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3D visualization model and key techniques for digital mine

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Abstract: Digital mine is the inevitable outcome of the information processing, and is also a complicated system engineering. Firstly, for the 3D visualization application of the digital mine, the ground and underground integrative visualization framework model was proposed based on the mine entity database. So, the visualization problem was availably resolved, as well as the professional analytical ability was improved. Secondly, aiming at the irregularities, non-uniformity, dynamics of mine entities, mix modeling method based on the entity character was put forward, in which 3D expression of mine entities was realized. Lastly, the 3D visualization project for a copper mine was experimentally studied. Satisfactory results were acquired, and the rationality of visualization model and feasibility of 3D modeling were validated.
Key words: digital mine; three dimension visualization; framework model; spatial data modeling

1 Introduction

As well known, the information and knowledge have become the main power and foundational base in the economical development of society. Digital mine is the unite understanding and digitization representation of the real mines and their related phenomenon. It plays more and more important roles in the development, processing and utilization of mines, and tends to be inevitable in the information times [1]. The activities of mine have obvious 3D characters, so that he complicated subsurface entities such as ore bodies, rock mass and mine workings need real-three-dimensional space expression to better understand the spatial information of ore bodies, the spatial relationship between the ore bodies and surface topography in order to increase the spatial analytical ability, and provide the assistant decision analysis and management for assessment of the mineral resources, mine planning, mineral exploitation design and safety in production. Therefore, one of the hot points of digital mine research is to establish the visualization model framework for the integration on the ground and underground of the digital mine.

2 3D visualization framework model of digital mine

3D visualization of digital mine is that the entity data getting through the calculation and measure of mine landform and landscape, underground ore bodies, tunnel and rock mass shall be changed to the intuitive, based on the graphical representation, physical phenomenon and quantity with time and space, in order to make users observe, simulate and calculate, and provide users interactive means of the simulation and calculation [2]. In recent years, many scholars did a lot of researches on visualization techniques, and also got many research results. But most of them are located in the local visualization of the underground space, and unable to form the ground and underground integrated visualization model. In this work, we mainly advance the construction of mine spatial database based on the feature, and the integrated spatial visualization model of the surface circumstance to underground space (shown in Fig. 1). This framework model describes well the visualization process and main functions of digital mine. The main parts of model are shown as follows.

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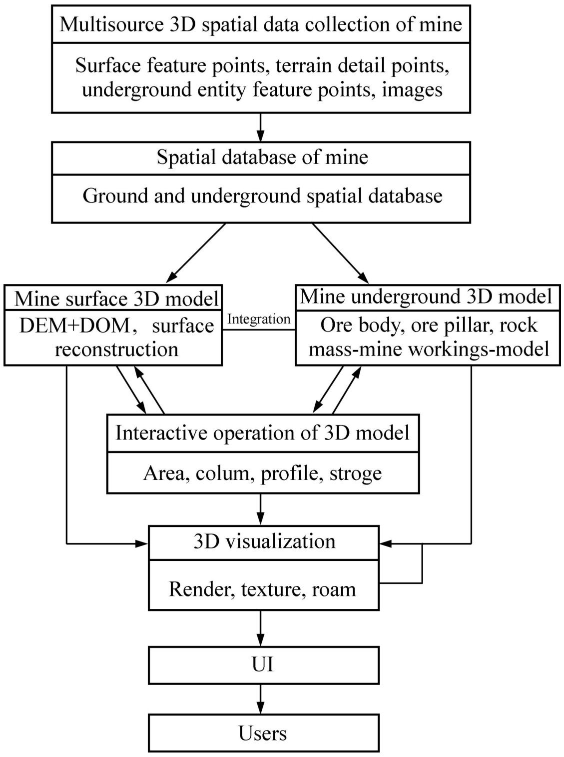

Fig. 1 3D visualization framework model of digital mine

1) Multisource 3D spatial data collection of mine

The multisource 3D spatial data collection of the mine consist of the data collections of surface and underground part. DEM, DOM, 3D vector models and textures are collected in the surface part, but they differ from the underground part, in which DEM and DOM are not collected, instead, the feature point, curve and region of the mine entities such as ore body, ore column, rock body, well tube, and tunnel should be collected.

