PATH PLANNING IN VIRTUAL MUSEUM BASED ON POLYGON’S VORONOI DIAGRAM

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Abstract

3D virtual museum is an environment where relics are displayed online and people can learn historical culture. How to design and select walkthrough paths to support users visiting the 3D virtual museum conveniently is an important problem to the system designer. This paper presents two methods of computing walkthrough path in the virtual museum, which are based on Voronoi diagram of polygon. Using our method, the user’s interaction becomes convenient and easy. If the user prefers to observe some special position of the museum, he can select the destination interactively, then the system will computes the walkthrough path that is along the polygon’s Voronoi skeleton automatically; if the user wants to browse the whole museum, then after the user has adjust the optical range, the system can compute the offset curves based on polygon’s Voronoi diagram as the walkthrough path. Methods mentioned above have been applied to the System of Digital Archaeological Museum of Shandong University, and also can be applied to other indoor virtual exhibition systems

Keywords: Virtual Museum; Path Planning; Voronoi Diagram; Offset lines

1. Introduction

In recent years, more and more digital museums are developed based on virtual reality, human-computer interaction and network as well as other computer technologies, to realize precious cultural resources sharing and protection. 18 universities have participated in the project of National Collegiate Digital Museum Project of China, and established 18 digital museums. In order to resolve the problem that the digital resources of these museums are isolated, heterogeneous, geographically distributed and difficult to be shared effectively, the successive project of University Digital Museum Grid (UDMGrid), an application of the MIPGRID is set up in 2004. Archaeological Digital Museum of Shandong University [1] is one important constituent of these projects. The digital museums allow users to retrieve the rich cultural resources including graphics, pictures, audio, video, text, 3D models and many other kinds of media information according to individual requirement. How to organize and present these rich resources by

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reasonable and convenient way and to improve the usability of cultural heritage resources is a key issue that needs to be considered when building a digital museum.

In a 3D virtual museum, how to set and select the walkthrough path properly so that the user can facilitate browsing and study is an important problem. If it cannot realize interaction conveniently and generating reasonable walkthrough path fast enough, the utilization of 3D virtual museum would be greatly limited.

Fig. 1 A typical indoor scene system with regular shape and controlled by the keyboard.

In traditional 3D scene, visitors usually can only choose the simplest browse mode that is using direction keys in keyboard or mouse to control the ongoing direction. To some spaces with standard shape such as rectangle, which can be divided into n line and n row, keyboard has great advantage to control the direction (see Fig. 1). While to some large-scale open spaces similar to our archaeology museum (see Fig. 2), such walkthrough method is unsuitable, because users cannot select the path freely, lacking of flexibility. Also in a big open space, merely depending upon the keyboard operation or the mouse towing, the browsing speed is somewhat slow and unable to realize long distance and large-scale adjustment. What’s more the interaction between users and the system is rather tedious. At present, there are some walkthrough methods based on interactive equipment, such as interactive walkthrough [2] based on hand signal (data glove), but the price is high. Some systems use fixed path method. Mostly the path is determined by sampling points automatically, lacking of users’ participation, so often cannot meet users’ various tour needs. Therefore, the problem of how to design and select the walkthrough path to support the user to visit the 3D virtual museum conveniently and adroitly is what this article mainly discussed.

In our museum, we devote to provide users one kind of real-time, nimble and convenient walkthrough method. Considering the creation, storage, visualization, interaction of the 3D virtual museum and so on, we design the 3D virtual museum based on polygon’s Voronoi diagram. Firstly, we realized cooperation design and data management system [3] in the virtual museum based on Voronoi diagram. This system supports fast scene building, flexible disposition of collections, and effective data management. Using this system, users can establish different subject exhibition to show different cultural relics based on different requirements. Take this as the foundation; we plan to make full use of the proximity and adjacency of Voronoi diagram, to solve the problems of path planning, visibility computing, and collision detection, shadow generating, illumination computing and so on. By this way we can improve the speed and
strengthen the real-time effect. The problem of path computing studied in this paper is just one part of the problems mentioned above.

