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3D visualization of urban underground pipelines by using SuperMap

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Abstract. For the complicated structure and spatial relationship of urban underground pipelines, it's necessary to employ 3D visualization technology in pipeline management and maintenance. It's not efficient to use 3D modelling software such as 3DS MAX in building a large range scene, and it's difficult and cumbersome to develop the functionalities for 3D visualization of urban underground pipelines from scratch by using the programming APIs such as OpenGL and DirectX3D. In this paper, based on the 3D visualization controls and interfaces by SuperMap, an adaptive method is proposed for building 3D models of urban underground pipeline network. At first, the detailed models of the pipe points and pipe segments are designed by 3DS MAX and imported as map symbols into a SuperMap Symbol library. Then the whole pipeline network is loaded and transformed into a 3D scene by using SuperMap interfaces. Moreover, the 3D models of the ground objects such as buildings are cached in OSGB format, and rendered with underground pipelines to support interactive queries and some professional analysis.

1. Introduction

In recent years, with the development and construction of urban underground utilities in China, current management techniques have become increasingly difficult to meet the demand in this field. Nowadays, 2D maps are still used as a method to support the operations of urban underground pipelines, such as repair, renewal and maintenance, while it's difficult to illustrate spatial relationship among various pipelines[1-3]. Recently 3D visualization technology begins to be a new choice for the management of urban underground utilities for its capability to clearly show the sophisticated spatial relationship of underground pipelines, cables, and tunnels[4]. A common method to build 3D models of urban underground utilities is to use 3D modeling software such as 3DS MAX, Autodesk Maya. However, it's time-consuming and requires quite a large storage volume to store the data of the 3D models of the underground utilities. As the main concern of most management agencies is the spatial locations and attributes of pipe points and pipe segments, some research such as (Lai Chengfang, 2013)[5], (Zhang Zhihua, 2010)[6], and (Sun Zhongzhao, 2009)[7], have been conducted to develop the 3D visualization programs of underground pipelines by using OpenGL, DirectX3D and other 3D



programming interfaces. In[6], to seamlessly depict the intersection of underground tunnels, a symmetrical modeling method is proposed to divide the tunnels along the central line into left and right halves at the intersections and assemble them according to the spatial relationships of these intersected tunnels. [7] and some other researches focus on the modeling of pipe sections, pipeline intersection and smoothing of turning. With the above two methods, the 3D pipeline network models can be built in an intuitive and realistic way, but it's difficult and not efficient in modeling. In large-scale pipelines applications, modeling is often done by using GIS software packages such as Esri ArcGIS[8], Skyline Terrasuite[9] and SuperMap[10], as they have provided components that support 3D visualization of underground pipelines, and application program interfaces(APIs) for developing programs according to end-users' requirements. In this way, 3D symbols of pipeline network components are necessary to render pipe segments and points in 3D space, and some adaptive rendering parameters should be used to seamlessly fit the point and line symbols together.

In this paper, the point and line symbols for the pipe points and segments are modeled by using 3DS MAX, then imported as map symbols into a SuperMap symbol library. Moreover, some parameters such as line width, height pattern, buried depth, coordinates and rotation angle, are chosen as the adaptive rendering parameters as they are crucial to render the pipeline network objects in vector format into a 3D scene with SuperMap' APIs. To speed up visualization of 3D pipeline networks, the 3D models of pipeline network and the ground objects such as building are cached in OSGB format. A pilot application has been developed to support 3D visualization and spatial analyses of pipeline network.

2. Massive and adaptive modelling of 3D pipeline network

The so-called adaptive modeling method is to automatically adjust the size, shape and position of a 3D model according to some adaptive rendering parameters, when the model is rendered. In order to realize adaptive modeling, it's necessary to build a symbol library of 3D pipeline network, in which each symbol is a 3D model of a pipeline component and has some adaptive rendering parameters.

