Establishment of 3D Virtual Reality Model for Underground Pipeline Combining Hand Position and Shape Tracking Algorithm

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Abstract. With the development of the social economy, data in various fields are increasing exponentially but lacks practical data analysis and mining. In this paper, structural analysis and model simplification is performed on underground pipeline based on the hand position and shape tracking algorithm. The 3D modeling process of the pipeline using virtual reality (VR) is proposed, which has implemented the rapid modeling from 2D to 3D, and finally, rapid modeling and 3D visualization roaming of large-scene urban underground pipeline, providing support for the modeling of urban underground pipeline.

Keywords: Hand Position and Shape Tracking Algorithm, 3D Visualization, Virtual Reality (VR), Underground Pipeline

1. Introduction

With the development of society and the economy, data in various fields are growing exponentially. The vast amount of data and the lack of sufficient means to analyze and understand these data will undoubtedly cause significant difficulties in understanding the data. Massive data generated at a considerable cost is not fully utilized [1-2].

The virtual method based on model rendering is implemented by computer graphics. It first abstracts the real scene, constructs a 3D geometric model with polygons, and establishes lighting and material models in the virtual environment, and then performs texture mapping and control parameter settings to complete model establishment [3-4]. The modeling method has been applied for a long time. The technical path is relatively mature, and the actual application is relatively wide. Its advantages are: (1) Most virtual landscapes have accurate corresponding geometric models, which can obtain delicate and realistic scenes; (2) It is convenient for users Interaction with virtual objects in the virtual scene and direct acquisition of the depth information of the virtual objects; (3) Implementation of virtual objects, even in the planning and design stage, as long as there are relevant architectural drawings to complete the establishment of the scene according to the corresponding proportions and dimensions [5].
Currently, the implementation of VR systems researched at home and abroad is mainly divided into three modeling methods based on the method of virtual scene establishment: model-based rendering method (MBR), image-based rendering method (IBR), and graphics and hybrid modeling method based on graph and image blending. In the image-based virtual modeling method, discrete images collected by a camera or continuous video collected by a camera are used as basic data to generate a real panoramic image through image processing [6].

In this paper, structural analysis and model simplification is performed on underground pipeline based on the hand position and shape tracking algorithm. The 3D modeling process of the pipeline using virtual reality (VR) is proposed to explore the path and scheme for 3D modeling of the urban underground pipeline.

2. Hand Position and Shape Tracking Algorithm

The automatic detection of hand shape during movement is an essential technology in the field of computer vision. Excellent hand shape detection algorithm should have the following three characteristics:

(1) The algorithm has high accuracy, which is the top priority of the algorithm. Whether the moving target can be automatically detected and the quality of the detection result is the greatest concern. A good detection algorithm needs to have low false detection and leakage, which can accurately extract target information;

(2) The algorithm has low computational complexity, while an excellent detection algorithm requires short running time and real-time calculation process;

(3) The algorithm has broad applicability. However complicated the environment is, the detection algorithm can run stably and has high anti-interference ability.

The general flow of hand shape detection is shown in Figure 1. An image is taken as input and subject to a series of image preprocessing processes such as grayscale and equalization, the image is scaled in sequence at a certain ratio, and then the classifier is trained in advance. The detection processing is performed. 20*20 sub-windows in the image are used to scan the image sequentially, determine whether it is a hand shape, and mark the position and size of the hand shape.

![Figure 1. Flow chart of hand shape detection](image)

The specific implementation process on the OpenCV platform is as follows: Firstly, the cascade classifier trained in advance is loaded through the CascadeClassifier class member function load in OpenCV. Subsequently, the video frame is read from the video file to obtain the grayscale through grayscale processing. After the histogram equalization process, the next step is the process of detecting hand shape. The CascadeClassifier class member function detectMultiScale function in OpenCV is called. Its primary function is to detect targets of different sizes in the input video image frame, and obtain the rectangular box vector group of the target to be detected. Finally, the target is placed in the video frame by the graphical method. The position and size in the image are displayed. After a series of image preprocessing, the video frame images captured by the camera are sent to the hand shape detection module. The shape of the hand to be tracked is extracted to obtain the rectangular area where the hand shape is located, and then transmits the rectangular area information to the tracking module. The TLD and Kalman equations of the tracking part are used to implement the automatic initialization of the tracking target during the TLD tracking process, and manual marking of the area to be tracked is not required.
3. Analysis and Simplification of Pipeline Model
There are many types of actual pipelines and their structures are intricate. The most acceptable method is to classify them according to the nature of their use. In general, the whole pipeline system can be divided into: water supply pipeline, drainage pipeline, and gas supply pipeline, heating pipeline, rainwater pipeline, power supply pipeline and other major categories. In the pipeline plan, looking at a certain type of pipeline, its pipeline object is represented by its center line, and a single-segment pipeline is shown as a straight line on the graph. From the perspective of the specific establishment process, the pipeline is a group of a series of standard pipe fittings and straight pipe sections of different lengths related in a certain spatial order and orientation. The 3D model of the pipeline is a reproduction of the real pipeline. The pipeline model mainly includes three components: pipelines, pipe-pipe connections, and rendering effects such as the texture and material of the pipeline. The establishment of the pipeline model should start from these three aspects.

