Optimal Path Finding Independent of Centerline Topology

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SUMMARY

Previous approaches in path finding problem are mostly conducted in GIS environment in which the arc-node data structure is adopted to generate centerline network. An alternative approach is to use exact cell decomposition algorithm in which an optimal path computation model is built dynamically upon automatic extraction of topology from base map features. In this paper, a review of this method for walking path computation and implementation in the CAD environment will be presented.

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1. INTRODUCTION

Network and transportation analyses within a GIS environment (GIS-T) have been studied numerously including Vuren et al. (1998), Horowitz (1996), Sutton (1996), Zhan and Noon (1998), Kirkby et al. (1996), Chen and Yang (1999), Han et al. (2001) and Goodchild (2000). The most common and convenient way to represent a road network is the arc-node representation. That is, nodes correspond to street intersections while arcs correspond to street segments between intersections. In many applications, network arcs so called road centerlines are digitized to lie between the centers of physical road margins. In order to support routing application, all road centerlines should be snapped together to form a connected road network. The connectivity of arc-node representation of road network thus allows the system to traverse through the network efficiently with the support of network data storage structure.

However, road centerlines are not natural features that can be found on ground. Data capturing techniques like surveying, photogrammetry, remote sensing and even topographic mapping are unlikely to capture this kind of data. Manual digitization, which is considered cumbersome and time consuming, becomes inevitably the most common way to generate these road centerlines lying between the road margins. Although many GIS software are enhanced to automate such process of centerline creation, the result could be unsatisfactory when some sophisticated cases are met. An alternative approach is to use map features such as street blocks, building blocks, roads and bridges to perform path finding or routing directly. The exact cell decomposition algorithm is introduced in this paper in which an optimal path computation model is built dynamically upon automatic exaction of topology from base map features. The method is first tested for pedestrian walking with success. Besides, the implementation of this method in a CAD environment will also enable more user-friendly and wider adoption among the non-GIS community.

2. EXACT CELL DECOMPOSITION FOR PATH FINDING

The cell decomposition method is one of the most extensively studied motion planning methods. The free space is decomposed into non-overlapping cells (Figure 1), such that a connectivity graph can be easily generated by connecting paths between any two adjacent cells. Nodes of the graph are the cells extracted from the free space and two nodes are linked if and only if the two corresponding cells are adjacent.