2.1. The framework for massive and adaptive modeling

In this study, the adaptive modeling of 3D pipeline network is implemented by using SuperMap' APIs and C# language. Different from building a large-scale 3D scene by using modeling software such as 3DS MAX, with adaptive modeling a large number of pipe segments and points can be rendered in 3D scene by using their detailed symbols and setting the adaptive rendering parameters for them. The detailed process is shown in figure 1.

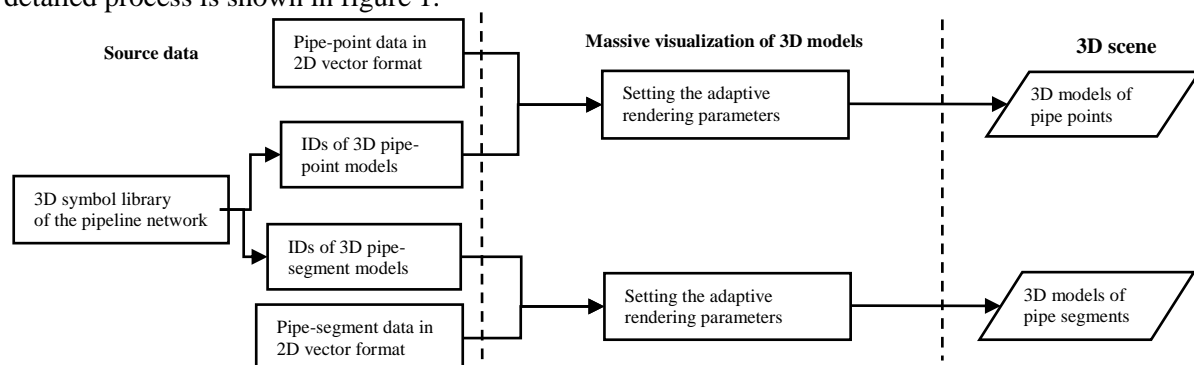


Figure 1. The adaptive modelling process of 3D pipeline network.

2.2. Adaptive rendering parameters for a pipeline network model

Urban underground pipelines include pipelines for water supply, drainage, gas, heat, electricity, communication, television, industry and pipe gallery. In the industrial standards of urban underground utilities, a pipe point mainly has the following attributes: ID, type, spatial location, bottom depth, and so on. A pipe segment mainly has the following attributes: ID, type, starting point number, end point

number, material, flow direction, size. In the rendering process, the appearance of a pipe point or a pipeline can be changed by changing the values of the adaptive rendering parameters. The rendering parameters for a pipe point and a pipe segment are listed in Table 1 and Table 2 respectively.

In Table 1, SymbolID is the ID of the 3D pipe segment symbol, LineColor and LineWidth are the surface color and size of pipe segments, respectively. BottomAltitude is the buried depth of a pipe segment, and AltitudeMode indicates whether a pipe segment is distributed underground or not. In Table 2, SymbolID is the ID of the 3D pipe point symbol. RotationX, RotationY, RotationZ are the connecting angles between the pipe points and pipe segments, ScaleX, ScaleY, ScaleZ are the scale of pipe points.

Table 1. Adaptive rendering parameters of pipe segments.

Index	Field name	Type	Remark
1	SymbolID	Int32	3D model IDs
2	LineColor	Char	Line color
3	LineWidth	Double	Line width
4	BottomAltitude	Double	Buried depth
5	AltitudeMode	Int32	Height pattern

Table 2. Adaptive rendering parameters of pipe points.

