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DEVELOPMENT OF A MATHEMATICAL MODEL OF THE GROUND SURFACE TO SELECT THE OPTIMAL ROUTE OF THE HIGHWAY

Statement of the problem. One of the main factors affecting the determination of a highway route is a relief. The algorithms used to determine the optimal route of the road to the volume of earthwork use large amounts of computation associated with the terrain. Therefore, an efficient mathematical model of the earth's surface is an important task in determining the optimal route of the road.

Results. A mathematical model of the surface of the ground to be used in the algorithms for finding optimal routing of the automobile road was obtained. The proposed model uses a hierarchical decomposition of the grid. On the upper level a quad tree is used— split, and at the bottom — binary triangle tree. The formulas for calculating the amount of memory required for the types of hierarchical decomposition of the grid were obtained.

Conclusions. A single-pass algorithm was developed to efficiently implement the mathematical model of the surface of the ground at a large size using of the minimal amount of memory.

Keywords: surface of the ground , mathematical model, choice of the optimal route, highway, relief of the area.

Introduction

One of the major factors to affect the choice of highway routes is a relief of the area. The algorithms used for optimal highway routes considering the amount of maintenance works to be carried out involve a great deal of calculations associated with the relief of the area. Therefore development of a mathematical model of the earth’s surface needs to be tackled while choosing an optimal highway route.

1. Presentation of the earth surface

In order to store information on the earth surface and the objects it houses, two formats are used: vector and raster. The vector format is for storing discrete data such as the objects of the area and specific information and the raster format is better suited for continuous data which is the relief of the area. Since the design of highways deals with large areas, the capacity used for the raster map can be considerably large [3, 4, 7, 11, 12]. The earth surface can be defined as a continuous function f: $R^2 \to R$, as a grid of triangles, i.e. a set of triangles with no more than two triangles sharing a side. These sets often contain several millions of triangles and thus cannot be processed at a necessary speed. A number of the projected triangles can thus be reduced not affecting the projection of the surface.

2. Ways to improve the models of the earth surface

One of the ways to improve the model is the calculation of the levels of detailing the earth's surface. Each level determines the same object with a different number of the triangles. Then the levels of detailing are chosen based on a certain metrics of the surface error. This approach raises a number of problems. The first one is that in considerably large objects, some of the areas can be in the proximity to the area involved in the optimization algorithm and are far for some. These areas need to be projected with different detailing levels.

The second one is encountered in changing the level of detailing of the surface: a different level of detailing causes distortion. A possible solution is choosing a necessary level of detailing for each projected triangle. This method is used in algorithms with a continuous level of detailing where the above problems are completely or partly dealt with. One of the advantages of the suggested method of operating large data is the implementation of an efficient interaction with the exterior data media [1, 8, 10, 19, 20, 22-24]. There is a classification of grids that divides them into two classes: regular grids and irregular grids (Fig. 1).

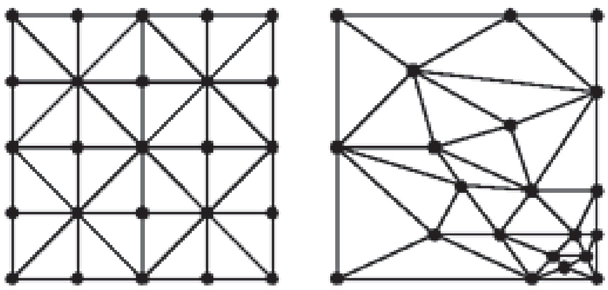

Fig. 1. Regular grids and irregular grids

The use of irregular grids helps fewer triangles to have fewer projected triangles. However, a number of calculations to project regular grids is a lot less frequent.

3. Mathematical model of the earth surface

The suggested model of the earth of the surface uses a hierarchical division of a grid. The upper level uses quad tree division and binary triangle tree is used on the lower one. The resulting grid looks as in Fig. 2.

Quad tree division allows for the comparison of the errors made in the peaks. Binary triangle tree compares the mistakes with the triangles.

The formula were obtained to calculate the memory capacity for the above types of division.

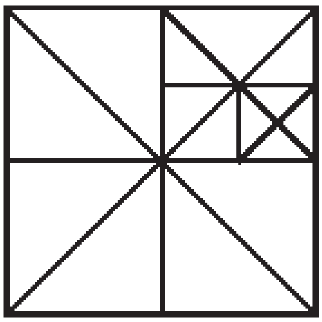

Fig. 2. Example of dividing a grid

For quad tree the memory capacity for a square block of dimensionality if a tree is presented as a static massive is $(2^n + 1)\times\times(2^n + 1)$:

$$M_q = n_{qb}\sum_{i=1}^{n} 2^{2(i-1)} + n_v(2^n + 1)^2, \tag{1}$$

where n_{qb} is a number of bytes for storing errors of the tree knot; n_v is a number of bytes for storing errors of the top.