The Voronoi diagram is a very important geometric structure and a significant research topic in computational geometry. A Voronoi diagram records the regions in the proximity of a set of generators (edges or concave vertices of a polygon). These regions called Voronoi region. Each Voronoi region corresponds to an edge or a concave vertex of the polygon, and points inside the Voronoi region are closest to this edge or concave (see Fig. 3). According to whether the Voronoi regions are adjacent, we can define the adjacent relationship between the generators of the Voronoi diagram. References [4]-[5] all referred to the shortest path problem in Voronoi diagram, which employ the Dijkstra Algorithm in common. Algorithm in [4] intends to find shortest path in the discrete points’ Voronoi diagram, while [5] mainly solves the shortest paths for Disc Obstacles. Although path computing in Reference [6] uses general Voronoi diagram theory, it considered too much machinery limits and dynamics factors, and its path is merely estimated path not very accurate. That is to say all methods mentioned above cannot be applied to our virtual museum indirectly.

Fig. 2 General interface of 3D virtual museum

Fig. 3 Voronoi diagram of a given polygon
This paper introduces two methods of generating walkthrough path based on Voronoi diagram theory in general polygon. One supports users to select the start and end point of the path interactively, and then the system generates the whole walkthrough path automatically, and the other offers users a offset path after users adjust the optical angle, so the users can browsing the whole museum along the walkthrough path.. The entire interactive process is concise and easy to operate, and the path produced by the system is quite flexible, may satisfy users different visit needs.

2. 3D virtual museum construction

In fact, if collections and people are not considered in virtual museum and art gallery, the empty 3D indoor scene can be projected to 2D, and then a polygon is gotten, we call the polygon as 2D map. Majority of indoor virtual scene integrated this kind of 2D map, to facility users to grasp the overall virtual scene, locate in the scene interactively, and control the advance indirection. Different from these virtual scenes, in our 3D virtual museum, you can see the polygon and its Voronoi diagram in the 2D map. The 3D room scene can be gotten through sweep operation on the polygon. The 2D map integrated polygon Voronoi diagram can make the interaction convenient. The virtual museum employed such method mentioned above supports multi-user to doing cooperate design, and realizes building the virtual scene fast, depositing collections flexible, managing data effectively, and enhances the design efficiency [2]. Also, using the proximity and adjacent of Voronoi diagram, path computing, visibility computing, collision detection, shadow building, illumination computing and so on can be easy implemented, so we can improve the speed of scene rendering and strengthen the real-time walkthrough effect.

Fig.2 shows the general interface of our 3D virtual museum. The left is various multi-media data, when design the scene, it records multi-media data currently researched preparing for the next dispose operation. After the scene is published, when user visits in it, the left preserves the multi-media data in the scene. The middle is 3D scene. The up of right is the text panel to show some text information; middle of right is the 2D map contains polygon’s Voronoi diagram; and in the downside of right is the picture or the 3D model of the current collection.

3. Path Computing

3.1. Voronoi skeleton path

The Voronoi diagram of a given polygon is showed in Figure1. Each edge or concave vertex of the polygon has its Voronoi region individual. When disposing the collection, each one lays on the edge of the polygon, so every collection belongs to a certain Voronoi region. Those Voronoi edges that are not connected with the polygon convex are called Voronoi skeleton (also called Middle axle). Voronoi skeleton separate the Voronoi region and also are the path, which must be taken from one Voronoi region to another. If the visitor wants to roam from the current position to the destination (in our system it is interactively assigned by the user), we may let he walk along the Voronoi skeleton, so during the walking he can also observe the collections on the two sides of the Voronoi skeleton. The main idea of our algorithm of path computing based on Voronoi diagram can be describe as follows: according to the adjacent relation between two Voronoi edges, we first build a path tree in advance; then after each re-location (selecting browsing start and end point), we search along the path tree to generate the walkthrough path composed by Voronoi skeletons.
3.1.1. Building adjacent matrix

Distinguished from any other graph searches, which regard points as basic elements, we regard Voronoi edges as the basic elements. For every basic element we give it a number (shows in Fig. 4) to present it and keep all the elements in order. See that, every Voronoi edge is adjacent to several Voronoi edges, so we can build an adjacent matrix like Fig. 5 shows, to record the adjacent relation between every two elements.

![Fig. 4 The preprocess of polygon Voronoi](image)

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![Fig. 5 The adjacent matrix corresponds to polygon showed in Fig. 4](image)

3.1.2. Building BFS tree

According to the information contained in adjacent matrix, we take out BFS search from the element 0, and build a data structure shapes like a tree (shows in Fig. 6) at the same time.

