An Effective Cost Distance Calculation Based on Raster Data Model Improved Algorithm

LU Hao[1,2*], ZHENG Wenjian[3], WANG Tianbao[1,2], WANG Shaohua[1,2]
[1]State Key Laboratory of Resources and Environmental Information System
Institute of Geographic Sciences and Natural Resources Research, CAS
Beijing 100101, China
[2]Graduate University of the Chinese Academy of Sciences, Beijing 100039, China
[3]SuperMap Software Co., Ltd., Beijing 100015, China
*Corresponding author, e-mail: luhao@supermap.com

***Abstract*—In many applications of geographic information science, we often need to calculate the shortest path from the source point to the target points. Network data model can be computed using the graph theory algorithm, when faced with raster data model, the grid cells of raster will be treated as network model nodes in general, and the eight neighborhood unit of each grid cell will be treated as the direct neighbor nodes in network model. Some scholars have pointed out that this algorithm which network model directly transplanted easily lead to the wrong direction in path finding and the high cumulative cost value problem, and gives the improved algorithm called wave spread cost distance algorithm. In this paper, we research and make experiments with the wave spread cost distance algorithm and then carried out further improvements, making the analysis of exception handling and the algorithm overall efficiency has been improved.**

Keywords-raster data model; cost distance; minimum cost heap

I. Introduction

GIS(Geographic Information Science) has achieved rapid development since it birth in the 1960s from Canada and the United States, with the continuous development of spatial analysis, GIS will move from general spatial transaction processing to spatial decision support direction, it has went from database-GIS into the analysis-GIS stage. Because the optimal path analysis problem in spatial analysis is applicable to wide range of areas and has highly targeted, extensive research has been made by scholars, but the research mainly concentrated in the shortest path of vector and network data model. With the development of remote sensing technology, large-scale, high-resolution and real-time access of data for the raster topographic data gradually enriched, so the location and path analysis based raster data model has been taken seriously. While the optimal path analysis based raster data model as a simple data structure, data-rich, suitable for a wide range of suitability analysis has attracted wide attention. The cost distance calculation method based raster data model is the foundation and necessary process of optimal path analysis.

Supported by the National Key Technologies R&D Program of China during the 11th Five-year Plan Period (NO. 2008BAJ08B15)

II. Cost Distance

The main study object of best path analysis is the minimum path problem from source point to the target point, which the cost can consume a variety of meanings, the case of common applications include distance, time costs, transportation costs. In the study of network data model, the cost mainly spent on the arcs which connection between nodes, while node itself can also exist cost (such as steering-consuming). So the best path is which the least cumulative cost of all the paths starting from the source point through a number of arcs and nodes to reach the target point.

However, because in the optimal path analysis based on raster data, the main cost known as consuming grid is stored in the raster data model which has the regular grid structure to express each pixel cost, so at this time the best path should take full account of raster data pixel adjacency relationship between the continuous distribution and the characteristics of this grid structure. The expression and calculate of cost raster data model is widely used in some of the topography analysis and optimal path analysis.

III. Existence Problems

To simplify the calculation model, we can assume that all the pixel grid takes the same value, then the optimal path starting from the source to the target point is equivalent to the basic connection between two points, while the cost of best path at this time can also be calculated by the pixel value which multiplying the distance between two points. The formula is:

$$C_t = \sqrt{(x_s - x_t)^2 - (y_s - y_t)^2} \times C_{ij}$$

Which C_t is the target point cost, the source point coordinates is x_s and y_s, and the target point coordinates is x_t and y_t, C_{ij} is the cost value for row i and column j in the consuming grid, because the assumption that all the pixel grid takes the same value, that value C_{ij} is a constant.

In the actual scenario, because the consuming grid will not meet the assumption of all the pixels have the same value, so the best path between two points is not necessarily a connection between two points, and the cost cannot be calculated through a simple multiply by unit cost and the distance of path.

In the common network data model algorithm, the raster data model can be second abstracted as the network data model. that is, the pixel grid is abstracted for the network nodes, and the eight (or four) pixels adjacent to center pixel are abstracted to nodes directly connected with the center node, while the cost of center pixel and adjacent pixels is abstracted as the arcs cost in the network model, as shown in Fig. 1 and Fig. 2.

