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Highway Alignment Calculation Method Based on Digital Terrain Model

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Abstract: The earthwork volume calculation based on three-dimensional design can overcome shortcomings of hats methods. Firstly, it takes only 1~2 sec to complete earthwork calculation, which helps avoid cumbersome hats calculation and saves more time for alignment design scheme comparison and selection. Secondly, the accuracy of three-dimension based calculation is higher than hats one, it applies true three-dimension differential theory to calculate cuts and fills amount of each differential triangle and its accuracy is controlled by designers. Thirdly, this algorithm is of high robust, it is suitable for calculating complex terrain like boundary between excavation and fitting, the old road reconstruction and interchange, the positions that are difficult to calculate for hats theory.

Key words: Highway, digital terrain model, alignment calculation, three-dimension

INTRODUCTION

Determining the design central line is the major point of alignment calculation, it carries out as follows, firstly calculating the horizontal curve coordinate, vertical curve elevation and cross-sectional design template, then doing hats calculation to the cross-sectional template based on ground elevation, lastly counting cuts and fills for balancing earthwork preparation. Among the above points, the most important is horizontal alignment calculation (Fu and Gong, 1998; Fu *et al.*, 2006).

Horizontal curve is composed of line, circular curve and transition curve end to end. The plane calculation includes computing geodetic coordinates (N, E) of central line and determining the mapping relation between route stake and geodetic coordinates. It can be achieved by two way, that are, calculating central line coordinates from route stake or back calculation route stake from random geodetic coordinates. The traditional calculation method tends to using analytic geometry theory to directly compute geodetic coordinate from the design stakes on geodetic coordinate system based on single function (Chen, 2004). The traditional method has two faults that following, first, the accuracy of analytic geometry methods may lead to unstable of calculation results; second, using single function to complete many tasks may results calculation redundancy which reduces computational performance. The unstable caused by

calculation redundancy showed as the failure in back calculation of route stakes within tolerance range of transition curve borders. Such as the intermittent failure in inverse calculation of stake in normal of transition curve starting point for some alignment design software, or the inverse calculation failure in transition curve's end point border. The performance problem show when doing back calculation of corresponding stake for target points, where the geodetic coordinate system is excess and the object coordinate system is enough to calculate line elements, which saves time for coordinate conversion.

Cuts and fills calculation is the key task for vertical alignment design, it is also the basis for earthwork automatic balancing and allocation (Liu and Fu, 2001). The traditional earthwork calculation carries out in manner of hats on cross-sectional template, that first measuring ground line of each design cross section; then comparing the roadbed cross section template with ground line to get the difference between ground elevation and design elevation at road shoulder to determine which template to use, the fill one or the cut one; finally doing hats calculation for fill and excavation area at each section thus the earthwork amount can be counted out. The method is easy to understand, while for the large computational workload, it is time-consuming and low accuracy, thereby limits optimization of alignment design.

The earthwork volume calculation based on three-dimensional (Eberly, 2001) design can overcome

shortcomings of fats methods (Gamma *et al.*, 1994; Cao and Qi, 2004). Firstly, it takes only 1~2 sec to complete earthwork calculation, which helps avoid cumbersome fats calculation and saves more time for alignment design scheme comparison and selection. Secondly, the accuracy of three-dimension based calculation is higher than hats one, it applies true three-dimension differential theory to calculate cuts and fills amount of each differential triangle and its accuracy is controlled by designers. Thirdly, this algorithm is of high robust, it is suitable for calculating complex terrain like boundary between excavation and fitting, the old road reconstruction and interchange, the positions that are difficult to calculate for hats theory.

AUTOMATIC CALCULATION ALGORITHM OF ALIGNMENT EARTHWORK AMOUNT

Proposed method includes following steps:

