

Spatiotemporal Data Model for Managing 3D Geological Solid Models in Coal Digging Simulation

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Abstract: The establishment of spatiotemporal mine information system will help to analyze the changes of mine information, and it plays a helpful role in evaluating mine status and formulating mine production plan. With the development of information technology, there is a growing demand for both space and temporal data processing. Spatiotemporal data model is the mainstream method to deal with temporal geological data. Multiple spatiotemporal data models were studied; and find that the management of 3D geological solid models doesn't earn enough attention. Coal digging is a typical spatiotemporal process. It provides a good research area of the dynamic management of 3D solid model data by simulating the digging process. Then the simulation of coal digging process was selected as the research content, and present the spatiotemporal data model for coal digging simulation through digging out the management methods of 3D geological solid models in spatiotemporal mine information system. By referring the existing spatiotemporal data model theories, and put forward three main technologies including the management of 3D geological solid models by geological spatiotemporal objects and versions, the observation data accesses with OPC technology, and the response of geological spatiotemporal objects to geological spatiotemporal events. In the experiment, 3D geological solid models were developed using actual coal mine survey data, the collection, standardization, access of observation data, the establishment and configuration of OPC Client and OPC Server, the programming of response methods. The results are quite good and verify the feasibility of theory and technology in this paper. On expectation the frame can be used for other solid mine or unexpected areas. Hope that the research work can promote the study of spatiotemporal data solid model and geological information system.

Keywords: *spatiotemporal data model; digging simulation; geological spatiotemporal object; 3D geological solid model; spatiotemporal process*

1. Introduction

With the development of information technology, Geographic Information System and Geological Information System become significant to deal with temporal data [1, 2], especially for solid mine information system. As an example, coal mine information system needs spatiotemporal consideration to analyze the changes of the whole mine and handle real-time information timely to make more reasonable production plan. In addition, it will be helpful to more realistic Geological Information System with real process and presentation precisely as in the real world.

Coal digging may be the most important concern in a coal mine and it is a typical spatiotemporal process of solid mine which involves the changes of a variety of attribute data and spatial data. By simulating the coal digging process using historical data and real-time data, the states of mine in different stages can be shown clearly, which will help us to understand the spatiotemporal features in solid mine information system. However, mostly existing research work of digging process simulation, mainly focus on the comprehensive management of various attribute data and pay little attention to 3D geological solid models which occupy an important position in Geological

Information System [3-8]. If endowing 3D geological solid models with spatiotemporal quality, a lot of local or global changes in solid mine can be shown much more intuitively.

Current Geological information systems do not provide a representation model that supports adequate description of spatial and temporal elements within the mine digging process. Fortunately, there are many existing spatiotemporal data models providing theoretical and technical supports.

So far, there are a variety of spatiotemporal data model, and current research mainly collected and analyzed nine of them as follows, GEN-STGIS [9], Cell Tuple-based Spatiotemporal Data Model [10], Cube Data Model [11], Activity-based Data Model [12], Object-based Data Model, Data Model for Zoning [13], Object Oriented Spatial Temporal Data Model [14], Multigranular Spatiotemporal Data Model [15] and Feature-Based Temporal Data Model [16]. All the spatiotemporal data models can be roughly divided into five stages: the extension of traditional static data model, object-oriented data mode, data mode based on object changes or sequence of events, data mode integrating temporal and spatial, data model regarding process as the core. The data involved in spatiotemporal data model mainly

includes the attribute data to describe the characters of the object and the spatial data to record the position and shape of the object. Various spatiotemporal data models ignore the 3D model data [17, 18].

In order to simulate the coal digging process more realistically, an appealing spatiotemporal data model should focus on the 3D geological solid models and their changing behavior. Based on our analysis, issues which are related to the capability of spatiotemporal data model are the management of 3D geological solid models in the system, the receiver of observation data outside the system, the response of solid models to digging events translated from observation data. In this paper, a spatiotemporal data model for coal digging simulation was presented. This model was developed to manage 3D geological solid models which will change as time goes on and also to automatically receive and response of observation data.

The present research work has both theory and application values which can not only extend the ways of studying spatiotemporal data model, but also promote the development of temporal mine information system.

2. Spatiotemporal Data Model for Coal Digging Simulation

The spatiotemporal data model mainly includes three parts: the comprehensive management of 3D geological models using geological spatiotemporal objects and versions, the observation data access with OPC technology, and the response of geological spatiotemporal objects to geological spatiotemporal events. This section will detail the contents of these three parts.