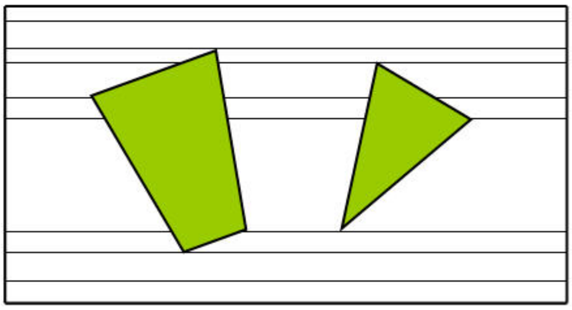


Figure 1 Decomposing the safe configuration space into horizontal slices

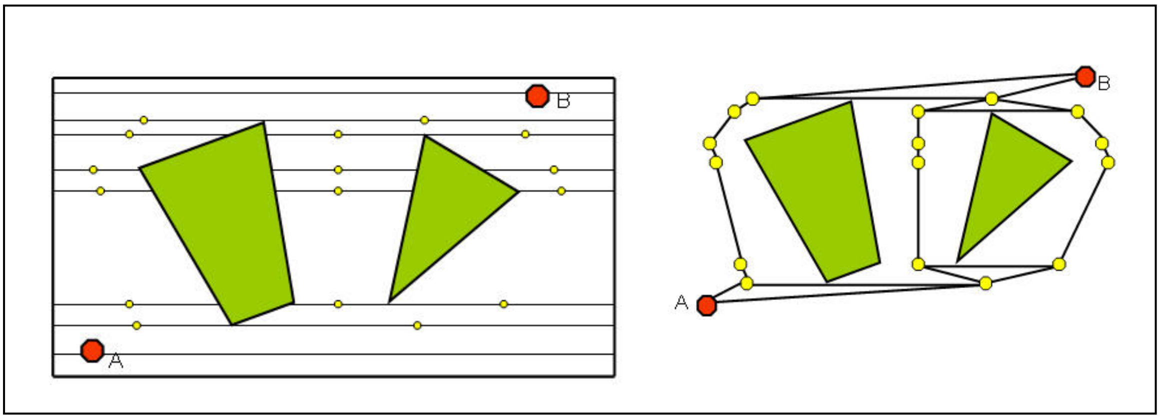


Figure 2 Forming a graph (right) by using the mid-points of each line segment (left)

When applying to networking of the land features as represented on a digital topographic map, the free configuration space outside the obstacles of walking path (such as buildings, road surfaces without traversing links) is divided into a number of non-overlapping horizontal or vertical cells. With the specified starting and destination points, the polygonal environment are decomposed into cells by drawing the extending lines from each critical point of the obstacle. In most cases, the mid-point of each line segment that is adjacent in the configuration space is connected to form a connectivity graph (Figure 2). This method is efficient to implement. The number of cells is linear in the number of edges n and the decomposition can be obtained in time $\boldsymbol{O}$ (n log n). The resulting graph with optimal number of nodes and arcs is pleasant enough to indicate a direction for pedestrians to follow. The main drawback is that the cells are not very natural looking and the resulting graph tends to be long and skinny.

3. INTERFACING WITH A CAD SYSTEM

A prototype is developed using 1:1000 digital topographic map data of Hong Kong. The area consists of several street blocks in the inner city with an extent of about 1.5 x 1.5 km^2. This approximates the maximum walking distance in everyday life. The cell decomposition method is programmed onto Autodesk Civil Series 2004 using AutoCAD Object Model and Visual Basic (Application) and Visual Lisp. The workflow is explained in the following steps.

Step 1: With the input of a digital map, the user specifies the map extent for optimal walking path networking and depicts the origin and destination graphically on the screen (Figure 3).

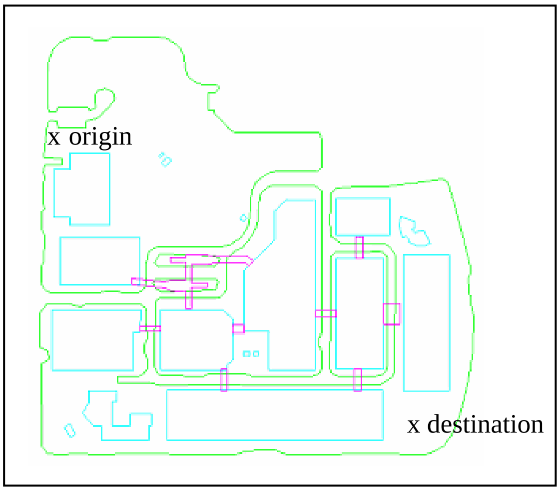


Figure 3 Defining map extent and origin-destination

Step 2: User specifies the type of objects used for networking (Figure 4). These should also be defined as free space (e.g. pavements), obstacles (e.g. building, road surfaces without traversing paths) and connectors (e.g. tunnels, bridges).

Step 3: Referring to Figure 5, the exact cell decomposition method first operates on individual street block by (a) getting all intersection points between obstacles and the free space, (b) deriving mid-points between each pair of intersection points that lie on the same horizontal line and (c) generating a connected graph. At the same time, these points are exported for routing between all concerned street blocks.