For binary triangle tree the formula is

$$M_b = 2(n_{bb} + n_p)(2^{2n+1} - 1), \tag{2}$$

where n_{bb} is a number of bytes for storing errors of the tree knot; n_p is a number of bytes for determining a triangle adjacent over the hypotenuse.

For $n_{qb} = 1$, $n_v = 2$, $n_{bb} = 2$, $n_{pp} = 1$ the M_q and M_b and n dependency graph is in Fig. 3.

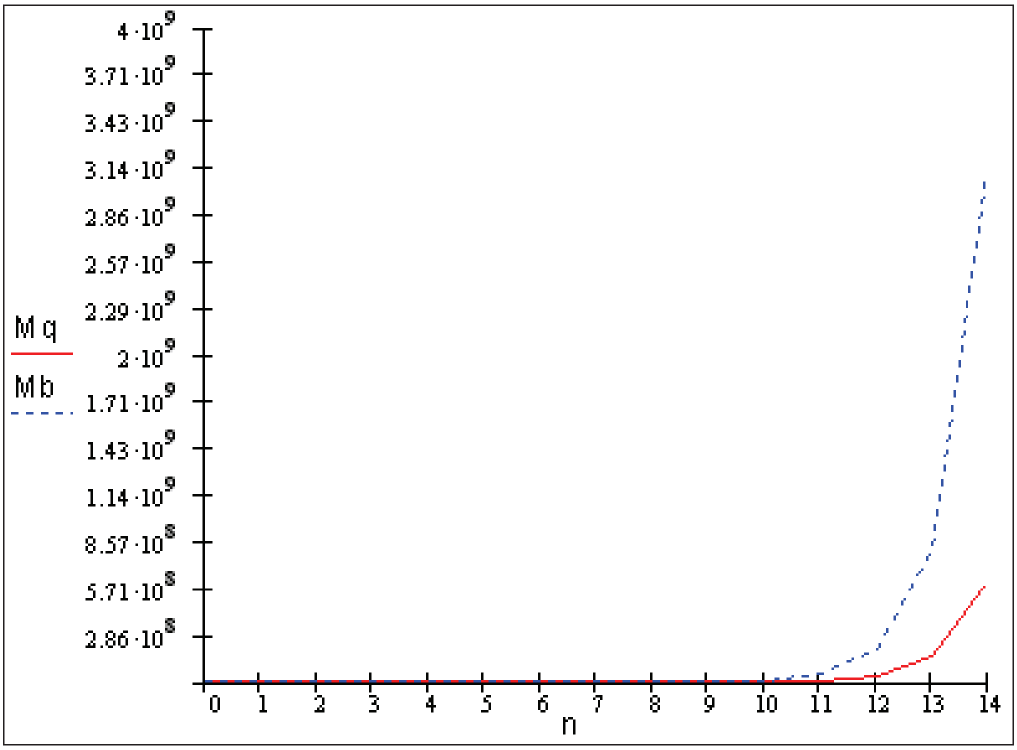

Fig. 3. Dependency graph of M_q and M_b on n

Since the division (2) needs a lot of memory and deep recursion in handling the tree than for (1), the division (1) is chosen.

The second major factor the memory capacity and presentation of the tree depend on is how C^0-continuity of the grid in the division is maintained.

The grid can be avoided from tearing (Fig. 4) by putting in another restriction: two adjacent blocks are to be different in their detailing levels in over a unit.

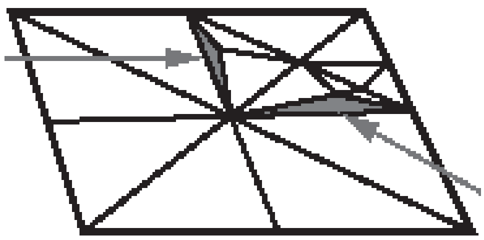

Fig. 4. Tears of a grid

Tears can also be avoided if the top dependency graph is closely followed [2, 5, 9, 13, 16, 17]. Each top of the graph depends on the other two. Closely following the graph means that no top can be added to triangulation unless its parent-top is added. The dependency graph is in Fig. 5. The arrows are from subordinate tops to the parent ones.

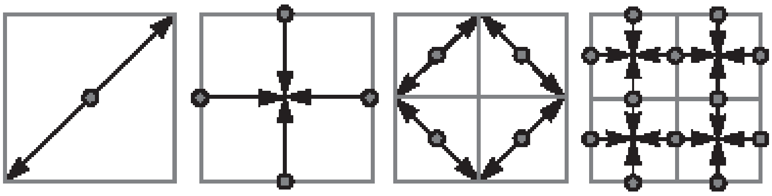

Fig. 5. Top dependence graph

However, tears can also be avoided without closely following the graph. During preliminary processing the landscape errors of each top are

$$e = \max(e_0, e_{c1}, e_{c2}, e_{c3}, e_{c4}), \tag{3}$$

where e_0 is an error of the top; $e_{c1}, \ldots, e_{c4}$ are errors of the four descendants of the top.

