The Design and Development of Indoor 3D Routing System

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***Abstract*—At present, the development and application of outdoor navigation is already quite mature. Car navigating system and mobile navigating system have been good to meet people's requirements to find the path in outdoor. With the development of outdoor navigation system, indoor navigation system is also being paid more attention, especially in an unfamiliar and complex indoor environment. This paper constructs 3D models of the building by SketchUP so as to provide a 3D scene for indoor navigation system, and builds 3D network model based on the building plan by ArcGIS. Finally, a indoor routing prototype system is developed based on ArcEngine, which does a preliminary study for indoor navigation.**

***Index Terms*—ArcEngine, 3D Network, Indoor Routing**

I. Introduction

With the establishment of the GPS navigation and positioning system, the development and application of the navigation system has been gradually mature and well [1]. The form of map has changed from paper into electronic screen, and a wide variety of car navigation system and mobile navigation system emerged endlessly. With the economic development, the level of urbanization and the number of high-rise buildings gradually increase in the city, and the building's complexity is beyond imagination. When people go from one city to another, or from a place to another in the city, all kinds of existing car navigation system and mobile navigation system can give a satisfied solution. But in a smaller area, especially some complex and unfamiliar building interiors such as airport terminals, shopping malls, exhibition halls, existing outdoor navigation system is powerless.

In the 1990s, an American company called Arc Second developed the first set of indoor navigation system - Indoor GPS. In 2007, the French aerospace company Thales developed a indoor positioning system called Indoor Positioning System. In 2010, at the Nokia World 2010 the General Assembly, Nokia Research Center launched a high-precision indoor navigation technology applications. In August 2012, Nokia, Samsung and other 19 companies set up jointly by In-Location Alliance. In October 2012, China is actively building a wide area indoor and outdoor high-precision positioning and navigation system—Xihe System [2]. These systems or application are focused on providing accurate positioning information, but difficult to implement indoor path planning and navigation.

Therefore, this paper tries to design and develop an indoor routing system according to the existing three-dimensional GIS theory and technology. The system is developed based on the ArcEngine component library. An indoor 3D navigation scene is built from the building floor plan data by SketchUp tools, and then is imported into the navigating system as navigating reference [3][4].

II. System Functional Design

Compared with outdoor routing, indoor routing is to plan or search path within the indoor 3D space, which is based on the indoor three-dimensional network model and the three-dimensional interior scene. Because ArcEngine10.0 provides more powerful functions to process three-dimensional spatial data and find the optimal path in three dimensional network, we choose ArcEngine10.0 and VS2010 as system development platform and tools. Main functional modules of the system include basic operation module, 2D and 3D linkage module, road network extraction module, path planning module and path dynamic presentation module, whose detailed content is shown in Fig. 1.

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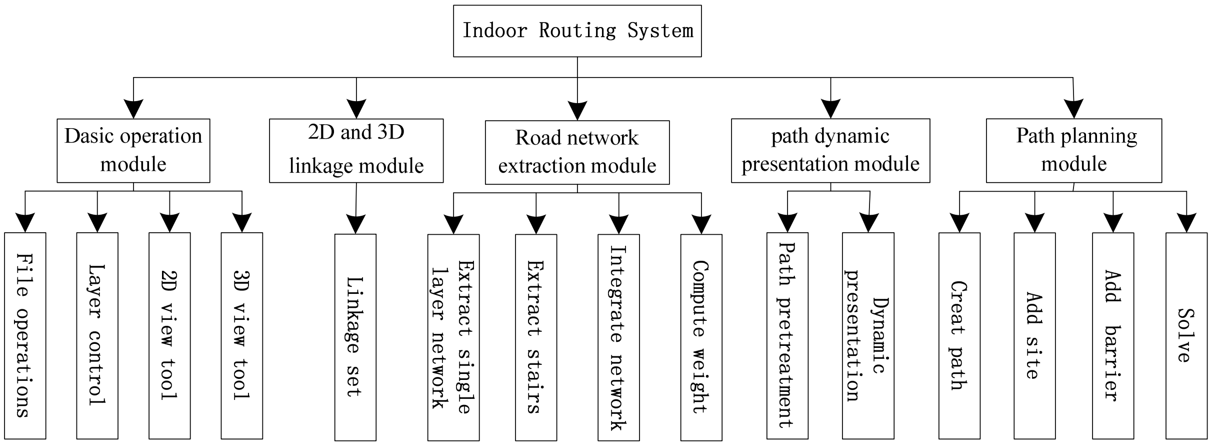


Figure 1. Structure of system function.

