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Trans. Nonferrous Met. Soc. China 21(2011) s637−s641

Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Real-time emergency route generating algorithm in tunnel

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Received 19 June 2011; accepted 10 November 2011

Abstract: As part of the digital mine system, a real time emergency route generating algorithm for a large scale metal mine is studied. The tunnel is abstracted and mathematically described by the center line model. A series of definitions are made and the center lines are regularized. In order to improve the quality of the final routes, a center line dataset preprocessing is done according to the factors including the slope threshold and the tunnel closed state information, etc. While in preprocessing, the mineshaft and shaft with the steep slope are excluded implicitly. The interface is preserved for point-like objects (e.g. blowers), directions (e.g. wind direction of blowers) and so on. The final path finding algorithm is optimized by the filter operation that the calculation is only performed at the endpoints and hub points, which can further reduce computing data amount. In our experiment, 3 368 nodes out of 22 401 nodes are selected as key nodes, therefore, the data processing amount of the algorithm is reduced to 1/7 and the routes can be found in real time. The algorithm is implemented and integrated into the final digital mine system.
Key words: digital mine; tunnel; path finding problem; DIJKSTRA algorithm; adjacency list

1 Introduction

Today, the digital mine has become a hot research topic in geographical information system (GIS). Traditional analysis and assistant decision-making are mostly based on two-dimensional tools. With the rapid development of computer processing capacity, spatial database technology and GIS, three-dimensional digital mine system begins in industrial applications. In order to reduce the waste of resources and environmental pollution and improve the social and economic benefits, digital mine research is conducted to integrate deposit and mineral development together in the framework of geographical coordinates with the knowledge of mineral economics, mathematical geology and information technology. Therefore, three-dimensional relationship is established to achieve the goal of reality mining and visualization so as to solve the technical issues such as dynamic production management, optimization decisions, production planning and rational development of resources [1].

As a significant issue in geography, the shortest path finding problem plays an important role in many GIS applications, such as transportation, urban planning, logistics management, network communications [2−7]. A lot of researches have been done in this area, and a large number of papers have been published. The algorithm of DIJKSTRA, which is named with its author, is recognized as the best method presently [3]. There are also a series of papers [8−15] published by domestic scholars, in which a lot of new algorithms have been put forward, such as the optimal routing algorithm based on the simulation of dispersion [9], the model and algorithm for the shortest path of multiple objectives [10], a bidirectional heuristic shortest path algorithm with turn prohibitions and delays [11]. A large amount of research results have been applied in many areas, but most of them are established in planar map datasets.

Considering the mine's complicated environment, an algorithm of real-time emergency route finding is systematically studied. The tunnel's feature is abstracted so that the corresponding model can be built. The dataset is culled in advance according to the actual needs, and the interfaces of the vertex attributes operation are preserved for further perfection. The algorithm is implemented and integrated into the 3D digital mine system developed by our team.

2 Model of tunnel

The mineral mountain is an extreme complex local

Foundation item: Project (41161071) supported by the National Natural Science Foundation of China
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system. The tunnel as an internal roadway plays a vital role in working and emergency. There are many complex elements in tunnels such as mineshaft, inclined shaft, ramp, air returned filling ramp, blower, drainage channel, gob and various pipelines. Therefore, the focus of the tunnel modelling varies from application to application.

From the point of view of spatial shape, the tunnel can be described by a collection of polylines which can be represented by a series of nodes. Mathematically, the set of nodes is represented with

$$\{(x, y, h)|(x_1, y_1, h_1), (x_2, y_2, h_2), \cdots, (x_i, y_i, h_i), \cdots, (x_n, y_n, h_n)\}$$

where triple tag (x_i, y_i, z_i) is the coordinates of node i. For convenience, some basic concepts are defined as follows.

Definition 1: Endpoint is a node which has only one branch.

Definition 2: General feature point is a kind of node which has just two branches.

Definition 3: Junction point is a node which has three branches or more.

Definition 4: Edge is interlinked by two adjacent nodes.

Definition 5: Route is a combination of sequential adjacent edges.

Definition 6: Standard route is such a route that starts from an endpoint or a junction point and end with an endpoint or a junction point.

Definition 7: Regulation is a process of converting edges sequence into the sets of standard route.