Most of the pipelines of the pipeline are cylindrical or truncated pipes. In order to achieve rapid modeling, the pipeline part is simplified as a standard round pipe, and its spatial geometric properties are determined by parameters such as position (3D coordinates), pipe diameter, length, and wall thickness. Among them, in the VR 3D visualization modeling process, the thickness of the pipe wall is not considered, which is regarded as a thin-walled cylindrical geometry. For the special case model that needs to consider the thickness of the pipe wall, the inner diameter and outer diameter of the pipeline can be simplified and concentric. Cylindrical surface is created by double pipeline modeling.

The method adopted in this paper requires that the complexity of model connectors be simplified without affecting the analysis and use of the model, and the pipeline can be automatically connected, including elbows, tees, crosses and other non-standard connectors at any angle, which is not subject to the limitation of the model database and suitable for automatic modeling of multi-category, multi-level, non-standard large scenes. The main purpose of 3D pipeline modeling is not to reflect the details of the pipeline connection, but to provide a complete 3D model of the pipeline for analysis. Hence, for the connection of the pipeline, the original connectors are simplified, and the adjacent pipelines are directly connected.

Various pipelines have different materials and textures. In the simulation process of VR 3D pipelines, various colors can be used to distinguish different pipelines. However, to increase the realistic effects, such as the intuitive difference between metal pipelines and cement pipelines, we should further add texture and material selection to the pipelines. Although the pipelines are buried underground, there is no lighting problem, the actual observation should be equipped with lighting. For the realism of the pipeline model, the lighting effects are also introduced during the modeling process for coloring.

4. Establishment of VR Underground 3D Model
Currently, the data sources of urban underground pipelines mainly include three forms of surveying and mapping data, pipeline paper blueprints and CAD files, and the automatic modeling implementation technology research is carried out on these three situations.

4.1. Automatic Modeling Based On Surveying and Mapping Data
After large-scale investment and establishment in recent years, many cities have established GIS-based 2D underground pipeline management information systems and put them into use, and collected the city’s underground pipeline information through surveying and mapping. How to do without duplication of investment and establishment, it is an urgent problem to quickly convert the existing 2D underground pipeline data into a 3D underground pipeline model.

By collecting and converting the coordinates, pipe diameter, material and other information of the pipeline in the existing underground pipeline management information system database, a model database is constructed, and a 3D underground pipeline is generated from the model database. The model database structure is shown in Table 1.
Table 1. Horizontal database structure table

| Pipeline section number | Starting point coordinate X | Starting point coordinate Y | Starting point coordinate Z | End point coordinate X | End point coordinate Y | End point coordinate Z | Pipe diameter | Material information | Pipeline category identification code |
|-------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------|-----------------------|-----------------------|---------------|---------------------|--------------------------------------|
| INT                     | Float                       | Float                       | Float                       | Float                  | Float                  | Float                  | Float         | Char                | Char                                 |

Based on the pipeline category, the system starts with the initial pipeline, reads records one by one, and continuously generates pipelines, including:

1. The location of the pipeline is determined based on the detailed pipeline centerline coordinate information and the size of the pipe diameter, and calculate the angle of the pipeline from the start and end coordinates to generate the pipeline.
2. The pipeline connection model is generated based on the connection of each pipeline connection, such as elbows, tees, crosses, and other information.
3. The material and texture mapping to the pipeline are assigned according to information data to perform the color processing.

4.2. Automatic Modeling Based On Drawing Data

Many old urban areas only have paper blueprints saved in the early stage, without CAD files and collected information databases. In this regard, this paper proposes a method for tree expansion of pipeline nodes. The nodes of the pipeline are numbered one by one. All nodes of the pipeline are traversed, and a relational database between connected nodes is established (see Table 2).

Given the coordinate value of the starting point of the pipeline centerline, the program calculates the coordinate value of each connection point in turn according to the connection relationship database between the pipeline points. The whole pipeline database is gradually traversed to generate the pipeline model and the node coordinate database of the pipeline. The connection between the pipelines (elbows, tees, etc.) is determined based on the number of connected pipeline points corresponding to the current point. The corresponding generation program is called to build the pipeline connection model.

