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Design and Implementation of 3D Urban Underground Pipe Network System

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Abstract. For the sophisticated spatial relationships of the urban underground pipeline networks, 3D visualization technology has become widely used for management and maintenance purposes of these types of underground utilities. With the increasing number of pipeline incidents, there is an urgent need for effective solutions for improving the management of urban underground pipe networks. In this paper, through a thorough analysis of the pipeline network management, a 3D urban underground pipe network system (3D UUPNS) was designed and implemented by using SuperMap.Net. The 3D models of the pipeline network and ground buildings are rendered by using SuperMap RealSpace Library, with 3D models of ground buildings being cached into OSGB format. Some analysis functions such as excavation analysis and section analysis, have been developed to support the management and operations of underground pipelines.
Keywords: Urban Pipeline network; 3D visualization; LOD

1. General Instructions

Urban underground utilities, such as lines for telecommunication, electricity distribution, natural gas, cable television, fiber optics, storm drains, water mains, and wastewater pipes, etc., are of great importance to the survival and development of a city, so are called as cities' "life lines" [1]. With its rapid urbanization process, nowadays China is confronted with more and more problems and challenges in underground utility management [1,2]. Underground utility accidents such as leakage, rupture, and explosion, frequently happen in China [2], which cause serious damage and loss to urban residents. On the other hand, the operations of urban utilities such as repair, renewal, maintenance, also result in problems such as traffic inconvenience. In 2013, the oil leakage and exploration of the Sinopec's pipeline in Qingdao, caused 62 deaths and 136 injuries, and direct economic loss of 752 million yuan (RMB) [3]. Underground utility management has become an important task of government departments.

Since the beginning of this century, geographic information system (GIS) has been employed in underground pipeline management. But at first, those systems were built with 2D GIS, it is difficult to directly express the complex spatial relationships of pipeline in 2D space, therefore some methods such as annotation and 2D perspective are used to enhance representation of those spatial relationships. In recent years, with the advent of 3D GIS technology, domestic software such as MapGIS and some foreign software such as ESRI CityEngine [4,5], Skyline [6-8] have been well applied in underground utility management. However, there are technical bottlenecks in Skyline and other platforms. For example, when expressing a 3D visualization space, a 3D model of 2D vector pipeline data is constructed in real time by the rendering algorithm, and the pipe point model and the ground building models are loaded in the way of reading. When the system adopts such a 3D visualization method, problems such as distortion of model detail expression, poor display efficiency and simple spatial analysis ability will appear in the expression of 3D multivariate data [9]. In order to improve the expression and application effect of 3D models, it is necessary to use other 3D visualization expression method to solve the abovementioned problems. With the rapid development of oblique photography, the OSGB models are gradually being applied to large-scale city modeling [10,11], geological disaster monitoring [12], copyright protection [13] and other fields. At present, in the development of 3D underground pipe network system using OSGB model as the basis of 3D visual expression, OSGB model is mainly used for interactive browsing of users and less involved in professional space analysis.

This paper proposes to use the OSGB models and the detail models to join the scene LOD operation to realize multi-scale expression of multivariate data when 3D visualization of urban buildings and underground pipe network. And proposes the integrated management of the 2D data and 3D models of the underground pipe network, establishes the data organization to improving the application analysis capability of the system to the underground space pipe network.

2. Requirement Analysis and Function Design

2.1. Requirement Analysis

The management of urban underground pipe network can be divided into four parts: daily management, data query, information statistics and spatial analysis.

(1) The daily management of pipe network focuses on the update of pipe network data. The main work includes sorting out the pipe network report submitted by various departments, inspecting the potential safety hazards of the pipeline, updating the pipeline information and maintaining the database in time;

(2) The data query requires the system to quickly find out and locate the spatial information in a large number of underground pipe network data;

(3) The purpose of information statistics is to visualize the information and dynamically mark the information of underground pipe network in the system. Finally, the statistical results are summarized by statistical charts;

(4) In order to make full use of the value of underground pipe network information, the management department divided the spatial analysis function into two aspects: accident analysis and scene analysis. Accident analysis focuses on providing the solution to the underground pipe network accidents caused by engineering excavation and the pipeline installation; 3D spatial analysis needs to analyze the pipelines, and grasp the spatial relationship between pipelines.