A. Basic Operation Module

The module are mainly used to import and export 2D vector maps, 3D indoor scenes and indoor network model, manage the project file and implement basic interactive operations. The detailed function list is as followed:

1) Create, update and open a project file. The project file stores the file paths of the mxd and sxd file, which is easy to load two kinds of data at the same time.

2) Import or export 2D floor map file (.mxd), 3D scene data file (.sxd) and network model data.

3) Add or delete the 2D floor map file, and view its attribute table.

4) Control layers. List all the layers that system contains, and add or delete any of them.

5) Basic interactive operation in 2D view such as zoom, pan, full view, search, select or identify features.

6) Basic operation in 3D view such as zoom, pan, full view, navigation, flight.

B. 2d and 3d Linkage Module

2D GIS doesn't have only strong spatial analysis functionality, but also is very easy to locate and identify direction. Although 3D GIS has advantages on 3D visualization of spatial information, users often lose themselves for lack of the overall navigation map when roaming in the 3D scene. Therefore, the system integrates their respective merits and adopts a combined interface of 2D and 3D window. Furthermore, when users interact with the scene or roam in the scene, the system will ensure the synchronous update of the 2D view and 3D view, which will be able to overcome their respective shortcomings. Detailed implementation is discussed in section III.A.

C. Road Network Extraction Module

Any path planning algorithm is based on the graph that consists of nodes and arcs. Therefore, the system must provide the ability to construct the three dimensional road network inside a building which represents connected relations among all walking parts of the building. At present, ArcGIS has provided the basic 3D path analysis function, but is unable to realize the automatic construction of three-dimensional indoor network from design data of buildings. The module provides single-layer road network extraction, stair extraction, network integration, path weight calculation and other functions, which can build a suitable three-dimensional network according to geometry information of buildings and characteristics of people's walking behavior. Detailed implementation is discussed in section III.B.

D. Path Planning Module

Path planning is a very important function of GIS software, and is also a necessary function of navigation systems [5]. At present, both GIS software and navigation system provide path planning function based on the 2D network, which can not realize indoor 3D path planning function based on 3D network [6]. For example, in a 2D view of the path planning, adding a site can directly click by mouse the place where you want to add, but the way can not be applied to the 3D indoor scene. Therefore, this system combines the query dialog box with the mouse click to provide a more suitable way for indoor path planning to add sites. When adding indoor site, users can firstly query a room through a variety of attributes of the room such as number, name, staff, and then add it to the scene. When adding outdoor site, user can directly click the corresponding position on the map.

E. Path Dynamic Presentation Module

Presentation of path planning result can be divided into static display and dynamic demonstration. Static display is often used to present and analyze the result of the global path planning, and dynamic demonstration to simulate real-time movement of people or vehicles along the planned path. Due to 3D indoor network in the 3D scene or 2D view will overlap or keep out, the dynamic demonstration function is designed to display the result of 3D path planning, which can display that the user walks along the planned path in the 3D indoor situations. To overcome user's disorientation when walking in 3D scene, the 2D window will synchronize with the 3D scene which can display the current location and the corresponding floor plan in real time. At the same time, this module also provides multi-mode navigation which integrates text, graphics and voice. This navigation way can make user more quickly and easily get navigation information such as walking direction or distance to the next corner.