The presented tops are determined using recursion by summing up the errors: error of the top is always larger or equal to that of its descendants. This causes monotonous errors.

The errors of the tops themselves are given by

$$e = \left| \frac{h_l + h_r}{2} - h \right|, \tag{4}$$

where h_l and h_r are the heights of the adjacent tops; h is the actual height of the landscape at the point in the middle of the hypotenuse (Fig. 6).

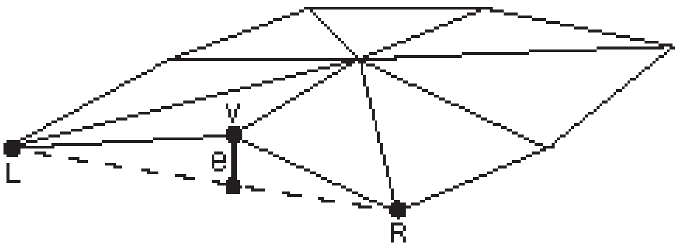

Fig. 6. Error for the top *V*

During preliminary processing the surface represented by a matrix where for each knot there is the height, is divided into square dimension blocks $(2^n + 1)\times \times(2^n + 1)$ where $n = 0, 1, 2, 3\ldots$. This restriction is caused by how the detailing tree is designed for all the algorithms of hierarchical subdivision methods. The total size of the initial surface matrix is $h(2^n + 1)\times v(2^n + 1)$ where h is a number of horizontal blocks and v is a number of vertical blocks. The initial matrix consists of 16-digit unsigned whole numbers. This presentation is chosen as most programs used in the operation of the earth surface can transform the initial data from USGS, SRTM, GLOBE, Mars Viking Orbiter, Mars MOLA, GeoTIFF, GTOPO30, etc. into a whole number matrix [6, 14, 15, 18, 21]. Besides, there has to be more information on the surface:

– distance between the knots horizontally and vertically (the same);

– range of the heights.

For each bloke the following is generated:

– massive of dimension heights $(2^n + 1)\times(2^n + 1)$;

– massive of dimension errors $(2^n + 1)\times(2^n + 1)$.

An example of using the developed mathematical model of the earth surface for an optimal highway route is in Fig. 7.

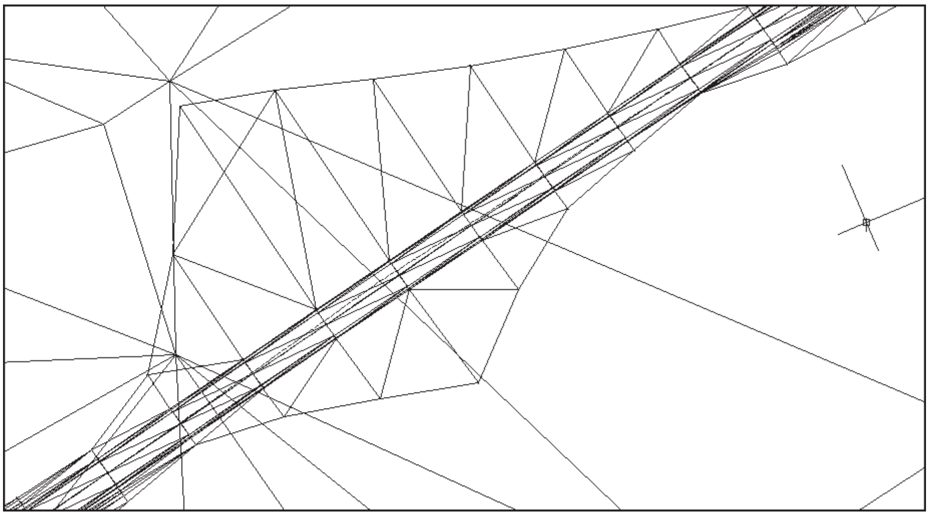

Fig. 7. An example of using the developed mathematical model of the earth surface for an optimal highway route

Conclusions

One of the major factors to affect an optimal highway route is a relief of the area. The algorithms used to determine an optimal highway route considering the amount of ground works to be carried out involves a great deal of calculations associated with a relief of the area. Therefore development of a mathematical model of the earth surface needs to be tackled in choosing an optimal highway route. The mathematical model was obtained of the earth surface to be used in the algorithms of identifying an optimal highway route. The suggested model uses a hierarchical division of the grid. At the upper level quad tree is used and binary triangle tree on the lower one. The formulas were obtained to calculate the memory capacity hierarchical types of the grid division.

A single-way algorithm is developed for the efficient implementation of the mathematical model on larger earth surfaces with a minimum memory capacity.

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