2.1 3D geological models management

In general Geological Information Systems, the geological objects can be expressed by 3D models to describe geometry data and attach attribute data. However, this method can only show the states of mine statically. For dynamic expression of digging process, the concept of geological spatiotemporal object and geological spatiotemporal version were introduced to realize the dynamic management of 3D geological models referencing the theories and technologies of Spatiotemporal Data Model for Real-time GIS [1].

In mine geological information system, the geological objects or artificial facilities such as ore body, strata, digged-out-area, and tunnel are expressed by 3D geological model. Along with the production process, the geological objects like strata, ore body and so on are digged, with the growing of digged-out-area and tunnel. This process can be simulated by replacement, marking, addition, deletion and modification of 3D geological models.

3D geological models can be divided into growth type and cutting type according to their trend in the digging process. The growth type mainly includes digged-out-area and tunnel, and the cutting type mainly includes the ore body and strata. Generally, the digging process can be divided into a series of stages according to time. There may be several different types of 3D geological model changing during one digging stage.

A geological spatiotemporal version can be defined using the changed 3D geological model sections which have the same characteristics during one digging stage. One version is only responsible for the management of the index information pointing to 3D geological model. Several 3D geological models with the same characteristics may be related to one version. The geological spatiotemporal versions can be divided into growth type and cutting type, too.

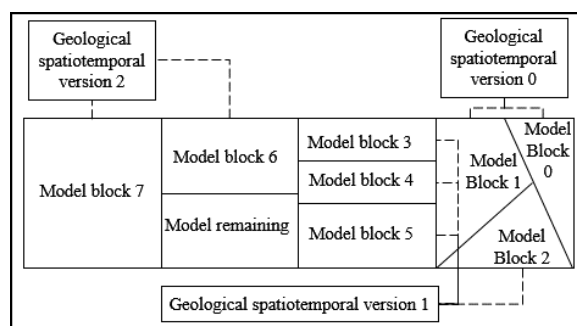


Fig.1 The mapping of versions to 3D models

Several geological spatiotemporal versions mapping to 3D geological models are shown in Fig.1. Some model blocks will be cut down from the original geological model and marked with “digged” after a digging stage. Eight model blocks marked with “digged” which are numbered 0 to 7 are generated after three digging stages. Then, three geological spatiotemporal versions were defined to manage these model blocks respectively. For the growth type, the differences are that model blocks are generated one by one and they are marked with “grew”.

The data structure of geological spatiotemporal version is mainly composed of the ID, distinguishing the version from others, the start time of the version, the end time of the version, and the indexes list of 3D geological models managed by the version.

Geological spatiotemporal objects can be defined to manage geological spatiotemporal versions. Several versions which are generated relying on the others should be managed by the same geological spatiotemporal objects. For example, the geological spatiotemporal versions shown in Fig.1 are all generated based on the previous one except the first one, so only one geological spatiotemporal object should be defined to manage these versions. Referencing the method to classify geological spatiotemporal versions, the geological

spatiotemporal objects can be divided into growth type and cutting type.

The data structure of geological spatiotemporal objects is mainly composed of Object ID, Object name, Object type, Indexes list of 3D geological models, and Version list. The version list is used to store the index information of geological spatiotemporal versions managed by the geological spatiotemporal object. And the model list is used to store the index information of the 3D geological models within the management scope of the geological spatiotemporal object. In addition, several event response methods which adjust versions and geological models according to the event information should be defined for the geological spatiotemporal object. The event response methods only adjust those geological models whose index information is stored in the model list. So to some extent, the operating efficiency of the system will be improved.

Sometimes, there are addition or subtraction operations between the versions contained in the same geological spatiotemporal object. In fact it is necessary to deal with 3D geological models and their index information. When adding two versions, the geological models belong to them will be managed by the result version. When subtract one version from another, the result version will manage the geological models belong to the latter but not belong to the former.

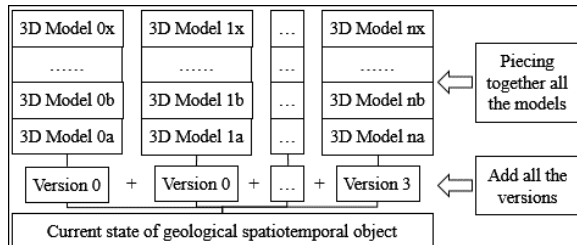


Fig. 2 The illustration of getting current state of growth type object

The current or historical state of a geological spatiotemporal object depends on the result of the addition or subtraction operations among the geological spatiotemporal versions. For a growth type object, the current state is the result of the addition of all versions. And for a cutting type object, the current state is the result of the first version minus all the other versions. **Fig. 2** is an illustration of the steps to get the current state of a growth type geological spatiotemporal object.