Index	Field name	Type	Remark	Index	Field name	Type	Remark
1	SymbolID	Int32	3D model IDs	7	ScaleZ	Double	Scaling multiplier around Z axis
2	RotationX	Double	Rotation angle around X axis	8	X	Double	X coordinate
3	RotationY	Double	Rotation angle around Y axis	9	Y	Double	Y coordinate
4	RotationZ	Double	Rotation angle around Z axis	10	Z	Double	Z coordinate
5	ScaleX	Double	Scaling factor along X axis	11	BottomAltitude	Double	Buried depth
6	ScaleY	Double	Scaling factor along Y axis	12	AltitudeMode	Int32	Height Mode

2.3. Building the 3D symbol library for a pipeline network

The refined 3D model of pipeline network can better illustrate the detailed pipeline network components and their spatial relationship [11-12]. In this paper, 3DS MAX and SuperMap are used to build a symbol library of 3D pipeline networks. The 3D models of the pipe points and pipe segments are classified according to their usages. Moreover, developers can choose corresponding symbols from the symbol library to render the pipe points or pipe segments. The detailed process consists of three steps, as shown in figure 2.

(1) Although pipe segments may have different geometrical shapes, most of them are cylindrical. In order to improve visualization speed, in this study all pipe segments are simplified as cylindrical. When using 3DS MAX to build 3D models of pipe segments, the tubular body are created by inputting the values of thickness and diameter of pipe segments. Moreover, the tubular body of a pipe segment is built by changing the value of its height and rendered with material texture.

(2) The size and type of pipe points are determined according to the industry standards of urban underground utilities. When using 3DS MAX to build 3D models of pipe points, these 3D point models are built by modifying the parameters such as length, width and height, and setting material

texture. The pipeline joints include straight-through joints, bends, tees, cross pipe etc. The rotation angle and magnification of these pipeline joints are calculated according to some attributes such as their flow directions and sizes, so that they can be correctly connected with pipe segments.

(3) After the 3D models of pipelines are built by using 3DS MAX, they are saved in SGM files by using a plug-in for 3DS MAX, and they are imported to SuperMap and saved in SYM files as pipe-point symbols and pipe-segment symbols.

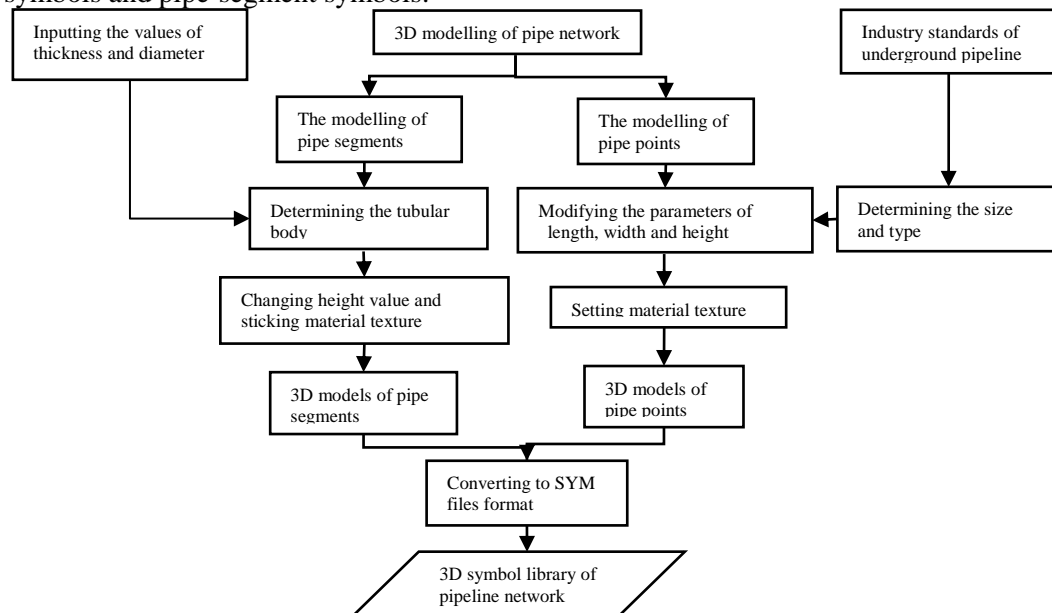


Figure 2. The diagram of building a 3D pipeline network symbol library.

3. 3D visualization of underground pipelines using SuperMap

In this study, the symbolic configuration method is used to visualize the pipeline network by using SuperMap Desktop. Moreover, the cache in OSGB format is used to optimize the visualization of the ground building models.