2.2. Modules of Software Framework

Based on the abovementioned requirements of urban management departments, the functionalities of the 3D UUPNS can be classified into four modules: Data Processing, Information Query, 3D Spatial Analysis and Statistics, as shown in Figure 1.

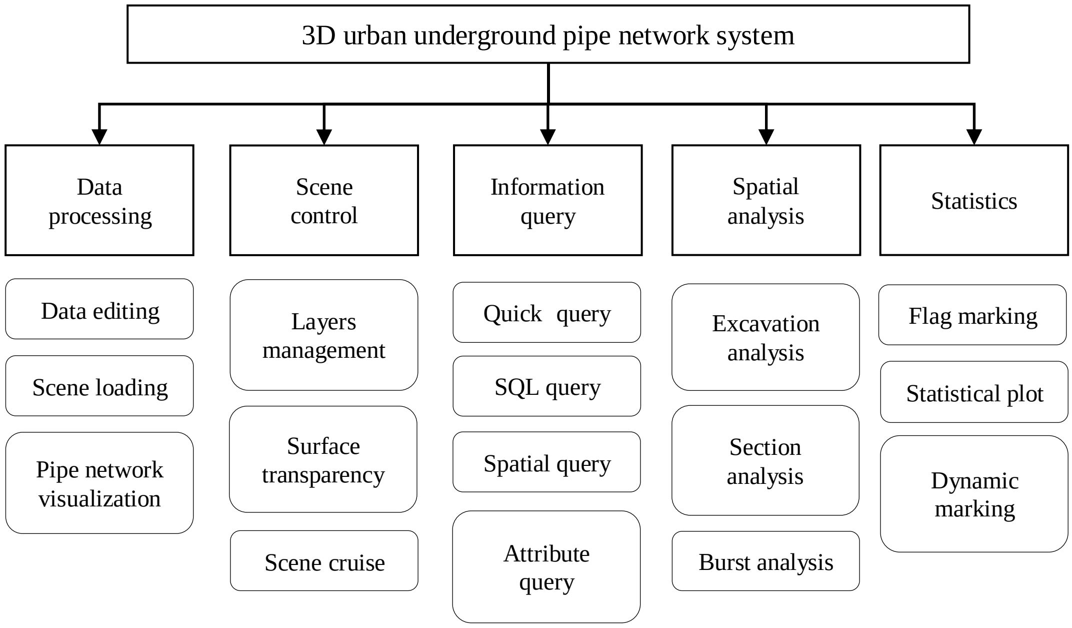

Figure 1. System Module Design

(1) Data processing module: System loads the ground OSGB models and the building detail model by using SuperMap Data Library. The users can add, delete, modify, etc. the 2D data of underground pipelines and pipe points in the system.

(2) Information query module: The system has three different information query modes: attribute query, spatial query and SQL query. The attribute query searches the spatial information according to the attribute field, and the spatial query queries the entity within the graphic range according to the user drawing graphic, SQL query is an advanced query function for the database. All query results are displayed as a list below the system interface.

(3) 3D spatial analysis module: This module contains a series of analysis functions such as 3D space measurement, excavation analysis and burst analysis, etc. 3D spatial measurement allows users to measure spatial distance and length of inter-elements in the scene. The function of excavation analysis is used to calculate the influence of excavation on underground pipelines, and simulates the excavation range and depth in the scene. According to the position of the burst pipelines, burst analysis can calculate the valve that should be closed and provide the shortest route to handle the accident.

(4) Statistics module: By tabulating data of the length, material and diameter required by the user, the statistical function could display this information in the form of a statistical chart in the system. The mark function allows the user to mark information directly next to the selected pipeline in the 3D scene, and dynamically changes the location of the tag information following the movement of the display area, which is convenient for the user to check pipeline information.