III. Implementation of Key Functions

A. View Synchronization of 2D and 3D Windows

For 2D data and 3D data have an unified coordinate system, view synchronization of 2D and 3D windows can be realized through adjusting center coordinates of views the same [7]. The 2D display window is developed based on the MapControl of ArcEngine and the 3D display window based on the SceneControl. When the mouse clicks on the 2D display window, map coordinates where the mouse clicks can be obtained through the OnMouseDown() event of the MapControl, and then be sent to the 3D window to refresh the 3D scene [8]. Similarly, when the mouse clicks on the 3D display window, the screen coordinate in the 3D scene can be converted into the 2D map coordinate through the OnMouseDown() event of the SceneControl, and then the FlashShape() method of the MapControl is used to flash the position determined by the coordinate in the 2D window.

Data required by 2D and 3D linkage arc composed of 2D spatial data and 3D spatial data. 2D space data include floor plans and architectural base maps which are stored in Shapefile data format. Architectural base maps provide indicative position reference to help users to locate their position in the 3D scene. 3D space data include DEM, building models and the 3D network dataset. DEM is generated by discrete elevation points, and then satellite images as a texture overlay on it. Building models are created by SketchUp software based on the floor height and internal structure of buildings, and then these created 3D building models are imported into ArcGIS. The network dataset created by ArcGIS is used for path planning.

B. Three Dimensional Road Network Extraction

The indoor 3D network model represents connected relationships of all internal spaces of a building, which can be divided into two levels: geometric network and topological network [9]. The geometric network is a 3D geometric network composed of indoor walking routes that are extracted directly from 3D spatial data of the building, which is used to produce the topological network and visualize the road network. The topological network is a graph consisting of arcs and nodes which is mainly used in the optimal path planning. Nodes usually represent rooms, connected point of more than two edges. Arcs with cost and capacity represent corridors, stairs, edges connecting rooms and corridors, and so on.

The procedure of constructing the 3D geometric network is that the geometric network of every floor is extracted first, then all geometric networks in each layer are connected by stairs. The existing methods of extracting the floor geometric network are as following: space decomposition by constrained triangle network [10], visibility graph [11], straight medial axis transform (S-MAT) [12][13], etc. These methods use the computational geometry theory to obtain geometric networks whose morphology are very different from each other because of different navigating purposes. Du provides a raster-based method to extract the skeleton line of corridors [14]. The thinning algorithm of mathematical morphology and the feature point extraction algorithm are used in the method, whose defects include low efficiency of the thinning algorithm and the need to convert raster to vector.

In this paper, the 3D geometric network is automatically generated based on the CAD plans of buildings. The concrete steps are as follows (Fig. 2.):

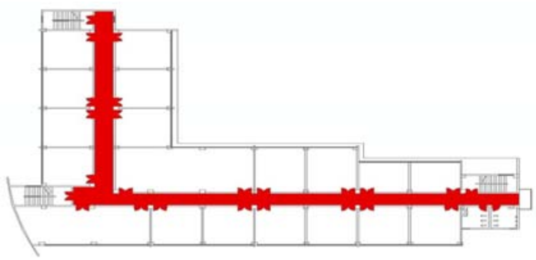
1) convert the corridor area enclosed by walls and doors to a closed polygonal region without consideration of each room of buildings;

2) divide the polygon region with the Constrained Delaunay Triangulation;

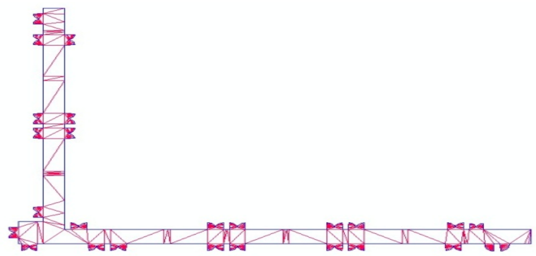
3) connect midpoints of unconstrained edges of triangles to get the medial axis of the divided region as the path of the corridor, and then join the connecting lines between rooms and corridor to form a layer of geometric network;

4) connect all layers of geometric networks by stairs to produce the three-dimensional geometric network.