3.1. Symbolic configuration of pipeline network models

The symbolic configuration of pipeline network is used to match between vector data of pipeline network and rendering parameters such as pipeline model ID, scaling ratio, rotation angle by using SuperMap' APIs, and the pipe segments and points are rendered in 3D scene. The detailed process consists of two steps.

A pipeline can be rendered by setting the parameters such as line width, line color, height mode, buried depth. SymbolID is used to search for the corresponding 3D model of a pipe type.

The feature points, wells and ancillary facilities, are rendered as pipe points. The rendering process includes two cases. Firstly, feature points such as elbows, three-way joints, four-way joints, multi-way joints, do not have a fixed shape, for example a three-way joint is not vertically connected to a pipe section. In this study, the parameters such as rotation angle are read by using NetworkBuilder3D.BuildNetwork method in the SuperMap API, to build the 3D models of the joints between pipeline segments and feature points. Moreover, the 3D network model is automatically connected to the pipe sections and corresponding feature points according to the spatial topological relationships. Secondly, pipe points such as square wells, round wells, rain grates and valves, water meters, fire hydrants, and ancillary facilities, are not connected to the pipe sections. So it is not necessary to connect them with each other. Only the parameters such as coordinates and scaling ratio are needed to render 3D ancillary facilities. Moreover, because the size and depth of a well are different, so its bottom depth are needed when rendering.

3.2. *Rendering pipe-networks with SuperMap' APIs*

The 2D vector data of pipeline network are rendered in 3D scene by using SuperMap' APIs. The rendering process consists of two steps.

(1) Parsing and loading 2D pipeline network vector data. In practice, these data are stored in SuperMap SMWU files. Firstly, a SMWU workspace is created by calling `Workspace.Open` method. Secondly, these data are attached to the workspace by setting connection parameters. Finally, the pipeline objects are loaded into a recordset by calling `DatasetVector.GetRecordset` method. Moreover, the rendering parameters such as `SymbolID` and buried depth are obtained by using `FieldInfo` interface.

(2) 3D visualization of the pipeline network. Firstly, a 3D layer is created by calling `Layer.CreateLayer` method. Secondly, according to the rendering parameters in (1), the 2D vector data of the pipeline network is loaded into the `SceneControl`.

3.3. *The optimization for models of ground buildings*

Rendering the models of ground buildings in the `SceneControl` may require massive amounts of memory, which may seriously slowdown the rendering operation. It's necessary to improve visualization effect by reducing the complexity in the scene. Therefore, here a cache-based method is used to reduce computations in the rendering process.

The models of ground buildings are cached in OSGB format by using SuperMap Desktop. The optimization parameters such as LOD layer number, tile width, image partition method, and filtering threshold, are required when generating the cache files. The configuration of the cache is saved in a SCP file, which is located in the path of the cache files. The ground buildings and the pipeline network can be rendered together with better visualization effect.

4. **Application example**

In this study, a management system of 3D pipeline is built by using SuperMap, Visual Studio, SQL Server, DevExpress to implement the 3D spatial functions, such as burst analysis, excavation analysis.

4.1. *The integrated visualization of 3D scene*

Not only are the urban underground utilities, but also the ground objects are rendered in the 3D scene[15]. The ground objects include ground buildings, trees, terrain surfaces, and so on. The 3D visualization effect is shown in figure 3. Figure 4 shows the integrated visualization of ground objects and underground pipeline networks.

(1) ground objects are modelled by using 3DS MAX. In this paper, based on the topographic map of the Guilin University of Technology (Yanshan campus), the outlines of the above-ground buildings are stretched into cubic models.

The pictures of the ground buildings are rectified by using Photoshop, and attached to the building models as texture. At the same time, the above models are imported into SuperMap by using SuperMap Max Plugin, and transformed into the model data sets. After that, these data sets are loaded into the 3D scene according to their spatial coordinates and elevations.