![Fig. 6 BFS tree corresponds to Fig. 5](image)
3.1.3. Generating the path

There is a distinctive path between any two Voronoi edges. When user selects the browsing end point using mouse dynamically, we compute and get the Voronoi region, which the browsing end point belongs to. At the same time, we may obtain the Voronoi edge that is nearest to the user, and the Voronoi edge that is nearest to the end point easily. Search along the BFS tree, we can get the final path consists of Voronoi skeletons (See the path notes with red lines in Fig. 7).

![Fig. 7 Walkthrough path along Voronoi skeleton](image)

This method of computing walkthrough path has good interaction, because visitor can select any point as the tour destination on the 2D map using mouse, then through searching along the BFS tree may get the walkthrough path consists of Voronoi skeletons. Since the polygon’s Voronoi diagram and the BFS tree is generated when the system generates the 3D scene, so after the user select the tour destination, system may search the BFS tree only once and get the final path; the whole search process can be accomplished in O (logn) time. The speed of generating path is relatively ideal. Fig. 8 attached behind shows the example situation of visiting along the Voronoi skeleton in our virtual museum. Green lines in Fig. 8 are the paths that generated by the algorithm corresponding to user’s current position.

![Fig. 8 (a) Walkthrough along Voronoi skeleton path in the museum](image)
3.2. Offset Path

In the traditional fixed path computing, the system often assigns one path to visit the whole scene in advance, all visitors carry on the tour along the same path. Although this method is easy to control by the system, it is unable to meet users various needs, because different collections in different distances may have different visual effects. Perhaps some users only want to see the collections at a relatively far distance, pursuing the overall effect, but some people are willing to have a short-distance to observe collections. In order to offer visitor to appreciate collections along the fixed path at one’s satisfied distance, this paper also introduces offset path, which is based on the offset curves of a polygon. The polygon’s offset curves are also computed based on the Voronoi diagram of a polygon. The give polygon’s offset curve shows in Fig. 9. It is series curves, produced based on the polygon Voronoi diagram, each offset curve maintains the polygon boundary original condition approximately, and also points on any given offset curve have same distance to the polygon boundary. Regardless what position of the user locates, near the boundary of the scene, or in the center of the scene, when he decides his observation distance, he may let the system generate the offset path. Through computing, we may obtain the Voronoi region that the user locates; then it is easy to compute the distance d between user and the boundary of the polygon. Take d as the parameter to compute the offset curve that is d far from the polygon boundary. Then the user can visit the scene along the offset curve. It is so convenient to users because during the browsing period, users may not adjust the advance direction by oneself completely; all adjusting operations are done by the system automatically.

In ours museum system, if the user wants to stop this kind of browsing, he may choose cancel this tour way at any time. Also he may choose suspending the browsing for a while, as well as adjust visiting speed according to one’s need. Figure 10 shows an example situation of visiting along the offset path in our virtual museum. Green lines in Fig. 10 are the offset paths corresponding to the user’s current position.
3.3. Location

Besides the two kinds of walkthrough paths based on Voronoi diagram mentioned above, our virtual museum also offers traditional keyboard control and mouse control to satisfy users various needs. By these methods users can adjust position and observe angle. Different from other systems, since our virtual museum is constructed based on Voronoi diagram, when users press some key in the keyboard or click the mouse, we may locate the operation scale to a certain Voronoi region, this localization may complete in $O(n)$ time. The advantage of localization lies in that we can locate the avatar’s position and send it to server, then the server updates the information in real-time, and does visibility computing, collision detection, and path computing if necessary. Then the server transmits this information to all users who are visiting at the same scene, to complete the cooperation between users.

4. Conclusions

3D virtual museum is an environment where relics are displayed and people can learn historical culture. So it plays a signify role in culture’s diffusion and cultural heritage’s protection. This paper introduces two algorithms for path computing based on polygon Voronoi diagram. Using these methods, users can visit the
3D virtual museum conveniently and facility. Also these methods are important applications of Voronoi diagram theory, base on which we can better solve the problems of visibility computing, collision detection, path computing, shadowing, and illumination computing. The work has already successfully applied to our digital museum system (http://211.86.49.180: 8088/museum/index/index1.jsp), and it also can be suitable for other indoor virtual scene systems.

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