As shown in Fig. 1, according to the branch count, a node which links the central line of the tunnel can be categorized into three types: endpoint, general feature point and junction point. In fact, the entrance, the exit and the end of the tunnel all belong to the endpoint set. The shape nodes which can only be moved along forward or backward are general feature points. Junction point contains more than three branches and guides to different routes; in most cases, junction point is a mineshaft (connecting the tunnels of different elevation layers), a scheduling centre, or a turning point led to other tunnels.

In practical applications, the centrelines of the tunnel are irregular, and the tunnel itself is often very long. Therefore, it must be divided into several segments

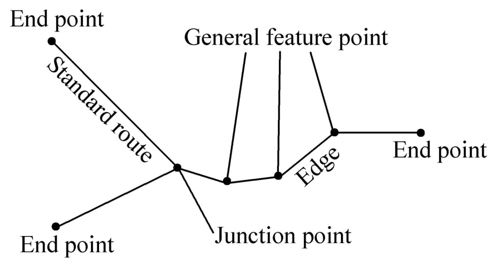

Fig. 1 Simplified tunnel model

for description in GIS application system. A piece of route can also be repeatedly drawn many times due to the heterogeneous data, which can bring about local overlap. Therefore, the regulation to tunnel's centrelines is indispensable.

The centrelines can be completely converted into a collection of standard routes. Assume that there exists a non-standard route in final data set, at least one endpoint of this route should be internal point, which does not conform to the actual situation; if the path is correct, the endpoint node can be the key node; otherwise, there is also another non-standard edge matched with the route, so as to be merged into a standard route.

The final tunnel model is constituted by a collection of standard routes, and the 3D tunnel model is built with spatial extension of the centrelines. For a point-like object, such as blower, the node can be used to indicate the location, and the additional property indicates its purpose. As for the wind direction of the blower, vectors can be used in the start or end node. This can also be used in many other aspects including water supply, electricity, etc.

Many factors have been considered in the algorithm, including the impassable of the mineshaft, the quality of the route, the speed decay model of the blower, etc. An extensible interface is preserved for future perfection. In fact, mineshaft is not suitable for passing through due to its high altitude difference and should be culled in the calculation. The slope factor is needed for controlling the quality of the final route. The blower has great power in maintaining air circulation in the mine. On the emergency route, walking before the wind is faster than that against the wind. New constraints can be added with the establishment of wind speed decay model.

3 Basic data structure

The data structures mainly used in the algorithm are described with a C-like style language, in which "long" is used to define an integer, "double" for the real and the "vector" is a dynamic array.

```
Struct Node
{
    long Attr;
    long BranchCount;
    double X, Y, Z;
    double B, L, H;
}
```

Node is the basic element which contains the planar coordinates (X, Y, Z), the geodetic coordinates (B, L, H), attribute (Attr) and branch count (BranchCount). In practice, different specific coordinate systems will be used due to different applications, sometimes planar system and sometimes geodetic system. Attribute field is used to set aside the compatibility of the point-like feature (e.g. blower, special objects, etc.). The branch count field is to help not only for distinguishing the general feature node from the key node but also for data pre-processing.

```
Struct StandardRoute
{
    double routeLen;
    double routeMaxSlp;
    vector<long> routeNodeIndexList;
}
```

Standard route structure contains actual distance (routeLen), maximum slope of the route (routeMaxSlp) and its node index list (routeNodeIndexList). Using an index instead of the node's actual information is much better, and the waste of computer memory resources can be reduced. On the other hand, the edge crack closure problem brought by the calculation of node data can be avoided. If the count of nodes is too large, path finding algorithm will cause long time delay without taking an optimized way to store the data. In this case, the final algorithm is difficult for practical use. In this work, there are 22 401 nodes and 3 368 key nodes. During this way, the data dealt directly by the algorithm is about 1/7, reducing the CPU load greatly.

```
Struct TunnelStruct
{
    vector<Node> m_NodeTbl;
    vector<StandardRoute> m_StdRouteTbl;
    vector<Node> m_EntranceTbl;
}
```

Node table contains all the nodes composed of the tunnel; standard route table includes all endpoint or junction point to the endpoint or junction point routes sequence. Because the standard route does not fork in the middle of the path, the algorithm can be speeded up by just considering the start and end points. Entrance table includes all effective entrances of the mine, and it also includes emergency refuge points. For final reference comparison, all possible routes will be calculated from the burst point to each entrance.