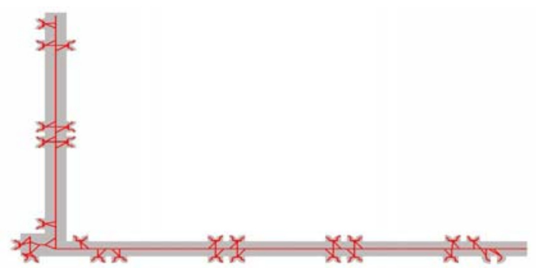
Of course, in order to make path planning, it's necessary to convert the 3D geometric network to a topological network. The weight of arcs of the topological network needs to take into consideration the geometric length of arcs and walking difficulty for people.



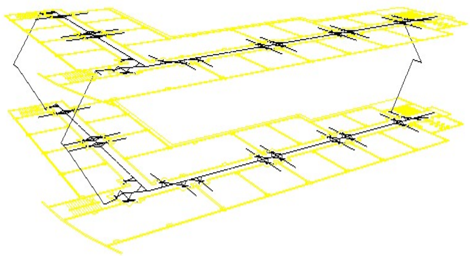
(a) The area of corridor.



(b) The Delaunay triangulation of corridor.



(c) The medial axis of corridor.



(d) The indoor 3D network.

Figure 2. The technical rout of building 3D network model.

C. 3D Path Planning

Implementation of 3D path planning is mainly based on interfaces of the NetworkAnalyst library such as INALayer, INAContext, INAClass, INAClassLoader, INASolver [15], and interfaces of the Geodatabase library such as INetworkDataset, IFeatureClass, IFeatureWorkspace, IFieldsEdit, IFeatureClass, IZAware. The main steps are as follows:

1) Create a memory workspace, and obtain the network dataset.

2) Create analysis layers, analysis context and 3D elements which is used to store site and barriers.

3) Load analysis feature points by the way of query or mouse click.

4) Set analysis properties, update the analysis context.

5) Solve and display the analysis result.

D. Path Description Information Extraction

In order to provide the user a detailed navigation message when he walks along the optimal path in the 3D scene, it is necessary to extract the turning locations (turning points) and the turning directions of the path after the path is planned well. The principle of extracting turning points is as shown in Fig. 3. Three points are obtained in turn from the planned path through the method get_Point() to form two vectors P12 and P23, and then the included angle between these two vectors is calculated. If the angle is greater than 22.5 degrees, it is considered that the second point is the turning point. At this time, if these three points are not in the same horizontal plane, it is considered that the second point is the junction of the stairs.

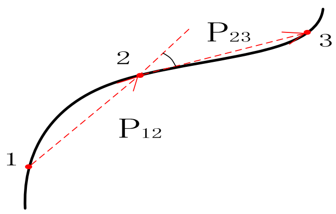
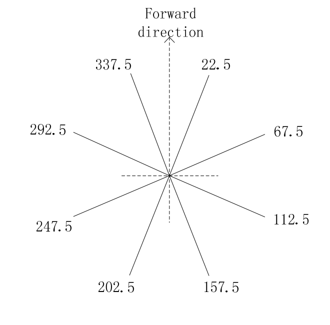


Figure 3. Turning point's extraction principle.

Turning direction is the most important indicative information for the user, which is also important guarantee for path description accuracy [16]. Turning direction can be calculated by two vectors P12 and P23. These points may not be in the same plane, so two cases must be considered as followed:

1) Not in the same plane. If the elevation value of the first point is less than that of the third point, then the second point is upstairs, otherwise the second point is downstairs.

2) In the same plane. For the range of calculated vector angle is between 0 degrees to 180 degrees, turn direction can't be determined only based on the angle. Therefore, it is necessary to calculate firstly the coordinate azimuth of P12 and P23, and then calculate clockwise deflection angle of P23 relative to P12 based on the coordinate azimuth, at last to judge turning direction according to the classification of the Fig. 4.



Clockwise Declination Angle	Turning Direction
22.5-67.5	Right Front
67.5-112.5	Right
112.5-157.5	Right After
157.5-202.5	After
202.5-247.5	Left After
247.5-292.5	Left
292.5-337.5	Left Front
337.5-22.5	Front

Figure 4. Turning point's extraction principle.