2.3. Database Design

Through analysis the characteristic of buildings and underground pipe network, this paper designs the UML model of underground pipe network, as shown in Figure 2. Underground objects include pipelines, pipe points and appurtenances, etc. which are expressed in two ways: visual representation of 3D model and geometric forms representation of point, line and face.

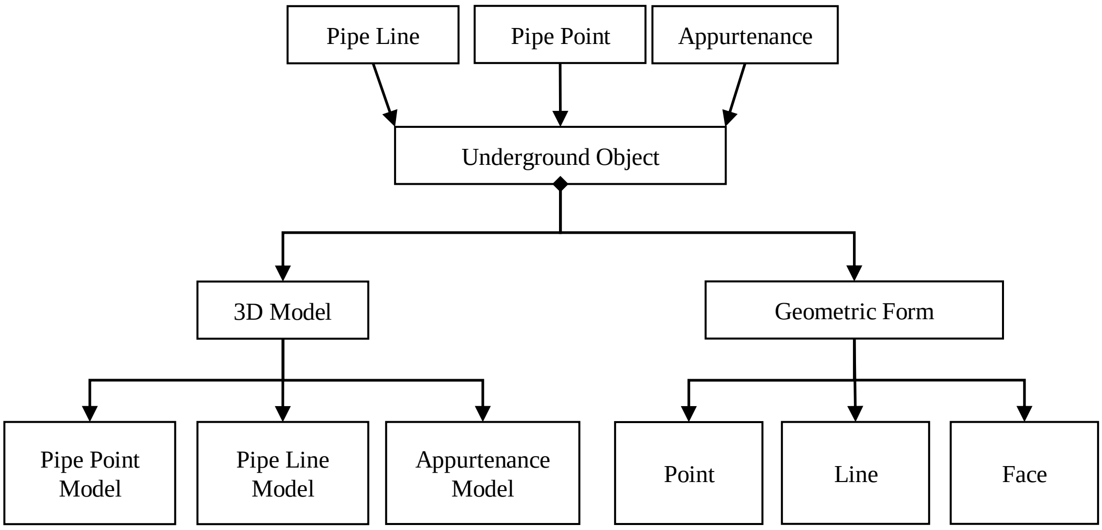

Figure 2. Underground Pipe Network UML Model

Based on the abovementioned two expressional ways of underground objects, the system needs to associate and manage 2D data with 3D models in the database with an integrated data organization [14]. There are two advantages of using 2D and 3D integrated data organization: I. It supports the unified management of 2D data and 3D models in the database; II. 2D data can be materialized so that it can participate in complex spatial analysis.

3D UUPNS uses SuperMap SDX+ spatial data engine combined with SQL Server to manage the 2D pipe network data and 3D models. SuperMap SDX+ data engine supports the integration of 2D data in the form of workspace as the top object management database, as shown in Figure 3. The workspace contains data sources, model libraries, and 3D scenes. The data source manages 3D network datasets, model datasets, and terrain datasets with the same spatial reference. The 3D network dataset is composed of the 3D point dataset and the line dataset of the same industry. The ground buildings, vegetation and water models are stored in the 3D model dataset. The 3D model library stores all the models made by 3DS MAX software, such as underground pipe points, underground pipelines and all appendages. When making a model with complete appearance, realistic proportion and realistic reality, the number of facets constituting the model should be reduced as far as possible, so as to reduce the rendering pressure generated when the system loads the 3D model.

There are many types of pipe fittings and appurtenances involved in underground pipe network in different industries [15], the types of pipe fittings should be simplified [16]. When the same pipe fitting model has various specifications, only one size can be modeled and adjusted according to the actual size when the model is matched. In order to improve the display effect and management efficiency of the whole system for the model, the pipelines, pipe fittings and man-made facilities existing on the ground, such as street lamps, electric piles, transformers and other ground objects, are stored in the 3D model library for unified management. When the 3D scene is loaded, the SymbolID field of the pipelines and the pipe points in the 2D pipe network data attribute table are indexed with the model ID field of the 3D models library to complete the process of matching the 3D model to the 2D data, and the corresponding relationship can be clarified.