- Inputting alignment information include starting and ending point stakes and differential area threshold, which means that the horizontal projection area of each differential calculation unit(triangle) should be less than it (Pu *et al.*, 2004)
- Examining each section of subgrade among the alignment to prepare for its cuts and fills calculation
- Judging that if the starting and ending stake of the current subgrade is in the range of user queries, if not, then the subgrade should be ignored and go on examining the next one
- Examining each cuts and fills triangle of current subgrade to prepare for its cuts and fills calculation
- Calculating horizontal projection area of current triangle, if its area is larger than the inputted differential area threshold, it should be cut into two new triangles from the longest side and then recursive calculate their earthwork amount, respectively
- If the current subgrade is not completely in the range of user queries, the stake corresponding to gravity center of each triangle of the subgrade should be calculated respectively. If the stake is beyond the range of user queries, the current triangle should be ignored and go on analyzing the next one
- Searching for the ground triangle that corresponds to current triangle's gravity center and calculating its projection point on the ground
- Calculating fill and excavation elevation of current triangle from the height difference between its gravity center and the ground triangle's horizontal

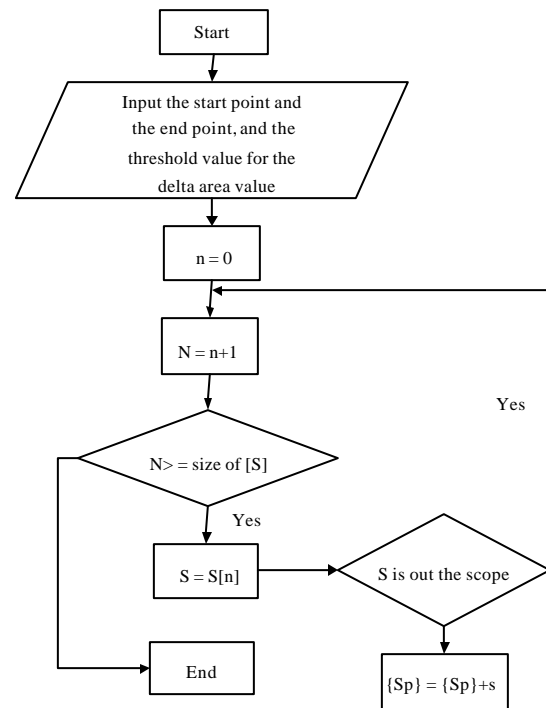


Fig. 1: Process of searching for subgrade list in the range of query

project, then the earthwork amount can be worked out by multiplying horizontal projection area of the triangle

- Adding up the volume of each triangle to get the total cuts and fills engineering amount

Search of subgrade list in the range of user queries. Firstly, finding out all subgrade lists in the calculation range which is a method of space for time, in fact, it just constructs an assemblage for the following calculations. The searching process is show in Fig. 1, where: {S}: assemblage of all the subgrades; {Sp}: the subgrade assemblage that intersect with query range.

Search of to be processed triangle list of subgrade: The purpose of searching for the triangle list that to be analyzed is to find out the triangle assemblage that hasn't processed among the current subgrade, which is the foundation for the subsequent processing. Where, [Tp] is the assemblage of to be processed triangles. The process is shown in Fig. 2.

Calculation of cuts and fills engineering quantities of to be processed triangle list: The purpose of calculating the cuts and fills engineering quantities of to be processed

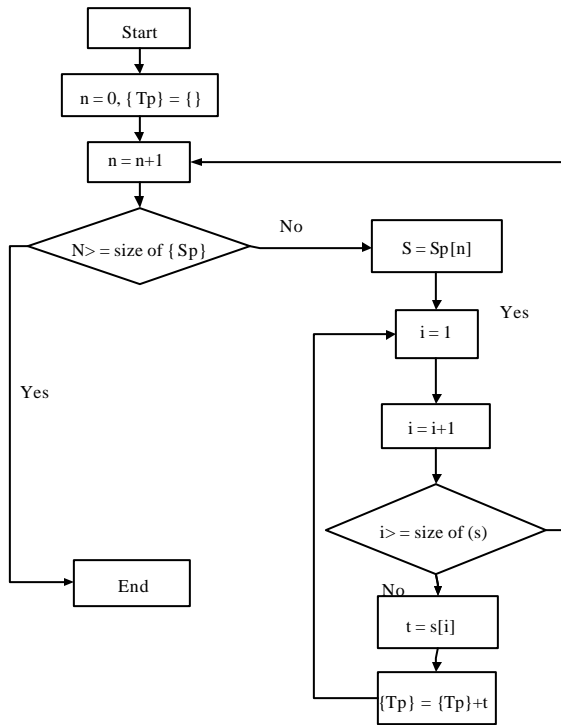


Fig. 2: Searching process of to be processed triangles in subgrade

triangles list is to give the final total amount of the above to be processed triangle of subgrade, where: Qf: fills engineering quantities; Qc: cuts engineering quantities. The searching process is show in Fig. 3.