2) Spatial feature database of mine

Based on the multisource 3D spatial data collection of the mine, spatial database of mine can be constructed, which mainly consists of the spatial surface database of the mine and underground spatial entity feature database. Spatial surface database of mine includes 3D vector model database, DEM database, DOM database, attribute database and etc, which are stored and managed by the object-relation type database system such as Oracle. DEM and DOM data need to create pyramid structure and take suitable spatial index mechanism to manage LOD data, however, 3D vector model data only need take a proper spatial index mechanism to increase the access efficiency of data, for instance, create R^+ tree index to organize and manage the 3D vector model data.

Underground entity feature space database consists of ore body, ore column, rock body, well tube, and tunnel etc. Database, which is collected in various ways from various feature points, polylines and polygons. Entity feature data of mine also takes the object-relation type database system such as Oracle to create suitable spatial index for organization and management.

3) Ground and underground 3D model of mine

The construction of 3D model of mine includes ground and underground parts. In the ground part, DEM data are firstly extracted from the spatial database, and the TIN or GRID surface model can be established, in which the surface real-feeling texture take DOM data, and 3D vector data with the same modeling ways builds the building models (hierarchy combination modeling), road 3D models (irregular triangular network). In the underground part, the feature points, polylines and polygons can be extracted from the spatial entity database. Simultaneously, the ore body, ore column, rock body, well tube, tunnel, and goaf models can be constructed from entity modeling method database.

4) Interactive operation of 3D model

After the construction of aboveground and underground 3D models, interactive operation can be realized. Through the interactive operation, spatial queries and analysis results can be directly understood, and spatial analysis can be increased. Based on the environment of 3D models of mine, calculation of mineral reserves, profile analysis of mine goaf and calculation of ore pillar can be realized.

5) Integration of 3D visualization

With the dynamic interactive 3D aboveground and underground integration, it can be shown to the users through the UI. So, 3D dynamic interactive surface and underground integration visualization are the basic character of digital mine. Usually, 3D visualization of the surface scene and underground scene are relatively independent. That means, the surface scene applications are only used for the surface environments, and the underground applications are only used for the underground scene. According to digital mine, surface scene and underground scene shall be integrated, in order to build an organized whole with the surface and underground. Man can walk freely from aboveground into the underground as if in the real world.

3 Key techniques of 3D visualization of digital mine

3.1 Spatial data modeling of digital mine

During the building of digital mine, in order to integrate the aboveground and underground scenes, the spatial data modeling is usually divided into aboveground and underground entity modeling. The aboveground entity modeling has little differences with the entity modeling of digital city, so, no more about this will be mentioned in this article. Considering the complexity of the subsurface mine, the subsurface entities such as the ore body, ore column, rock body, well tube, tunnel, and mine goaf shall be expressed and analyzed with 3D, which is the important contents of the digital mine. With the hot point of study on the 3D geo-object modeling, many experts and scholars carried on a great deal of research and obtained a lot of research results. These modeling methods are utilized as well as for 3D modeling of the digital mine. Three aspects are as follows.

1) Entity modeling based on surface

The common methods include multi-layer DEMs modeling [3], generalized triangular prism modeling [4] (GTP) and analogical triangular prism modeling [5] (ATP). By the multi-layer DEMs modeling, the interface points of the layers are interpolated with DEM method to form grids, and then are divided with layer that attributes to form skeleton structure of the 3D surface layer model; GTP modeling firstly divides TINs with certain regulations for the layer interfaces, and then these TINs will be connected to describe the layer entities using planes. Considering the non-planes of triangular prism profile caused by GTP modeling method, some scholars advanced the ATP method.

2) Entity modeling based on body

The usually used methods include tetrahedron modeling [6] (TEN), Octree modeling [7] (Octree). In TEN modeling, no intersected lines are used, no repetitive points set is related two by two to form triangular sides, and then TEN is constructed by no intersected triangular sides. In Octree modeling three-dimensional space is divided into 8 quadrants, and 8 data elements are stored on each tree node. When the type of all the elements in the quadrant is the same, this type’s value is deposited into the data element of nodes. Inhomogeneous quadrants are separated finely until the area of each node is homogeneous.

3) Mix modeling with surfaces and bodies

There is mainly the TIN+Octree [8] entity modeling method. TIN is used to describe the interfaces, and Octree is used to describe the internal structure of entities, which composites both advantages of TIN and Octree to make the topological relationship very effectively.