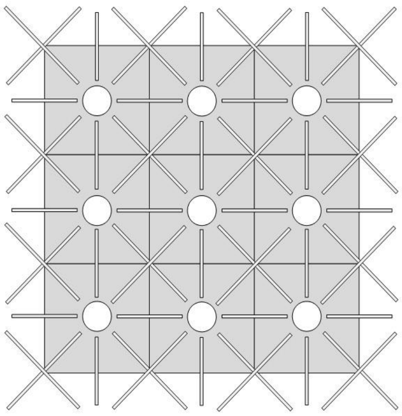

Figure 1. Eight neighbor network model

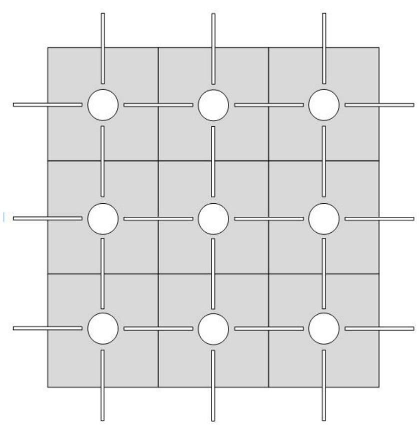

Figure 2. Four neighbor network model

For this model, many scholars give solving algorithm for calculation the cost from source point to each target point [1-3]. To visual representation the algorithm follow-up, we can spend the consuming grid as a spread medium, then the best path between two points that can be seen as waves emitted from a source (such as light, sound or other waves) to the target point which path is the fastest in the transmission medium. That the best path at this consuming grid problem can be transformed into a non-uniform medium wave-proliferation issues.

It is noteworthy that this network model-based calculation method will result in some computational problems, such as the eight neighborhood model the direction of wave propagation is limited to horizontal, vertical and 45° tilt, because at this time the wave diffusion octagonal rather than circular spread, so the calculated cost is greater than the distance from the true cost, the deviation may reach 8.24%[4]. The refraction and diffraction phenomena wave propagation in an inhomogeneous medium are not be considered and simulation.

IV. EXISTANCE ALGORITHMS

A. *Node Connective Enhancement Algorithm*

According to the above analysis, the raster data model is abstracted as the network model, due to each pixel has surrounding eight adjacent pixels; the overall spread of the show is octagonal mode rather than the ideal state of circular spread mode. It is this difference led to the diffusion mode propagation in the presence of errors. It is easy to think of starting from the diffusion model to be improved.

One possible way to improve is link the source pixel and its neighbor pixels which are not directly connective through a virtual arc. Such as with the original eight neighbor pixels expansion outward of two pixels, this time, the source nodes will have direct access 16 nodes, the diffusion model has become a regular ten hexagon. At this point relative to the ideal state of circular diffusion model, the error has been reduced to 2.75% [4], if they continue to increase non-directly adjacent grid nodes with virtual arcs, the approximate diffusion model can be further spread in the round. The dispersion modeling error can be further reduced.

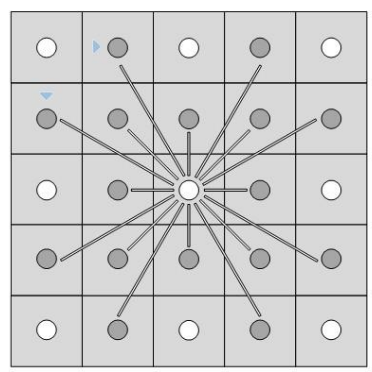

Figure 3. Node connective enhancement

B. Neighborhood Expansion Algorithm

The above nodes connective enhancement algorithm, as the new non-adjacent nodes is also direct connected to the other nodes, so easy to calculate the path which is not unique. To solve this problem, Xu and Lathrop (1995) proposed a neighborhood expansion algorithm [5], in the algorithm the adjacency relationship can be more flexible definition, and the cost of each point will be calculated for the minimum cost path.

When the number of neighborhood nodes increases the calculation amount of this algorithm will be significant growth. According to the author, the overall time calculating consumption increased one to two orders of magnitude than the traditional method. So it is difficult to meet the exact real large-scale data calculation.