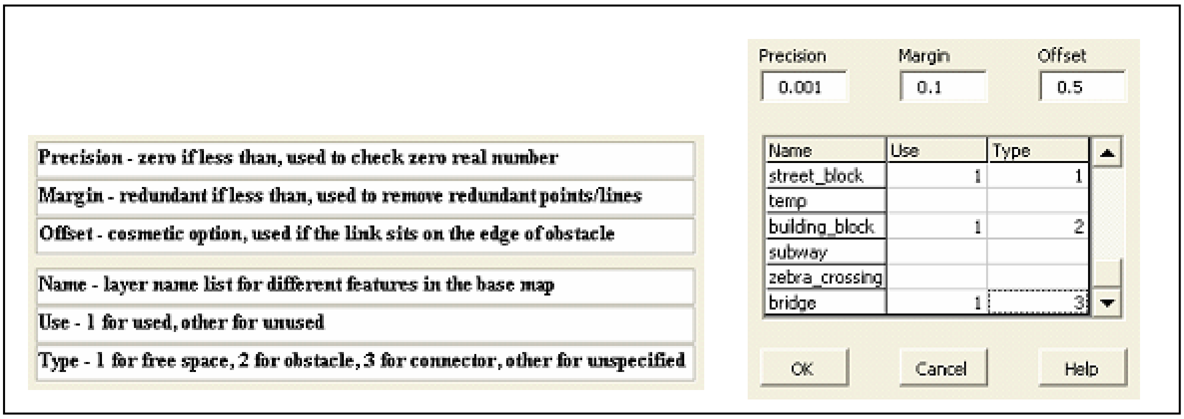


Figure 4 Defining types of objects from digital map data

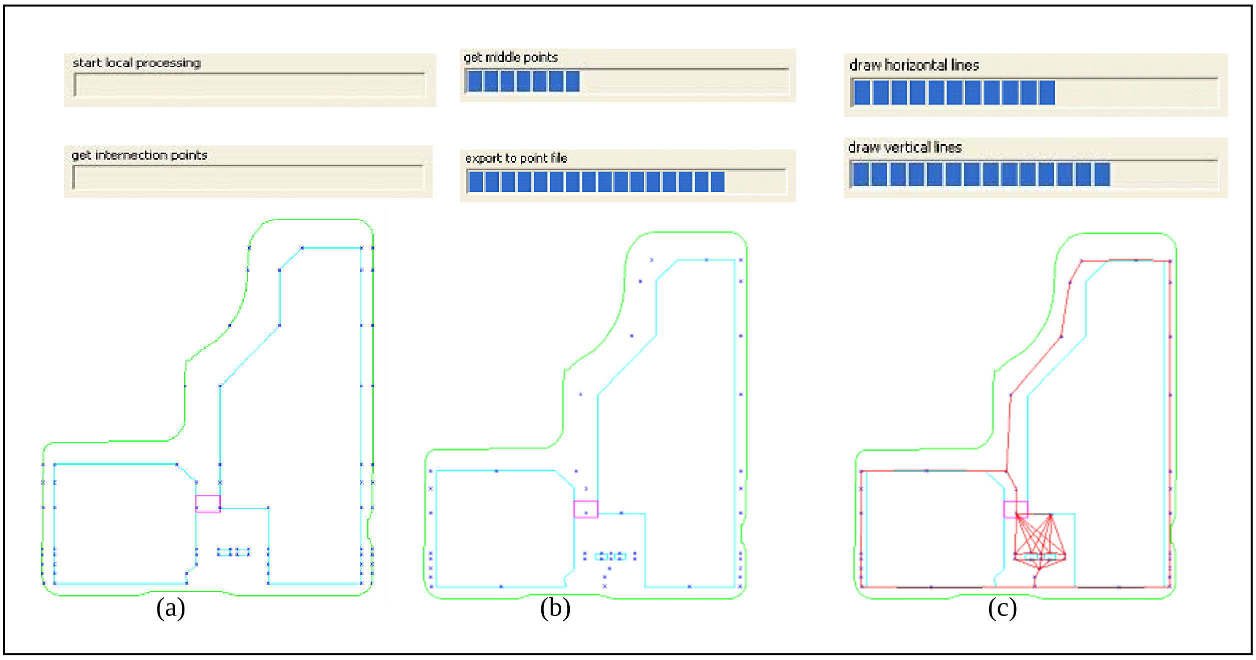
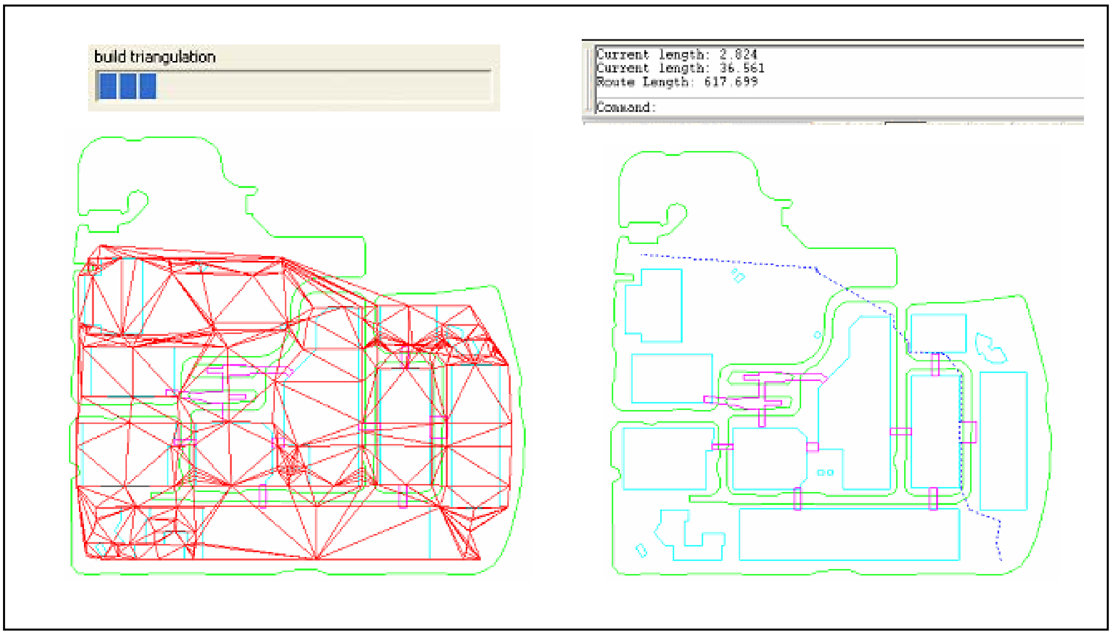