In order to verify the extraction method of the turning point and turning direction, the 3D network of a building is selected to carry out shortest path planning experiments. Fig. 5 shows the extraction effect of the turning point in the shortest path. The larger square block on the path is used to mark the extracted turning point.

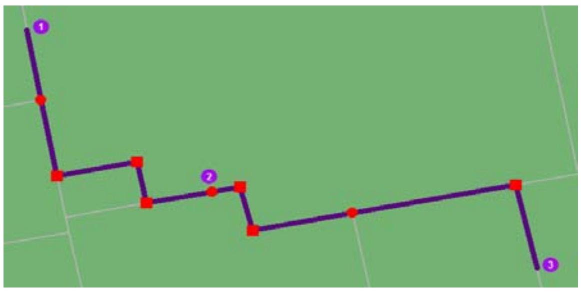


Figure 5. The path turning point extraction results.

E. Dynamic Presentation of the 3d Path

The principle of 3D path dynamic presentation is shown in Fig. 6. The thick line indicates the planned path. O, T(O') and T' represent points taken from the path. Dotted lines with arrows provide the line of sight. Dynamic presentation of the path is implemented through the continuous change of the position of points O and T under the control of the Timer component. The main steps are as follows:

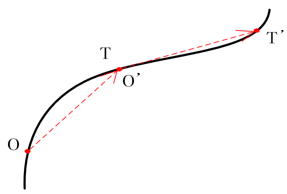


Figure 6. The principle diagram of the path dynamic demonstration.

1) Get the optimal path. The planning result layer can be obtained through the method get_Layer() of the interface IMap, and then it is added into the 3D scene to achieve the polyline representing the demo path. Before the start of the demonstration, a variable is declared to represent the distance from the initial position to the current position of the user. The demonstration is over when the walked distance is greater than the length of the polyline. That is, The user has already arrived at the end of the path.

2) Get points on the path. In order to get dynamic viewing parameters of the 3D scene, two adjacent points on the path are obtained through the method QueryPoint() of the interface IPolyline, which are respectively used as the observer position and the target position of the viewing camera.

3) Get the position of the user, which can be obtained according to the 2D building basemap. What and how the 2D window displays is determined by the position. If the position is outdoor, the 2D window shows the entire scope of the polyline. Otherwise, the 2D window shows the floor plan where the user is.

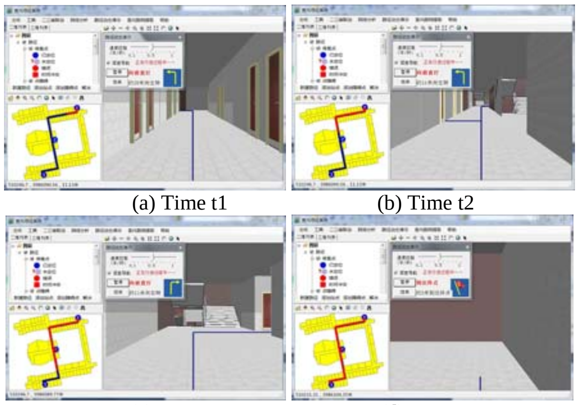
4) Get navigation information. The first turning point is taken from the turning point set TurnPoint, and then the distance is calculated between the turning point and the observer point. If the distance is more than 5 meters, the first line of the navigation text displays "straight ahead", the second row shows the turning direction and distance; if distance is less than 5 meters, the navigation text shows the turning direction. At the same time, voice prompts turning action. If the distance is less than 0.5 meters, the next turning point is retrieved from TurnPoint, and the above judgment is continued.

IV. System Applications

To test and verify the running effect of the system, the building of Geomatics College of Shandong University of Science and Technology is selected as an example. After reconstruction of the indoor scene and 3D path planning, the dynamic demonstration of indoor navigation is carried out. As shown in Fig. 7, the 2D window shows the current layer where the user is, in which the red part of the path has passed and the blue part is going to walk; the 3D window shows the current view of the indoor 3D scene. When the user walk indoor, the 2D window will show the different content according to the user's current position. If the user is outdoor, the 2D window shows the entire scope of the planned path. If the user is indoor, the 2D window only shows the floor plan where the user is. At the same time, the navigation window provides the user walking direction, turning direction, distance to the corner, etc in the way of text, image or voice.