SYSTEM EXPERIMENT AND ITS IMPLEMENTATION

The system main interface is composed of three parts: menu bar, toolbar and information display area, showed in Fig. 4.

The menu bar includes project management, engineering operation and scenarios setting; the toolbar includes shortcuts of associated sub-operations, such as new project, open project and so on; the information display area is used to show the three-dimension scene of terrain road, the scene contains trees, bridges, road, terrain and other three-dimension objects (Li and Zhu, 2003). The use interface of system and input of DTM (Digits Terrain Model) (Shewchuk, 1996; Tan and Daman *et al.*, 2004) is shown in Fig. 4 and 5.

Figure 6 shows the triangle network model before stitching of road and terrain (Voronoi, 1998).

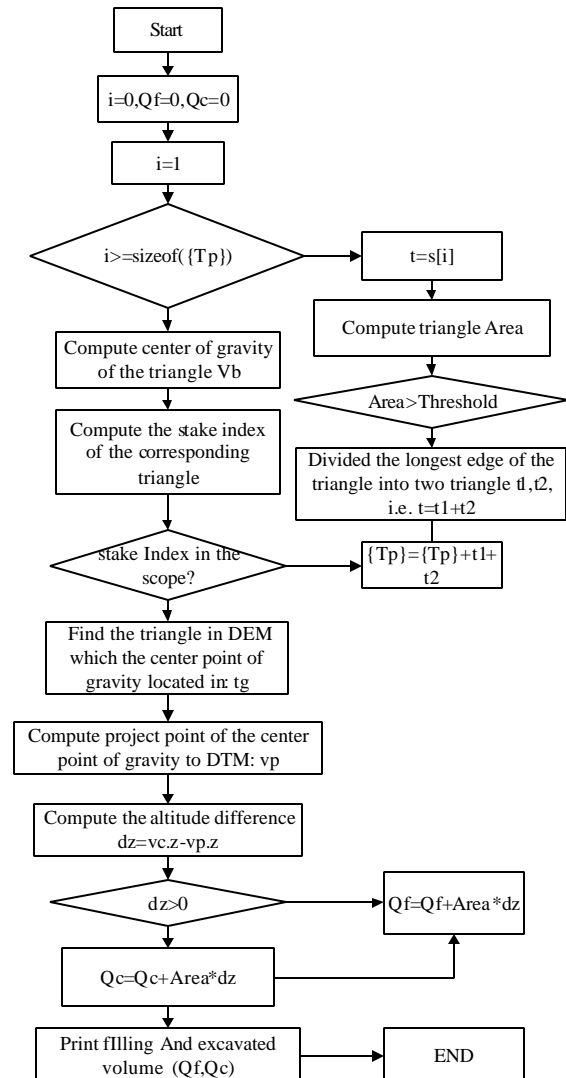


Fig. 3: Calculation method of cuts and fills amount for to be processed triangles

Figure 7 is the interface of loading road data. Choosing the file of road design, bridge design and tunnel design, then clicking “load” to read data. The “save” button can be clicked to save the loaded road data and set project status, if one wants to reload road data, the “delete” button can be should be clicked (Zhao *et al.*, 2005; Song *et al.*, 2003).

Figure 8 is the interface of road modeling. First setting the texture of pavement, lane lines, soil shoulder, hard shoulder, ditches and slopes, etc. (Zhao *et al.*, 2005; Song *et al.*, 2003). Then clicking “create” button to create road model, finally clicking “save” to save the created