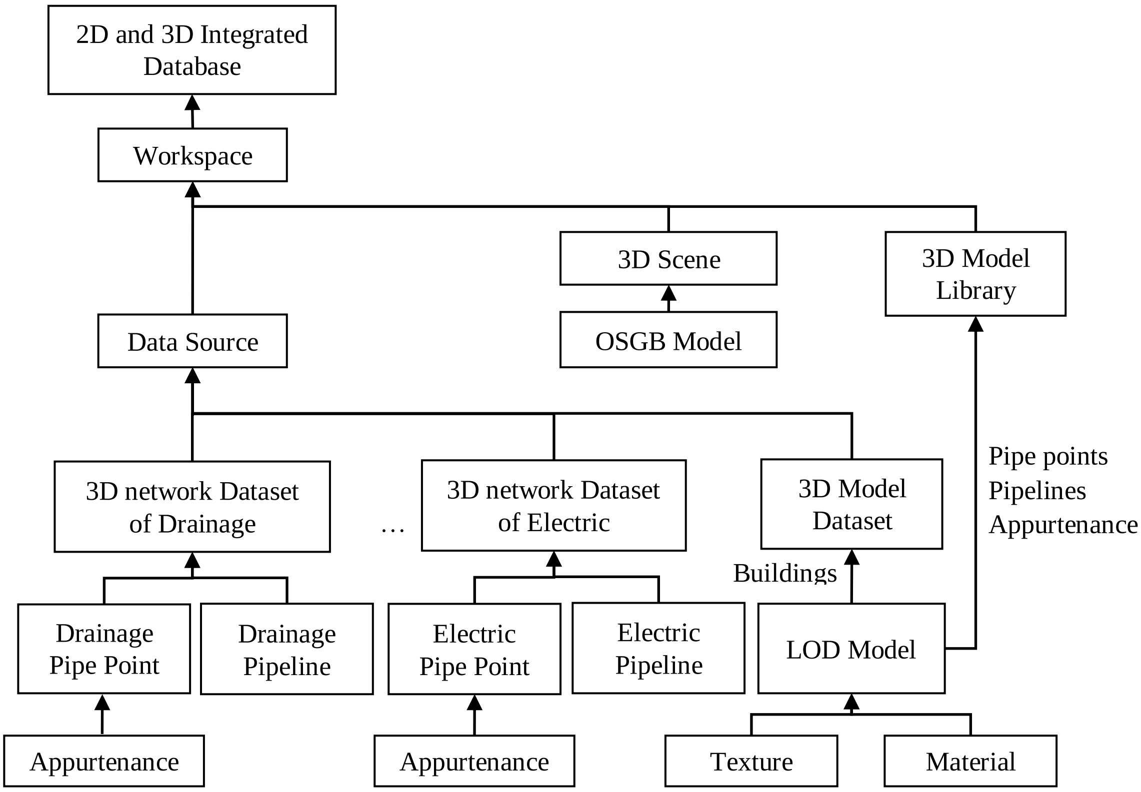

Figure 3. System Database

The matching between the 2D data and the 3D model library completes the conversion of the 2D data of the underground pipe network to the 3D entity, and realizes the accurate expression of the spatial information of the 3D underground pipe network, as shown in Figure 4. In addition, the resource occupation of the device running system can be alleviated, and the problem that the system running efficiency is reduced by the algorithm for rendering the 3D pipeline models when the system is loaded can be solved. The 3D visualization method of the underground pipe network can better preserve the details in the model display process, and can further support the information bearing and associated analysis of the city underground pipe network.