The other ground objects, such as roads, trees and rivers, are also 3D MAX, and attached with their textures. They are loaded into SuperMap in the way mentioned above.

(2) Visualization of digital elevation model (DEM) and Digital Orth photo Image (DOM). The 19th level satellite image of Guilin University of Technology (Yanshan campus) was acquired by using Google Earth. After being rectified and restructured, these images were imported into SuperMap as raster images.



Figure 3. 3D visualization of ground features.

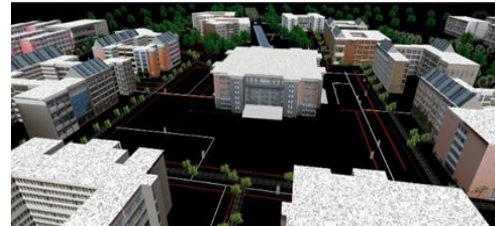


Figure 4. Integrated 3D visualization of above ground objects and underground pipeline networks.

4.2. The cache in OSGB format based on LOD

The 3D scenes built without using OSGB cache is shown in Fig. 5 (a), while the 3D scenes built by using OSGB cache is shown in Fig. 5 (b). Our test shows that it's more effective to render the above-ground building models by using OSGB cache. Moreover, the "white edge" effect is appeared as a result of lack of textures around the building when rendering without cache.



Figure 5(a). 3D scenes rendered by using OSGB cache.



Figure 5(b). 3D scenes rendered by using OSGB cache.

4.3. The spatial analysis based on 3D pipeline network model

In this paper, the 3D layers of pipeline network are created by using SuperMap' APIs, and these layers has attached the object-related attributes to support the pipeline management functionalities, such as burst analysis and excavation analysis.

(1) Burst analysis can simulate an emergency situation when an area is affected by a broken pipe segment, to provide decision-support for emergency response. The function is designed based on FacilityAnalysisResult3D class. After users select an accident point in the scene, the system can display the relevant valve IDs and affected pipe segment IDs in a 2D table. Moreover, the accident point is highlighted by using 3D animation. The burst analysis is shown in figure 6.

(2) Excavation analysis can display the pipelines and their ancillary facilities underground when an area to be excavated is specified in the scene. The function is designed with GeoRegion3D class. Users can specify an excavation area by drawing a polygon in the scene, and the system will calculate the total volume of excavation body according to the depth and shape of excavation. The excavation analysis is shown in figure 7.

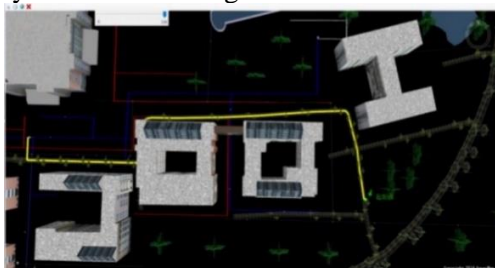


Figure 6. Burst analysis.

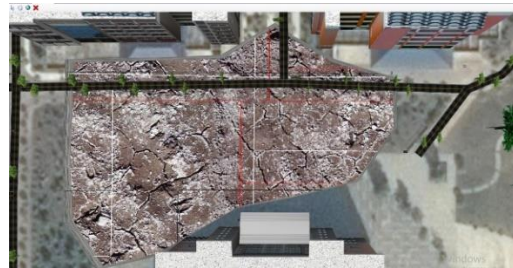


Figure 7. Excavation analysis.

5. Conclusion

In this paper, an adaptive modeling method based on SuperMap is used for the visualization of urban underground utilities. The method has high efficiency in 3D visualization effect, and it can not only realize the massive and fast dynamic modeling, but also support the integration of 3D pipeline network models and ground objects. The OSGB cache can reduce the amount of real-time rendered data, and also can improve the simulation effect of ground buildings models. A 3D management system of urban underground pipeline, with spatial analysis functionalities, has been developed to support pipeline management tasks.

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