4 Pre-processing of dataset

Before calculating the path, a pre-processing to the centrelines is necessarily needed which culls the interference of the source data such as coincidence, repetition and other side depicts. After pre-processing, the source path data will be converted into a set of standard routes.

Setting the distance threshold E_{psilon} equals 10 mm, if the delta distance between current point and the point in container $d_{\text{ist}} \le E_{\text{psilon}}$, it is the coincidence point; otherwise, it is a new node. To compare the starting/ending points between the new sub-segment and the segment in the container, an operation of merging or merged after reversing is necessarily done. Ultimately, a set of regularized centrelines are provided to the algorithm.

5 Path finding algorithm

5.1 Burst point positioning

Assume P is the burst point, traversing in the edge table and an edge is selected as the current edge AB. A judgment of the relationship between P and AB is carried out as follows (shown in Fig. 2). Taking point A as the original point, calculating the vectors

$$\boldsymbol{AP} = (x - x_{\text{a}}, y - y_{\text{a}}, h - h_{\text{a}}) \tag{1}$$

and

$$\boldsymbol{AB} = (x_{\text{b}} - x_{\text{a}}, y_{\text{b}} - y_{\text{a}}, h_{\text{b}} - h_{\text{a}}) \tag{2}$$

If the dot product $\boldsymbol{AP}\cdot\boldsymbol{AB}<0$, then point P is out of the range of edge AB. Taking point B as the original point, calculating the vectors

$$\boldsymbol{BP} = (x - x_{\text{b}}, y - y_{\text{b}}, h - h_{\text{b}}) \tag{3}$$

and

$$\boldsymbol{BA} = (x_{\text{a}} - x_{\text{b}}, y_{\text{a}} - y_{\text{b}}, h_{\text{a}} - h_{\text{b}}) \tag{4}$$

If the dot product $\boldsymbol{BP}\cdot\boldsymbol{BA}<0$, then point P is not in the range of edge AB.

If point P passes the dot product tests (including points A and B), there are $\boldsymbol{AP}\cdot\boldsymbol{AB}\ge 0$ and $\boldsymbol{BP}\cdot\boldsymbol{BA}\ge 0$, which means point P is in the range of the current edge. A distance test is followed while letting iMaxDistRng equals 3.0 m. Calculating

$$\cos\theta = (\boldsymbol{BP}\cdot\boldsymbol{BA})/(|\boldsymbol{BP}|\cdot|\boldsymbol{BA}|) \tag{5}$$

If the spatial distance $|PL|$ between point P and edge AB,

$$|PL| = |BP|\sqrt{1-\cos^2\theta} < i\text{MaxDistRng} \tag{6}$$

then the position of point P is determined.

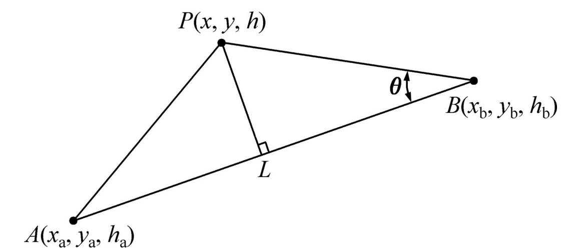

Fig. 2 Burst point positioning

The starting/ending points of the route are recorded, in which the burst point is determined. If there is no edge which meets the conditions after traversing the standard route table, a route finding failure report will occur.

5.2 Dataset culled under constraints

A slope factor θ (Fig. 3) is introduced to control the quality of the route. If the maximum slope factor of the standard route is greater than the given value, the route will not participate in the final calculation, which will be culled during the period of neighbour list building. In this work, the given slope factor is 40°, which means that the slope of the routes generated finally is less than 40°. Under the constraint, the mineshaft and steep with large slope are excluded implicitly.