Each entity related in the building of digital mine not only has the irregularities, non-uniformities, but also has 3D dynamic characters in the geometrical structure and internal characteristic. This complex and dynamic spatial entity characteristic limited to one modeling method is hard to realize, so a universal 3D modeling method with mine characters should be advanced. In the work, we propose a mix 3D modeling method based on the entity feature to realize 3D expression of complex mine entities. The basic idea is: firstly, build mine entity modeling method database, in which general 3D modeling methods such as TIN, GRID, multi-layer DEMs, GTP, ATP, TEN, and Octree are included. Afterwards, mine entity data are extracted from mine entity spatial database, entity character (surface, multi-layer-surface, body) which waiting for modeling is judged, the modeling method will be called from 3D modeling methods database by entity character. At the end, 3D models are stored into the mine entity model database. For instance, the model entity to be built is ore body, which has obvious body character, so TEN or Octree modeling method is called from the method database to build 3D ore body model. The main process is shown in Fig. 2.

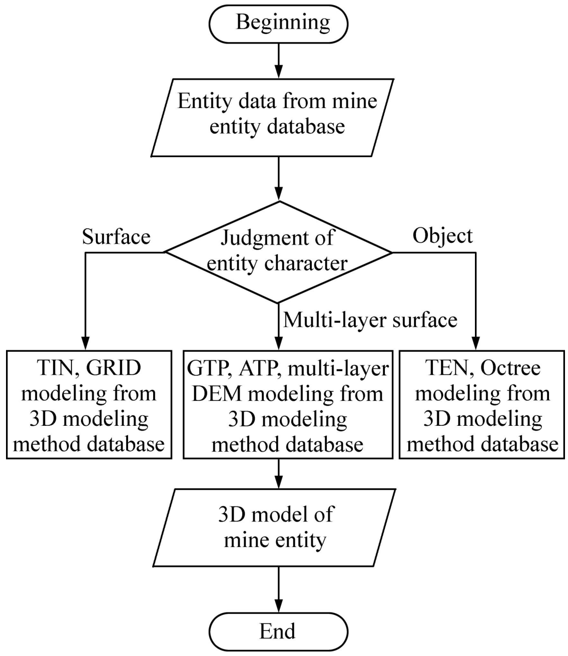

Fig. 2 Workflow of mix modeling method based on entity character

3.2 3D interactive visualization of digital mine

In order to fulfill the 3D interactive visualization of digital mine, we need not only rapidly constructed spatial data management system and complex 3D mine entity modeling methods, but also gradual rendering technique which supports LOD and real-time procedures. The main key techniques are shown as follows.

1) LOD technique

LOD technique can be utilized to control the scene complexity and increase the efficiency of the 3D scene rendering. LOD model represents one object with various resolutions and quality, and can be built with the preliminary or simplified scheme. The preliminarily built scheme is usually based on the independent viewpoint method, and the LOD model can be stored in the database. Real-time simplified scheme is based on the dependent viewpoint method to simplify the models during real-time roaming. For instance, during the real-time roaming, the objects near the viewpoint can be kept higher level detail than ever, instead, the objects away from the viewpoint can be simplified to lower level detail. In the dynamic interactive visualization system, two methods are usually used alternately.

2) Dynamic loading based on data pages

The method of dynamic loading based on the data pages is utilized to increase the dynamic real-time display efficiency of 3D scene. The rendering data for each frame scene is corresponded to one data page in the computer storage, that is, a storage space consists of continuously distributed terrain-blocks. During the dynamically rendering, the data block in the data pages should be continuously updated with the movement of the viewpoints. But it takes time to read in new data to the storage, thus caused to the visual delay. To solve this critical problem, fore-background data pages cache should be constructed, and through the multi-threading technique the data exchange between two caches can be resolved. Foreground cache serves directly the 3D display, and the background cache serves the data exchange for the spatial database.

3) Multi-threading technique

With multi-threading technique, the data update of the data page cache can be resolved. Through the judgment of the plane relations between the current viewpoint location and geometric center of data pages, the dynamic data pages can be real-time updated. Thus is realized to real-time roaming to the random direction with the mass data in the same scale. If the altitude of the viewpoints is changed during the movements, the viewing range should be recalculated. If the ratio of projective area of viewing range and data page is bigger than a threshold, the current data layer should be replaced to relative data layer to update the whole data page.