V. Conclusion

Compared with the developed outdoor navigation system, the indoor navigation system is still in the initial research stage. This paper provides a preliminary study on the design and implementation of the indoor 3D routing and navigation system based on ArcEngine components, which implements the integrated display of the 2D and 3D scene, 3D optimal path planning, path dynamic demonstration and multi-mode navigation based on text, sound, graphics and other forms. Of course, with the gradual development and mature of the indoor positioning technology, to introduce real-time indoor positioning information into the navigation system will make it more practical. In addition, how to translate the system platform from PCs to smart phones, PDA and other portable mobile devices will be the focus of future research.



(a) Time t1 (b) Time t2

(c) Time t3 (d) Time t4

Figure 7. Indoor navigation in the three-dimensional scene.

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References

[1] J. Yan and X. S. Xu, "Design and experiment of SINS/GPS integrated navigation system," *Journal of computers*, vol. 8, no. 8, pp. 1973-1978, 2013.

[2] Z. Sun, "China is buliding a Xihe system to realize the indoor and outdoor high-precision positioning," 2012, http://news.ifeng.com/mil/2/detail_2012_10/09/18116409_0.shtml.

[3] M. Zhang, "Tourist attractions guide three-dimensional GIS design and development techniques," Southeast University, 2009.

[4] Y. Yu, M. Lu, D. Xu, et al, "Design and implementation of 3D virtual campus based on GIS," *Journal of Nanjing University of Information Science & Technology*, vol. 4, no. 1, pp. 81-85, 2012.

[5] L. N. Lan, X. R. Gou and Y. H. Xie, "Intelligent GSM cell coverage analysis system based on GIS," *Journal of computers*, vol. 6, no. 5, pp. 897-904, 2011.

[6] Q. L. Ma, W. N. Liu and D. H. Sun, "Hybrid multi-sensor data for traffic condition forecasting," *Journal of computers*, vol. 7, no. 8, pp. 1870-1879, 2012.

[7] N. Ding, Y. Sun, G. Hao, et al, "The research and application of 2D and 3D interactive system based on SketchUp and ArcEngine," *Science of Surveying and Mapping*, vol. 35, no. 5, pp. 183-184, 2010.

[8] D. Hong, W. Lun, W. Li, et al, "The design and implementation of 3 d virtual campus system," *Geospatial Information*, vol. 10, no. 1, pp. 84-87, 2012.
[9] U. Isikdag, S. Zlatanova and J. Underwood, "A BIM-oriented approach for facilitating indoor navigation," *Proceedings of 3D City Modelling & Applications and the 6th International 3D GeoInfo Conference*, Wuhan, 2011.
[10] F. Lamarche and S. Donikian, "Crowd of virtual humans: a new approach for real time navigation in complex and structured environments," *Computer Graphics Forum*, vol. 23, no. 3, pp. 509-518, 2004.
[11] E. Stoffel, B. Lorenz and H. Ohlbach, "Towards a semantic spatial model for pedestrian indoor navigation," *Proceedings of Advances in Conceptual Modeling*, pp. 328-337, Springer, 2007.
[12] J. Lee, "A three-dimensional navigable data model to support emergency response in microspatial built-environments," *Annals of the Association of American Geographers*, vol. 97, no. 3, pp. 512-529, 2007.
[13] J. Choi and J. Lee, "3D Geo-Network for Agent-based Building Evacuation Simulation," *3D Geo-Information Sciences*, Springer, pp. 283-299, 2009.
[14] J. Du, "Construction, planning and expression of 3D route graph for building," Beijing Jiaotong University, 2008.
[15] P. Han and Q.Wang, "Geographic information systems development: ArcEngine method," Wuhan University Press, pp. 396-400, 2008.
[16] D. Chang, B. Li and M. Zhang, "The chinese description of GIS path based on continuous polar coordinates," *Journal of Geomatics Science and Technology*, vol. 28, no. 4, pp. 307-312, 2011.

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