Table 2. Node relational database structure table

| Pipeline point index value | Connect point index value | Length h1 | Pipe diameter 1 | Angle 1 | Link 2 index value | Length h2 | Pipe diameter 2 | Angle 2 | … | Coordinate value (X/Y/Z) |
|----------------------------|---------------------------|-----------|----------------|---------|--------------------|-----------|----------------|---------|---|--------------------------|
| INT                        | INT                       | Float     | Float          | Float   | INT                | Float     | Float          | Float   | … | Float                    |

The pipeline number is shown in Figure 2 (dimensions are omitted), traverse to generate a database.

Figure 2. Pipeline numbering diagram

Drawings are materials that save more and relatively complete underground pipeline information. Generate a model database from the drawings, and then build a 3D underground pipeline model. For a 3D underground pipeline, it can make full use of existing data and reduce the huge data collection.
work. The establishment of a 3D underground pipeline in the old city has important practical significance.

4.3. Automatic Modeling Based On DXF Files
With the development of this information technology, computer-aided design (CAD) software is commonly used in pipeline design, which can directly read CAD format files and generate 3D pipelines, which is of great significance for the visualization of urban underground pipelines. Because DXF is AutoCAD The drawing interchange format is widely supported by other CAD programs and has become the de facto international general graphics data exchange standard. Hence, the DXF file of the pipeline distribution map is read for rapid 3D modeling of the pipeline. The modeling of surveying and mapping data is similar, and the process is:

(1) The name of each layer in the DXF file corresponds to the underground pipeline category identification code. The DXF file is accessed, the start point and end point coordinate value data of each layer line segment are read in turn as the centerline coordinates of the pipeline, and written after numbering into the database pipeline temporary information table according to the pipeline category. The corresponding pipeline additional information table is called, and the corresponding additional information such as pipe diameter, material, and texture is imported to generate a complete pipeline information data table;

(2) Read the pipeline information table, and use the quadrilateral fitting method to generate a 3D pipeline model from the start and end coordinates of each pipeline section, and the pipe diameter value;

(3) Traverse the start and end coordinates of the pipeline information table, calculate the number of pipelines at each connection point, determine the connection of the pipeline, including the elbow, tee, four, etc., and call the corresponding pipeline connection program. Complete the generation of the connection port of the pipeline 3D model and establish the entire 3D pipeline model.

As the current mainstream 3D visual development tool Vega Prime is fully compatible with Creator, the Flt model of above-ground buildings, the Flt model of underground rock formations, and the Flt model of pipeline can be introduced into the system, which can implement the common use of other models such as above-ground buildings, strata, underground pipelines, etc. hence, Vega Prime is selected as the scene roaming development software. Vega Prime is a cross-platform real-time tool built on the VSG framework. It is an extended API of VSG, including a graphical user interface Lynx and a series of callable programs, using C# implemented database files and header files. Vega Prime provides a complete C# language application interface API, with a wealth of practical database functions and many functional modules, which can create an efficient virtual environment.

Starting with the characteristics of the scene and the convenience and speed of user roaming, two roaming modes of manual roaming and automatic roaming are set to meet different roaming requirements.

(1) Manual roaming refers to using the mouse and keyboard as input methods to control roaming. The default vpMotionDrive method is used to move. Click the left mouse button to move forward, the right mouse button to go back, and the middle mouse button to stop the movement. The left and right swings of the mouse controls the rotation of the viewpoint. The vp(observer) class represents the camera, and the keyboard can be used as an input method to control roaming. It has six degrees of freedom and assigns the motion mode to vpObserver. Thus, the camera can perform movements such as translation and rotation, and the scene will change as the position of the camera changes.

(2) Automatic roaming refers to using the user-defined exercise mode provided by Vega Prime. Through vpPath and vpNavigator, the scene can be roam according to the specified path. A path is a set of preset spatial control scraping points, and navigator is a set Interrelated control points defined in Path, a set of specific Navigator can act on these data structures on the controlled object. Each control point contains six degrees of freedom, which controls the 3D space coordinates of the control point and Orientation, turning angle and inclination. Every two control points form a path and direction. The control points and navigation lines are set through the API functions vpPathWayPointSet and

\[ \text{vpPathWayPointSet} \]
vpPathNavigator in VegaPrime, and the scene is set to the automatic roaming state through the setStrategy method of the camera. It is possible to switch between automatic roaming and manual roaming.

5. Conclusions
The underground spatial information is developed slowlier than that of the above-ground one. However, the layout of vital livelihood facilities in urban construction is an essential guarantee for urban development. In this paper, 3D model is established based on the hand shape tracking algorithm using VR technology and simplified through underground pipeline model analysis, which has implemented the rapid modeling from 2D to 3D, providing support for the modeling of urban underground pipeline.

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