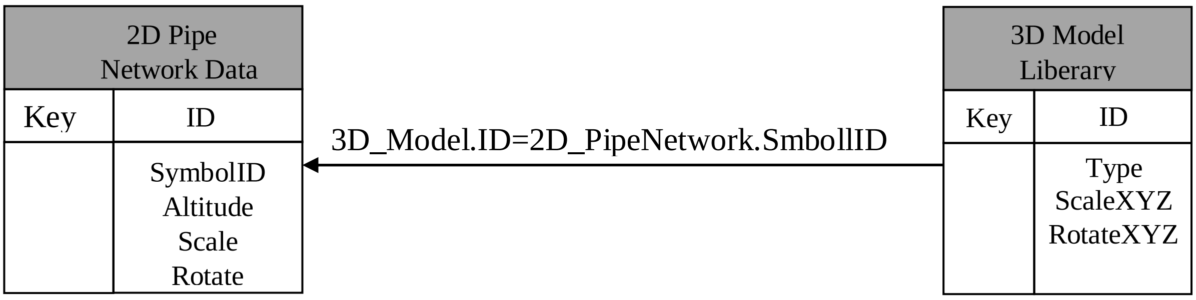

Figure 4. Matching Model Library to Model

3. System Design

3.1. System UI Design

The main elements of the system interface are divided into five areas: title bar, module bar, function area, data window and sidebar. In the module bar at the top of the system interface, there are five module tabs: Data, Query, Analysis, Statistics and Editing. The function areas of the five functional modules are divided into different function blocks, each functional block is distinguished to facilitate users to quickly locate the function buttons, which they need to use. In the data window section, the 2D map and the 3D scene are respectively set to display the form, and the user completes browsing of the data and other operations in the data window. The sidebar contains SuperMap LayerTree control for layer management, SuperMap DataTree control for data management, etc., as shown in Figure 5.

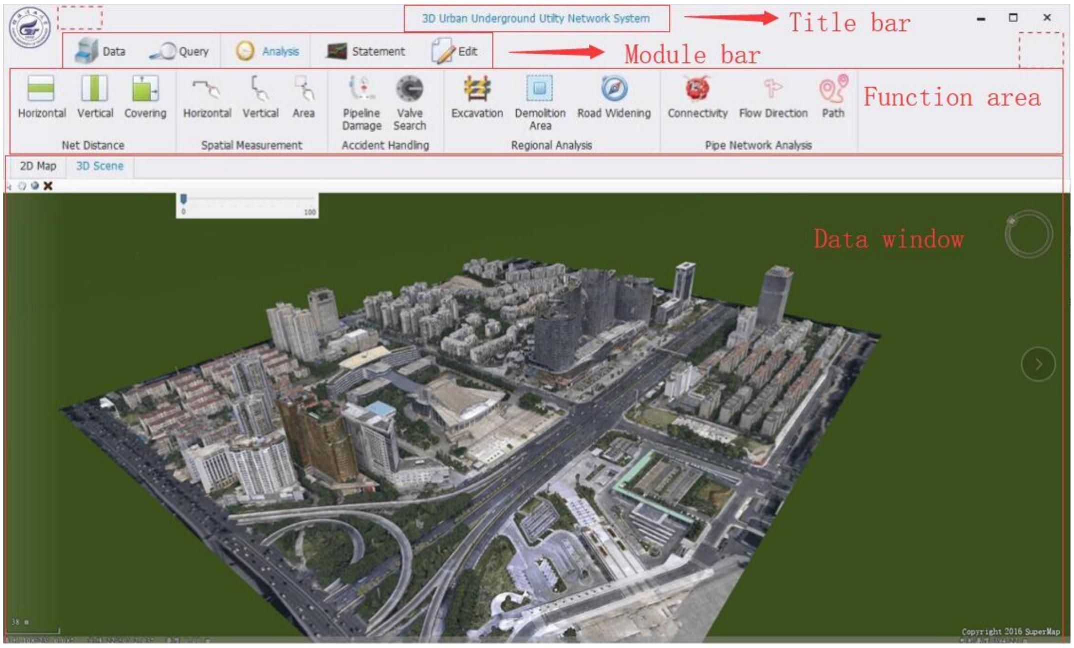

Figure 5. System Main Interface

3.2. 3D Visualization Optimization

Because it is hard to use a single type of 3D model to accomplish the visualization of multivariate data at different LOD level, so it is difficult to provide spatial representation and management solutions for 2D data and 3D models in traditional pipe network system [17].