C. Wave Spread Cost Distance Algorithm

Professor Tomlin (2010) presents an improved algorithm which known as wave spread cost distance algorithm considered the calculation of both accuracy and efficiency [4]. The core algorithm consists of two aspects, correction of cost distance accumulation and correction of cost direction. To simplify the problem, we can assume that diffusion takes to spread in a homogeneous medium, the spread from the source point should be similar to the circular, that is similar to the light emitted from the source, but the original diffusion algorithm cannot simulate this effect.

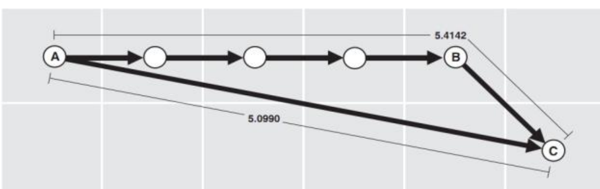

Figure 4. Correction of cost distance(Tomlin 2010)

As shown above, A is the source point, B is spread to reach the current point, when calculated from point B to point C of the cost distance, the original algorithm will add two distances AB (4 units) and distances BC (1.414 units), while Professor Tomlin's algorithm is more reasonable to calculate directly cost of distance AC (5.099 units), because the original algorithm is the use of piecewise diffusion ideas for cost increases and the cumulative distance, so the only record of each node (C point) of the previous node (B point) can be, but because of the improved algorithm to calculate each node (C point) and its source point (A point) of the direct distance, so the improved algorithm need to record the source node of each node in diffusion process. Because each pixel value of the grid may vary, so the specific formula is:

$$F = \frac{(Dis_{SN} - Dis_{SA})}{Dis_{AN}}$$

$$C_{SN} = C_{SA} + C_{AN} \times F$$

A point is called the source point, B point is called the active point, and C point is called the neighbor point, F is the ratio correction factor, Dis_{SN} is the distance from source point to neighbor point, Dis_{SA} is the distance from source point to active point, Dis_{AN} is the distance from active point to neighbor point. C_{SN} Is the cost need to be calculated from source point to neighbor point, it is be added by C_{SA} which the cost from source point to active point and $C_{AN} \times F$ which the cost from active point to neighbor point plus the correction factor.

When the source is located in non-homogeneous media, it is also need to consider correction of the propagation direction, depending on the different situation; it can be divided into two cases including refraction and diffraction. Refraction is when the active node cost is greater than the neighbor, then the active node as a new source point. The diffraction occurs mainly with the barrier in non-homogeneous media, professor Tomlin makes definition of sixteen kinds of diffraction conditions as shown below, and the active node also needs to be updated for the new source point when the diffraction occurs.

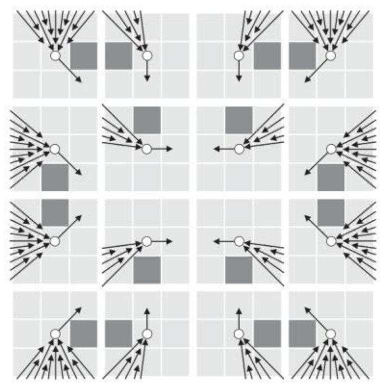

Figure 5. Diffraction situation (Tomlin 2010)

In addition when spread in non-homogeneous media may also meet barriers, which the situation cannot continue to spread, this situation also requires special handling. The overall wave spread cost distance algorithm process as shown below:

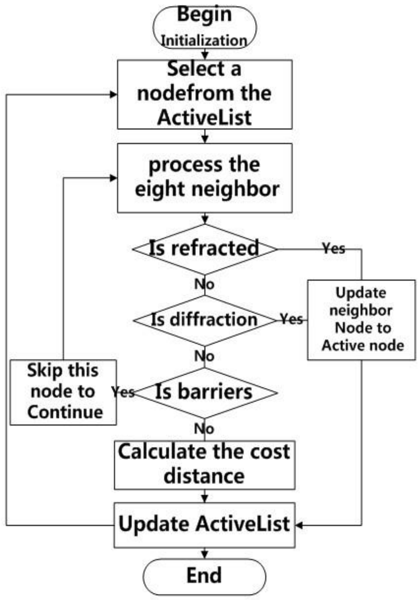

Figure 6. Algorithm flowchart

V. TOMLIN'S ALGORITHM IMPROVEMENT

Although in professor Tomlin's wave spread cost distance algorithm, the two effective improvement aspects including correction of cost distance calculation and correction of cost direction, but when we achieved during the validation of this algorithm, the algorithm was found to be some areas for improvement, including the correction of cost distance in some special circumstances improvement and the performance improvement from spreading the source point.