Figure 5 Operation of cell decomposition method

Step 4: With the input of all points lying on the traversable free space including the origin, destination and connectors between street blocks, triangulation is performed (Figure 6a) and the resulting optimal path is generated with a suggested length (Figure 6b).

Concerning implementation efficiency, computation can be done in 5 minutes if the area is small as about 200 x 200 m^2. But when the area is doubled, the running time may be increased by 10 times or more. This is probably due to the enormous file size of storing, sorting and processing points that consumes a lot of RAM. Yet, this does not pose a great problem for the specific application of pedestrian walking as the concerned area will usually not be large. For other applications like vehicle routing, some other methods or modifications of the algorithm to enhance computational efficiency have to be researched.



(a) (b)

Figure 6 Triangulation and derivation of optimal walking path

4. CONCLUSION

This paper addresses and presents a new method for computing the optimal path with a connectivity graph and information about the path and topographic features. All the input to the proposed model is only a digital map with its associate topographic features, without the pre-prepared of any network. The model is based on the exact cell decomposition method to generate a connectivity graph by connecting a path between any two adjacent horizontal cells. The possible routes can be generated to provide useful information for pedestrians in determining their ways. The main advantages of this new method is the identification of users' familiarized land features from a digital map by themselves so as to obtain the desired results of path finding. The model and the customized program automatically handle and generate the routes and information in real time, without the generation and maintenance of the arc-node network data. This prototype could be further investigated, say, with the considerations of modeling the entrance point of buildings and facilities (e.g. lift, stairs) inside buildings such that the walking path could become more realistic to have both "horizontal" and "vertical" movements of pedestrians.

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BIOGRAPHICAL NOTES

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