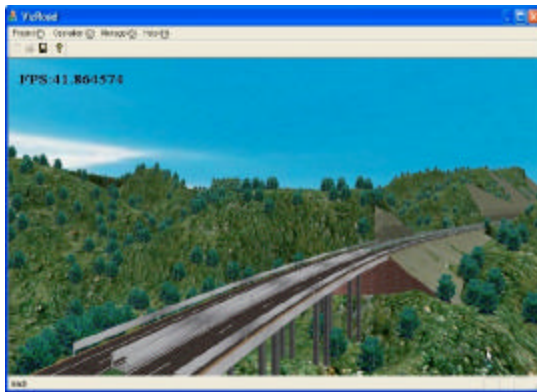


Fig. 4: Main use interface of system

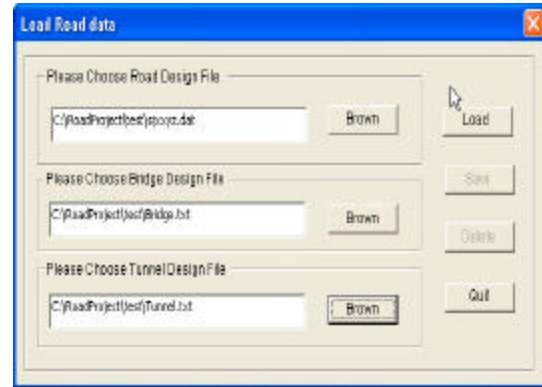


Fig. 7: Interface of road data loading

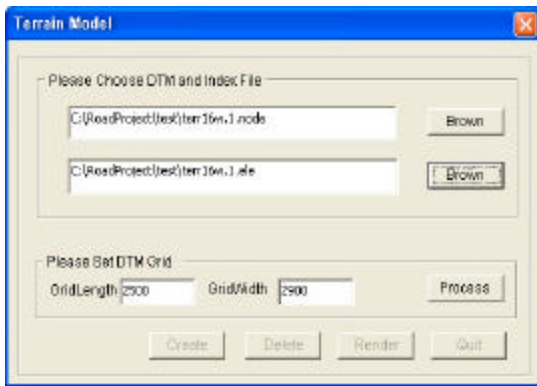


Fig. 5: Terrain modeling input interface

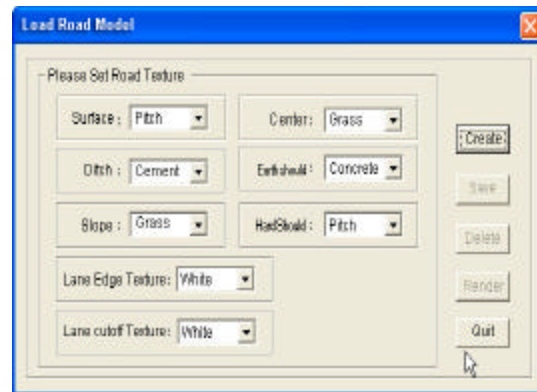


Fig. 8: Road modeling interface



Fig. 6: Terrain triangle network before stitching

road model and set the project status. If the model needs to be recreated, the “delete” button can be clicked.

Figure 9 shows the terrain triangle network model (Lee and Schachter, 1980) after extracting road boundary



Fig. 9: Terrain triangle network after deleting road range

line and remove the triangle within the scope of road. Figure 10 shows the overall triangular network after stitching the road and terrain. Figure 11 shows



Fig. 10: Triangle network after stitching the road and terrain

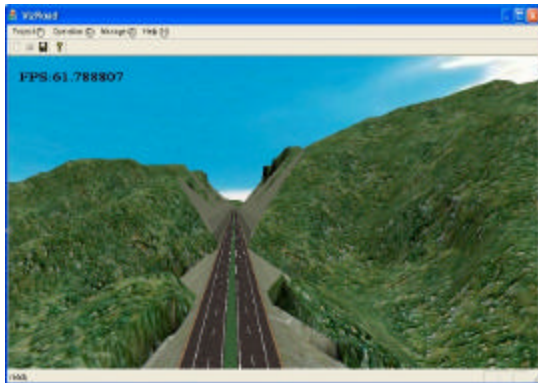


Fig. 11: Road and terrain after setting texture

the three-dimensional effects of terrain and road in scenarios after setting texture.

CONCLUSION

This study brings out a new calculation method of earthwork amount based on three-dimension highway design, the characteristics of the method is as follows: (1) It takes only 1~2 sec to complete earthwork amount calculation, which helps avoid cumbersome calculations and saves more time for alignment design scheme comparison and selection. (2) Its accuracy is higher than hats calculation, it applies true three-dimension differential theory to calculate cuts and fills engineering quantities of each differential triangle and its accuracy is controlled by designers. (3) This algorithm is of high robust, it is suitable for calculating complex terrain like boundary between excavation and fitting, the old road reconstruction and interchange, the positions that are difficult to calculate for hats theory.

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