A. Correction of Cost Distance Improvement

We use C++ language for the algorithm implementation and data validation based on paper which provided reference code and describes [4]. In the test of actual data, we find with some data distribution situation the result of cost distance correction could be negative. Because the cost distance represents the cost of a path reach the target point, so the negative cost value is obviously unreasonable, and need to be improved.

Because the correction factor is calculated as the formula

$$F = \frac{(Dis_{SN} - Dis_{SA})}{Dis_{AN}}$$

Due to expansion of the eight neighborhood, so there may be the case $Dis_{SN} < Dis_{SA}$, then the correction factor F is negative, and because $C_{SN} = C_{SA} + C_{AN} \times F$, when the time $F < -\frac{C_{SA}}{C_{AN}}$

There will be $C_{SN} < 0$. That now calculates the correction cost value is abnormal. Therefore require special handling at this time, skip this node to calculate the other eight neighboring nodes.

B. Spread Performance Improvement

Thesis algorithm of source diffusion process using linked list structure to store and find position, when faced with a large amount of data this linked list process will consume most of the algorithm time, based on the need for the source point spread, if we structure with minimum cost heap for source storage and diffusion, it can significantly enhance the performance of the algorithm, so this algorithm can be applied to real large amounts of data calculation cases. Improved method that constructs a minimum cost heap structure, initially all the source nodes to join the heap, the spread of new nodes will be directly into the heap, because the minimum heap structure will automatically maintain the heap data, the process should just spread from the heap top.

C. Experiment and Analyses

To verify the effectiveness of this algorithm, we use C++ language to develop a prototype system and make the compare test with real data. Experimental environment for a frequency of 2.6 GHz dual-core processor PC, RAM is 3GB. We take 15 sets of performance test with four algorithm including the traditional algorithm with minimum cost heap (TAMH), the cost distance function in ArcGIS 10.0(ArcGIS), wave spread algorithm with minimum cost heap (WSMH), Tomlin's wave spread algorithm (WS).

TABLE I. CONTRAST TEST RESULTS

No.	***Pixel Count***	***TAMH***	***ArcGIS***	***WSMH***	***WS***
1	15	0.30	2.00	0.50	2.52
2	18	0.38	3.00	0.58	3.13
3	22	0.45	4.00	0.72	4.25
4	27	0.56	5.00	0.91	6.00
5	34	0.72	7.00	1.17	8.75
6	44	0.95	10.00	1.55	13.28
7	60	1.19	15.00	2.30	24.88
8	69	1.58	19.00	2.66	28.34
9	80	1.86	23.00	3.27	38.48
10	87	1.98	25.00	3.47	41.09
11	94	2.22	29.00	4.00	50.28
12	103	2.42	33.00	4.34	54.47
13	123	2.98	43.00	5.70	79.69
14	136	3.23	48.00	6.55	94.23
15	151	3.63	56.00	7.19	105.61

a. The pixel count unit is 1×10^4 the time unit is second.

As shown above, because the algorithm time-consuming is directly related to the number of pixel unit, so we selected 15 sets of raster data for experimental comparison, of which the least number of pixel unit is 150,000, the largest number of pixel unit is 1,510,000. We first compare the traditional algorithm with minimum cost heap(TAMH) with the cost distance function in ArcGIS 10.0(ArcGIS), then compare the wave spread algorithm with minimum cost heap(WSMH) with Tomlin's wave spread algorithm(WS), at last we compare the traditional algorithm with minimum cost heap(TAMH) with the wave spread algorithm with minimum cost heap(WSMH). The experiment chart is below.