To obtain the historical state of the geological spatiotemporal object, it is needed to specify the period to search the satisfactory versions. Take out these versions whose start time is later than the start point of the target period and end time is earlier than the end point of the target period. If the start point of the target period is earlier than the start point of the first geological spatiotemporal version, then the

versions taken out can be added or subtracted as the steps above-mentioned. The result is the state of the object at the end point of the target period. If the start point of the target period is later than the start point of the first version, then the versions taken out can be added only. The result is the sum of the object's changed states during the target period.

2.2 Observation Data Access

The state of a geological spatiotemporal object will not change without the interference of external conditions. But in order to achieve the aim of digging simulation, geological spatiotemporal objects are hoped to adjust their versions and 3D geological models according to the actual mine production data. So the observation data is needed to be accessed in.

Observation data refers to the parameters generated in actual mine production and obtained through various ways. The users of the geological information system can edit the geological model using observation data. According to the acquisition period and access means, observation data can be divided into real-time data, historical data and simulation data.

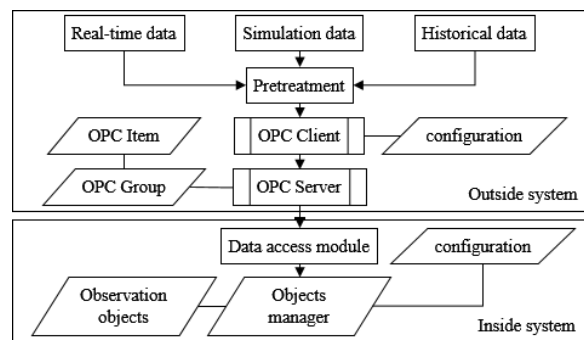


Fig. 3 The lines of observation data transfer

Observation data is transferred to observation objects which will convert these data into geological spatiotemporal events, and these events will be sent to geological spatiotemporal objects. This process moves in circles driving the whole system. The transfer lines of observation data from outside to the observation objects are shown in **Fig. 3**.

Before the using of the observation data, it is necessary to carry out pretreatment including removal of the useless or redundant data, and standardization of data format. The observation data pretreated can be divided into identification code which is used to distinguish different observation data and data body which is composed of several data fields. The observation data with the same identification code has the same collection source and target geological spatiotemporal object. Their difference can be only reflected in the data stored in data fields and the time when the data was generated and terminated.

Object Linking and Embedding for Process Control (OPC)[19] can be adopted to transfer the observation data from outside to inside of the system. It includes a

set of interfaces, properties and methods which makes it become reality that transfers data among different devices expediently.

The OPC Client and OPC Server need to be built and to be connected. The OPC Client is the start of observation data transmission who reads the pre-treated data and sends them to the OPC Server one by one according to the scheme the users set. The OPC Client can choose the desired OPC Server through the address and port.

The OPC Server is a temple station used to store data that is updated by OPC Client. On the OPC Server, there are number of OPC items each of which stores a data field of the observation data. An OPC group can be defined to manage several OPC items with the connection with each other. An observation data is linked to an OPC group, and the data fields are linked to OPC items in the OPC group.

The system can choose the OPC Server according to the address and port like the OPC Client doing. When the values of OPC items are updated by the OPC Client, the data access module will obtain the observation data immediately through the callback function. The observation data is initially given to the observation object manager which will distribute these data to specific observation objects. The observation data with the same identification code is always distributed to the same observation object. Therefore, there is a one-to-one mapping relationship between the OPC group and the observation object. This is determined by the user and stored in the configuration file.

The observation object is the abstraction of the source of the observation data in the actual production in the system. The duty is to store and manage one type of observation data and transform the observation data to geological spatiotemporal events. The data will be stored in several value lists each of which corresponds to one observation data field. The length of each value list should be consistent, as it comes from the same number of observation data. The data taken out with the same sequence number can be used to construct geological spatiotemporal event. And geological spatiotemporal events should not be repeatedly generated generally so current number is needed to record the start position of unused data.

2.3 Digging Event Response

Observation data will be transformed into geological spatiotemporal events by observation objects to transfer information in the system. Geological spatiotemporal events can be divided into two parts: event-type code and data body. The data body contains several parameters each of which maps to the data field of original observation data.