In this paper, two different formats of 3D model are used, the detail models made by 3DS MAX software and the urban OSGB models made by Smart3D software. However, the difficulty in the optimization of 3D visualization expression of large-scale urban buildings is the automatic transformation from the high LOD model to the low LOD model [18].

This study proposes to integrate the OSGB models and the detail models to participate in the LOD operation, to control the scene simplification rate at different LOD grade, and then control the scale of information visualization of the whole scene and the precision of the model. The following steps are used to optimize the 3D model used by the system to complete the multi-scale integration of the two different formats of model in the same scene:

(1) This study converts the building detail models from the model-file format to the OSGB format. It can reduce the system pressure at loading;

(2) The urban OSGB models are divided into 5 LOD grade, and the simplification rate varies from large scale to small scale: starting from 0%, each level is increased by 25% until the simplification rate reaches 100%;

(3) The maximum visible scale of the OSGB models of the ground building is unified with the minimum simplification rate of the oblique photogrammetric model, and the minimum visible height of the oblique photogrammetric cache is the same as the maximum height of the building models.

After 3D visualization optimization, in the process of scale and scene height change, when the model in the full range is accommodated in the window at vertical view, it is used as the minimum scale of the scene. Only the minimum scale is displayed, and the selected city oblique photography model is used. After the maximum height of the building models are reduced, only the models of the above-ground building can be displayed. The optimization can ensure the seamless connection between the building models and the large-scale city models to achieve LOD and hierarchically filter the geographical information, so as to meet the real-time linkage effect between users' exploration of underground pipe network and aboveground buildings, as shown in Figure 6.

4. Function Realization

In this paper, SuperMap.net components are used to complete the secondary development of the spatial analysis function of the system. Through 3D space calculation, cover analysis, excavation analysis, burst analysis, section analysis and other 3D spatial analysis methods, the business needs of the management department are integrated to provide a scientific and intuitive basis for urban planning and construction. Next, the excavation analysis and section analysis are taken as examples to illustrate the realization process and effect of the space development function.

Figure 6. Ubran OSGB Models

4.1. Excavation Analysis

The excavation analysis simulates the effect of the real world on the designated area of the excavation in the 3D scene, mainly showing the impact of ground objects, buildings and underground pipe network in the excavation process. Based on the process of excavation, system analyzes the pipeline damage, evaluates the affected scope of the accident and provides a solution.

The difficulty of excavation analysis is to let the ground model participate in the calculation of excavation effect. Detail models have the characteristics like solid models. It can participate in surface excavation directly. However, the OSGB model does not have the property of solid model, but a 3D cache file that has been processed by LOD. Therefore, in order to enable the OSGB model to participate in the excavation calculation of the terrain, the following solutions are applied: First, the OSGB model is loaded into the 3D scene as the type of layer3DOSGBFile and stored in the form of a layer, so that all the OSGB models can be loaded into system as a whole layer. Next, the layer Tree control in the sidebar is used to manage the OSGB layer, and the IsExcavation property of the OSGB layer is called to adjust the OSGB model.

The excavation range set by the user in the system is attached to the OSGB model. The excavation function removes the terrain model at the excavation range, increases the underground excavation texture, and shows the underground pipeline model, thus realizing the effect of simulating the excavation surface. The result of excavation analysis is shown in Figure 7.