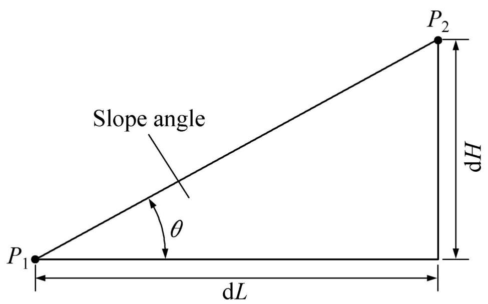

Fig. 3 Model slope calculation

In the case of sufficient data, wind speed decay model of blower can be built. The factor of rail vehicles can also be taken into account. In order to control the quality of the resulting path, it is effective to control the dataset participating in final calculation. In this regard, the appropriate interface is preserved.

5.3 Path finding

As a template, the classic algorithm DIJKSTRA is used, and the corresponding adjustments are carried out according to the actual needs (the weight of the edge in DIJKSTRA algorithm is replaced by the edge distance and the centrelines are culled under the constraints of the slope and the tunnel state information). The basic principle is as follows: extending a new point with the shortest distance each time and updating the distance between adjacent points; continuing to promote the process, the current point is always synchronized to maintain the shortest path, until the target point is found. Algorithm processes are as follows [3].

1) Creating the red point set and the blue point set.

2) Traversing through the neighbour list to find the nearest point which has not been checked and putted into the blue point set for checking.

3) Finding the nearest point to the starting point from the blue point set, finding all the child nodes, and then putting them into the red point set.

4) Traversing through the child nodes of the point investigated, calculating the distance between these child nodes and the starting node, and putting the child nodes into the blue point set.

5) Repeating step 3 until the blue set is empty or the target point is found.

6 Experiment

The algorithm is implemented with the C language and the tunnel data of a large scale metal mine is used in the experiment. There are five entrances in this mountain. So, for a given burst point the algorithm can find five routes. Two of the routes are shown in Figs. 4 and 5. The tunnels are expressed with the centrelines and the road is marked with a series of points.

By setting the maximum slope factor to be 40°, five routes are generated and their statistical information is listed in Table 1. It is easy to find that every route’s maximum slope is less than 40°. Under the constraint of the slope factor, all shortest routes are generated successfully. To meet the needs of a large scale metal mining enterprise, a package of 3D digital mine system is developed, in which emergency path finding module is integrated.

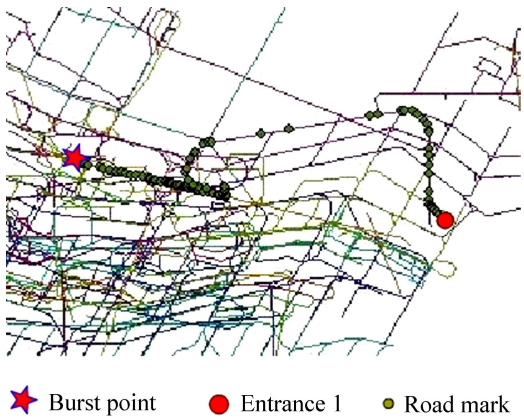

Fig. 4 Emergency route 1

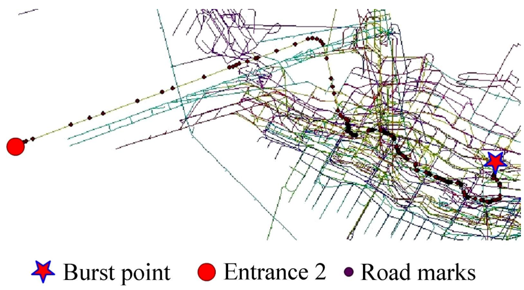

Fig. 5 Emergency route 2

Table 1 Statistical information of all routes

Route index	Maximum slope/(°)	Route length/m
1	33	3 083.775
2	36	1 641.456
3	22	2 357.377
4	22	2 325.725
5	22	2 373.976

7 Conclusions

1) Taking slope and whether the tunnel is closed or not into account, all emergency routes can be achieved immediately and the final paths found by the algorithm are also proved to be very practical.

2) The algorithm is successfully integrated into the digital mine system, but a number of factors are not adequately considered because of the complexity of the tunnel. The final route generating algorithm will become more effectively if making the appropriate modelling to various conditions underground such as establishing a corresponding speed decay model of the blower.

3) In order to improve the quality of the emergency routes, a series of factors will be studied deeply in the next step including point-like objects (such as blowers and other features), linear elements (e.g. rail vehicles), direction of the elements (such as the wind direction of the blowers), etc.

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(Edited by CHEN Wei-ping)