Geological spatiotemporal objects choose the response action based on the event-type code and

decide the magnitude of the action according to the parameters in the data body.

Whether the same geological spatiotemporal event can be responded by multiple geological spatiotemporal objects depends on the users' requirements. But in any case, there should be a configuration file to store the mapping relationship of the observation objects and the geological spatiotemporal objects. The Geological spatiotemporal object manager distributes geological spatiotemporal events received from observation objects to one or several geological spatiotemporal objects according to the mapping relationship.

The target geological spatiotemporal objects must have existed and be able to respond to geological spatiotemporal events before the geological spatiotemporal object manager starts the events distributing process. So the users must create geological spatiotemporal objects and initialize them before everything starts.

The general steps summarized to initialize mine geological spatiotemporal objects are as follows.

- 1) Define a new geological spatiotemporal object and set its basic information including name, ID, type and so on.
- 2) Determine the management scope of the geological spatiotemporal object, then fill the index information of 3D geological models located in the scope into the index list;
- 3) If it is a cutting type object, an initial version should be created as the first version using all the 3D geological models whose index is in the index list;
- 4) Some geological spatiotemporal versions should be created according to the digging situation if there has already been digging operation;
- 5) Add all the versions completed to the geological spatiotemporal object;
- 6) Add the object to the geological spatiotemporal object manager which will organize all the objects by category to search quickly.

Such events are mainly concerned about which come from actual digging process and can lead to the changes of the geological objects shape. In system, 3D geological models can change as these events called exploitation event. The general response steps of geological spatiotemporal objects to exploitation events are as follows.

- a) Observation objects generate new exploitation events and are sent to the geological spatiotemporal object manager when new observation data is received;
- b) The geological spatiotemporal object manager distributes exploitation events to target geological spatiotemporal objects according to the mapping relationship of observation objects and geological

- spatiotemporal objects stored in the configuration file;
- The geological spatiotemporal objects received exploitation events calculate the influence range according to the parameters stored in the exploitation events;
 - The geological spatiotemporal objects retrieve own index list extracting the 3D geological models which locate in the influence range;
 - If the geological models need to be cut or edited, then use the functions provided by the system or call the users for help;
 - Store new models into the geological model library and replace the old model indexes (mainly included in the geological spatiotemporal objects' index list and extracted in step) with new indexes if the step exists and is completed successfully; the old geological models should not be deleted as they still may be used by other ones;
 - Create new geological spatiotemporal versions using the geological models extracted;
 - Add the versions to the geological spatiotemporal object.

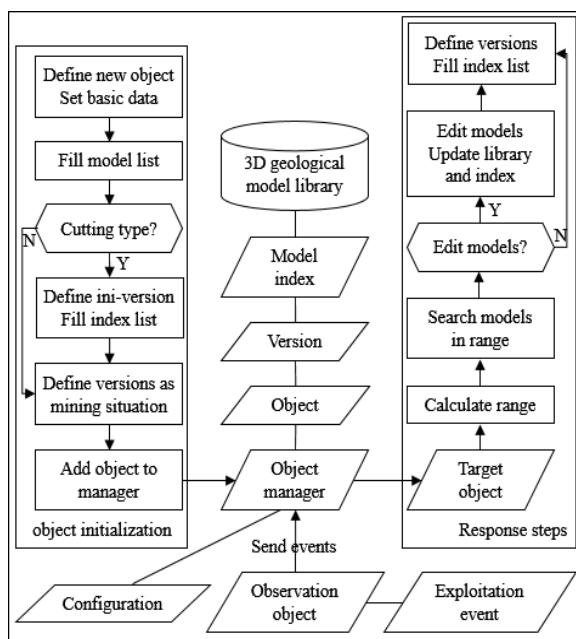


Fig. 4 The response steps of exploitation events

The initialization and response steps of geological spatiotemporal object are shown in Fig. 4.

3. Experiment

To verify the correctness of the theory and design above, an experiment are carried out by using actual mine survey data. The test software system for coal digging simulation is developed on the QuantyView platform owned by Wu Han Dida Quanty Technology Co., Ltd. Taking advantage of the system, the construction of 3D geological models, the observation data access, the transmission and response of exploitation events and the automatic simulation of coal digging process are realized.