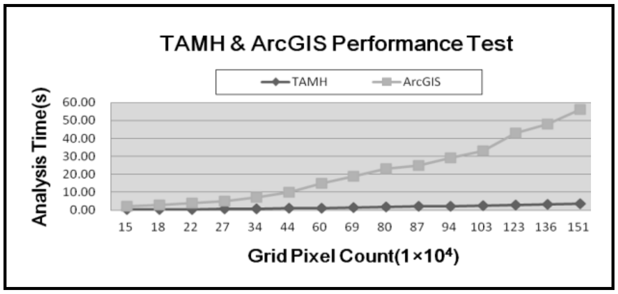

Figure 7. Performance test 1

It can be seen from the figure above, the performance of traditional algorithm with minimum cost heap (TAMH) has been significantly improved, the average performance for the TAMH is ten times of ArcGIS 10.0, and with the increase of the test data its performance advantage further enhance, in the final group test data, ArcGIS 10.0 requires about 56 seconds, while the improved TAMH algorithm requires only 3.63 seconds.

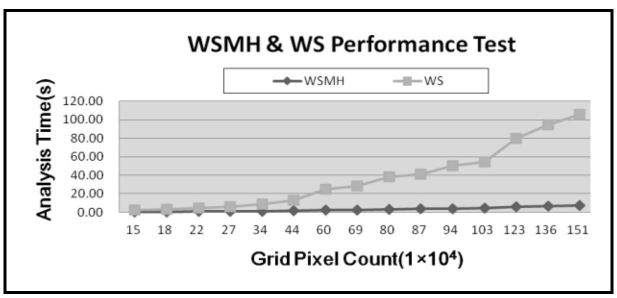

Figure 8. Performance test 2

As shown above, the performance of wave spread algorithm with minimum cost heap(WSMH) has been significantly improved compared to the Tomlin's wave spread algorithm(WS), the average time is about the one-tenth of the Tomlin's wave spread algorithm(WS).

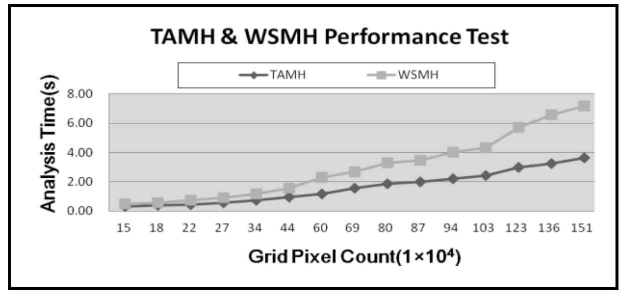

Figure 9. Performance test 3

It can be seen from the figure above, although the TAMH and WSMH both used the minimum cost heap to improve, but the WSMH performance is still lower than the TAMH, because the WSMH process considered in the correction of cost distance and correction of the cost direction and the barriers, which make the result more realistic and reasonable.

VI. CONCLUSION

In this paper, we firstly introduce the frequently used site planning shortest path calculation based on raster data model, and point out the existing calculation methods and shortcomings. Then gave three kinds of improved methods and analysis including node enhancement algorithms, neighborhood expansion algorithm, the wave spread cost distance algorithm, and focus on the latest research of the Tomlin's wave spread cost distance algorithm to verification and improve the algorithm. We make the correction of cost distance in some special circumstances improvement and the performance improvement from spreading the source point, and through comparison and analysis of experiments to verify the effectiveness of improvements. Follow-up study is to continue improve algorithm result and analysis the result error quantifies.

ACKNOWLEDGMENT

The authors would also like to express appreciations to colleagues in our laboratory for their valuable comments and other helps.

REFERENCES

[1] Deo, N. and Pang, C., 1984. Shortest-path algorithms: taxonomy and annotation. Networks, 14 (2),275–323.

[2] Dijkstra, E.W., 1959. A note on two problems in connection with graphs. NumerischeMathmatik, 1 (5),269–271.

[3] Tomlin, C.D., 1983. Digital cartographic modeling techniques in environmental planning. Thesis(PhD). Yale University.

[4] Tomlin, Dana., 2010. Propagating radial waves of travel cost in a grid. International Journal of Geographical Information Science, 24:9, 1391–1413.

[5] Xu, J. and Lathrop, R.G., 1995. Improving simulation of spread phenomena in raster-based geographic information systems. International Journal of Geographic Information Systems, 9 (2), 153–168.