4) Potential visible integration calculation

In the 3D interactive visualization, the visible question is not only a question that is simple to judge the relationship of the occlusion area. Particularly in the underground 3D scene, with the generated computing complications and stability question, we need not only to consider the alternant real-time property, but also to consider the quality and stability of frames. Many factors influence the visibility judgment. In view of the 3D visualization and the complex underground scene, in this work we use the occlusion tree method [9] to resolve the potential visible calculation. Through the analysis of the spatial relationship between the scene entities, the scene is organized with KD-tree [10], and the space of the occlusion area can be effectively combined. With the viewpoints, some parts of the occlusion area can be rapidly and correctly decided, therefore, we need not calculate the real visible objects strictly. Using the spatial structural levels to express the topological structure, the occlusion tree can be created based on the given viewpoints and a set of hinders, and finally through the viewpoints data sets of visible objects can be calculated.

4 Effect of practice

The experimental study has been proposed by a 3D visualization project of digital mine by a Yunnan copper mine. Focused on the project's aim, 3D spatial data on the mine surface shall be collected, which includes DEM, DOM, and the buildings, roads in the mine. The underground area data collects mainly a part of ore body, tunnel and auxiliary facilities data, and build the spatial database of mine. In addition, the experimental study adopts mix modeling method based on the entity character mentioned in this work to build 3D models of ore bodies and tunnels. Based on the 3D visualization frame model, 3D visualization system of the digital mine is advanced to realize above-underground integrative roaming and spatial analysis, which provides the scientific basis for mine exploitation and satisfactory results, shown as Figs. 3−6.

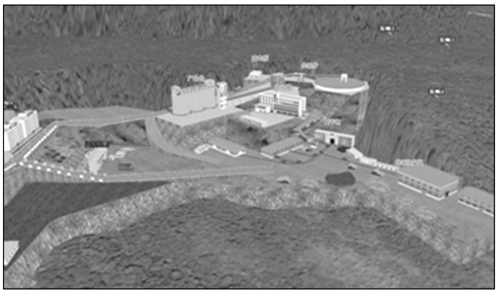

Fig. 3 Ground 3D scene of mine

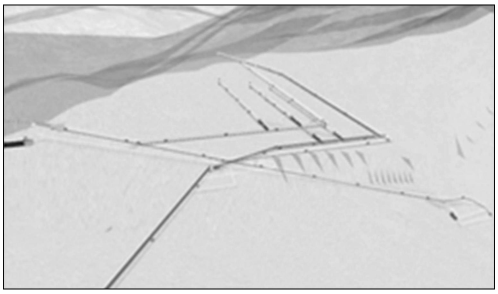

Fig. 4 Underground 3D scene of mine

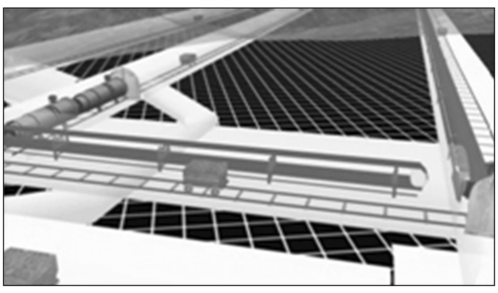

Fig. 5 Underground tunnel 3D scene of mine

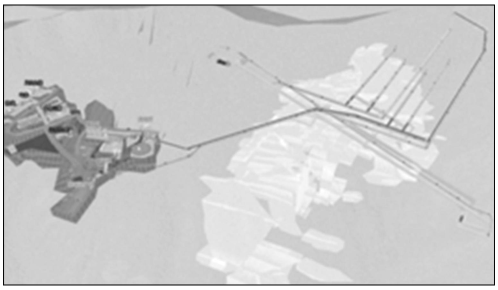

Fig. 6 Ground and underground integrative visualization

5 Conclusions

Digital mine construction is a complex system engineering. In this work, we researched the 3D visualization application of digital mine construction, and furthermore, discussed the 3D visualization frame model and key techniques. According to the character of mine, ground and underground integrative visualization the model based on the mine entities character was adopted, and a visualization solution was provided for the digital mine. Aiming at the irregularities, non-uniformity, dynamic of mine entities, we proposed the feature-based mix modeling method during the modeling of mine entities, and realized the 3D expression of various mine entities. Finally, the experimental study on the 3D visualization project of Yunnan copper mine was proposed to validate the rationality of visualization model and feasibility of 3D modeling.

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