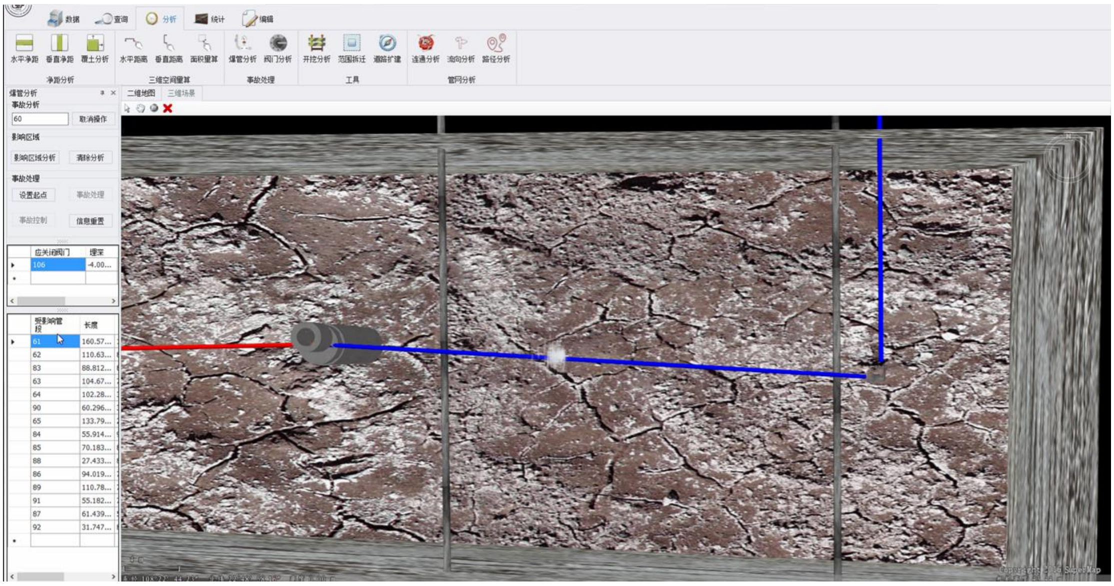

Figure 7. Excavation Analysis.

4.2. *Section Analysis*

The section analysis performs a partial “slice” on the underground pipeline, and intuitively reflects the buried depth between the underground pipeline and the surface and the road, and the spatial relationship between the pipelines. The user draws the section line in the system to determine the section analysis area, and the section intersects with many kinds of pipelines. The system traversals and screens the underground pipelines according to the section line, obtains the record set of pipelines in the section, obtains the information including the buried depth, material, pipe diameter and type of pipelines, and presents the results to the user as a section analysis diagram.

There are two key points in section analysis: one is to determine the drawing sequence of the section involving the pipeline on the section diagram; the other is the generation of the section analysis diagram. There are currently two ways to generate section analysis diagrams: using GDI drawing tools or using Devexpress, a plugin. Using GDI drawing method, it is necessary to dynamically adjust table contents and draw section table contents in real time when dealing with multiple groups of data and large quantities of data. With the plugin Devexpress, only the pipeline data used for importing the section analysis is used. The background automatically adjusts the table style according to the data, without having to write the code for drawing the table.

In addition, the difficulty in section analysis is to obtain the pipelines and pipeline information below the section line drawn by the user. At present, the main pipelines in this paper include three types: power pipeline, water supply pipeline and drainage pipeline. The underground pipeline model is entity model, and the pipeline information acquisition is based on the topological relationship of lines intersect, specific plan is as follows: get the vector datasets of the three pipelines and append them to a new dataset, then get the circumscribed rectangle of the section line drawn by the user, perform Query method calculation on the dataset and the circumscribed rectangle, get the intersecting pipeline record collection, and store in the *recordset*, get the name and depth field of the record in the *recordset* and add it to DevExpress's ChartControl control to display the pipeline type and pipeline depth information. In the final section analysis diagrams, the X-axis shows the section intersection number, and the Y-axis shows the section intersection depth, and the different color section points indicate different pipeline types.

5. Conclusion

This paper completed the design and implementation of the 3D UUPNS. The SuperMap spatial data engine SDX+ is used to design the 2D and 3D integrated data organization. The 3D visualization scheme based on the OSGB model and the LOD to express large-scale city scenes is proposed. The SuperMap 8C .net component library was used to develop an underground pipe network information management system with 2D information management and 3D spatial analysis functions. At present, the above research has been applied to the 3D urban underground pipe network system, which solves the hot problems such as the 2D data and 3D model difficulty in linkage and the rapid display of large data volume in the comprehensive underground pipeline information construction, and is applied to city large-scale 3D pipelines. System construction provides scientific technical support and analytical tools for urban pipeline planning and auxiliary design.

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