays plane data acquisition of building is mainly drawn from two-dimensional projection of building or from aerial images and remote sensing images.

In 3D GIS, texture has not any effect to the data administration and spatial analysis of GIS, however, superposing the true texture image on terrain model and building model surface can stand out the visual scene information, and build 3D perspective scene. The furthest direct and uppermost origin of the texture image is aerial image and close-range photogrammetry image. So extracting the corresponding texture feature of the terrain model and the building model is significant to establishing the 3D perspective scene. At present, extracting texture data mainly depends on as fellows: (TAN Ren-chun, 2003)

① extracting from ground photograph image directly

This kind of method needs to shoot a large number of profile photos of buildings with the camera. Its advantage is having third dimension, but it has the disadvantages of lower acquiring speed, huge amount of data and more following operations.

② simulating in computer simply

This kind of method adopts vector texture. It has the advantages of fewer data and high browser speed; however the disadvantage is being short of the third dimension and seeming not very real.

③ creating in computer according to ground photograph images

For the buildings which have similar textures, abstract those textures by computer and process them together to cut down texture abstraction greatly and reduce the following work. But it seems less real compared with the first method.

④ Acquire from aerial photogrammetry

This is a way mainly to acquire the image on the ground. But aerial image also contains part of flake textures of buildings. Abstraction and processing those textures could help to reduce following works, but it also causes distortions and reduces the sense of reality.

In three-dimensional GIS, the concept of scale still matters. And as the dimension increases scale means much more. It includes not only classified display of tree-dimensional geographic factors——LOD（Level of Detail), but also classified affixation of model exterior textures——image pyramid. So we hold the view that at least more than two kinds of texture data with different particularities are needed on texture data acquisition of buildings. Hence computer could transfer textures with different particularities according to the position of the building and the stadia when creating three-dimensional sight. To be specific, endow textures with parameters to classify them. Parameter tells the classification of texture display. It means that to what extend the window is open could the texture can be transferred. By this means only simple textures are transferred when the panorama is shown on the screen, gradual enlargement and shrinking could re-transfer the textures according to scales and classifying parameters. This way could help to speed up the display and will not reduce the sense of reality.

4. INTEGRATION

We have established three-dimensional models for various kinds of elements of terrain and building separately in front, but in order to express spatial characteristics of real world objectively, we need to integrate these models organically according to their spatial positions. As to the integration of terrain and building model, it equals to insert these border points of building model into the surface of terrain model, and to keep its border characteristic at the same time. We adopt the algorithms of triangle constructing to realize the integration, which means calculating the points and contour on the intersection of building model and terrain model, inserting those points and contour in the former terrain model to re-create square grid or triangle grid, and then deleting areas covered by the building to make a seamless integration of building model and terrain model. Partial codes are as follows:

```
// judging the terrain grid point that are in the area of surface feature polygon.
/* Suppose the every point coordinates of the polygon is ：……$P_{k-1}(x_{k-1},y_{k-1})$, $P_k(x_k,y_k)$, $P_{k+1}(x_{k+1},y_{k+1})$, $P_{k+2}(x_{k+2},y_{k+2})$ ……*/
//the coordinates of inserted points are: $Point_i (x_i, y_i)$;
Int count = 0, isvertex = 0;          // count memorize the number of the points of intersection
For (j = 1; j <= vertexnumber; j++)     //j is circle variable,
{Float xmin = $x_k$, xsecmin = $x_k$;
 If (k == 1) {$x_{k-1} = x_{vertexnumber}$; $y_{k-1} = y_{vertexnumber}$ ;}     //When the intersection point is the first point or the endpoint
 If (k == vertexnumber ) { $x_{k+1} = x_1$ ; $y_{k+1} = y_1$ ; $x_{k+2} = x_2$ ; $y_{k+2} = y_2$ ; }
 If (k == vertexnumber-1 ) { $x_{k+2} = x_1$ ; $y_{k+2} = y_1$ ; }
 getrange(xmin, xsecmin, $x_k$, $x_{k+1}$, $x_i$);          //Calculating intersection of abscissa by calling function
  //when $x_k = x_{k+1}$
  If (($x_k$ == $x_{k+1}$) && ($x_i > x_k$))
  {If (($y_{k+1} > y_k$&& $y_{k+1} > y_i > y_k$) || ($y_{k+1} < y_k$&& $y_{k+1} < y_i < y_k$))
      Count++;
   Else if (($y_{k+1} > y_k$&& $y_i$ == $y_{k+1}$) || ( $y_{k+1} < y_k$&& $y_i$ == $y_k$))
      Count++, isvertex++;
   Else If (($y_{k+1} > y_k$&& $y_i$ == $y_k$&& $y_i > y_{k-1}$) || ($y_{k+1} < y_k$&& $y_i$ == $y_{k+1}$&& $y_i > y_{k+2}$))
      Count++, isvertex++;
  }
   //when $y_k$ != $y_{k+1}$
   If ($y_k$ != $y_{k+1}$)
     {m = $(y_{k+1} – y_k)/(x_{k+1} – x_k)$;
       n = $(x_{k+1} y_k – x_k y_{k+1})/(x_{k+1} – x_k)$;       //Calculating the slop and the slant range of the line equation
       x = $(y_i - b)/k$;       //Calculating the coordinate of points of intersection
```

```
        y = $y_i$;
    If (xmin <x<xsecmin)        //When the points of intersection locates between the endpoints of the line
    ……………………
}
```

5. CONCLUSION

Adopting the method of TIN integrating with RSG, the author sets up DEM of Poyang Lake region, and establishes three-dimensional model of surface feature (such as buildings) under small scale, superposes those models with image information of vegetation coverage and land utilization to reconstruct three-dimensional terrain and building in Poyang Lake region vividly. In addition, the author also utilizes three-dimensional spatial entity modeling method mentioned above to establish three-dimensional models of a residential block in this region under large scale, shown as Figure 1。

Figure1. Three-dimensional digital mini-area under large-scale

In a word, it is a feasible and practical method to adopt integration with various kinds of data models to realize 3D spatial entity modeling, because it not only describes terrain characteristic better, but also occupies less memory. So it's worth generalization.

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