3.1 3D Geological Solid Models Construction

The first mining district of Wangjialing coal mine was considered as the experimental area. The reconnaissance data collected includes geological section maps, location maps, maps of mine working, drill columns, drilling information, etc. Then integrated the geological section maps stored independently with others into the QuantyView 3D environment according to the spatial information. Constructed stratigraphic boundary surfaces with stratigraphic boundary lines using the lines-to-surface tool provided by the platform. And then geological models were constructed including stratum models, coal models with stratigraphic boundary surfaces using the surfaces-to-body tool provided by the platform.

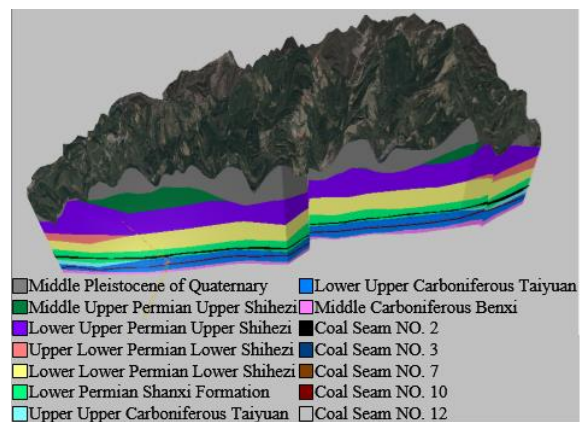


Fig. 5 Completed models

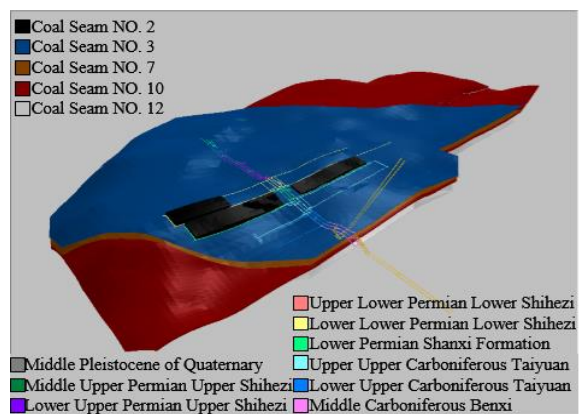


Fig. 6 Models of three plan digging areas

The final 3D geological models include stratum models, coal models, tunnel models, etc. The models are shown in Fig. 5. There are three plan digging areas from 2012 to 2014 located in the coal seam numbered 2 which are selected as the experimental area for coal digging simulation. It is shown in Fig. 6.

The simulation process is hoped to be like this: the coal seam models located in the influence range of exploitation events are replaced by digged-out-area models as the simulation process spreads. There are two ideas to realize this thought.

The first one is cutting the coal seam models and marking the models cut down real-timely. This method has higher requirements for the efficiency and accuracy of cutting algorithms. The second one is cutting the coal seam models which locate in the plan digging areas into a series of model slices which will be marked as the minimum units in the digging simulation. This method has smaller simulation accuracy but has better stability and is much easier to come true. In order to guarantee the feasibility of the experiment, the second method is chose.

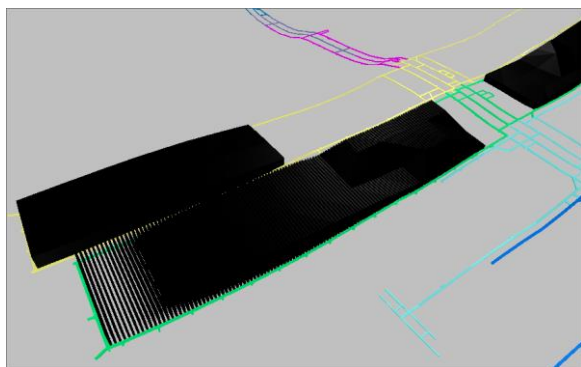


Fig. 7 The illustration of model slices of plan digging areas

The model slices deriving from the coal seam models are shown in **Fig. 7**. The three coal seam models are cut every ten meters, and form a series of model slices along the digging direction. To have a much better visual effect, some slices of the left lower coal seam model are hidden. Relying on the existing function of the QuantyView platform, the geological models can be quickly and accurately cut with any reasonable distance.

3.2 Observation Data Customization



Fig. 8 Digging records in the map of mine working

The observation data mainly comes from the maps of mine working of the first digging area of Wangjialing coal mine, as shown in **Fig. 8**. The map records the digging behaviors with almost constant widths and mobile positions generated once a month. Space information and time information can be extracted which are comprised of the start digging position, the digging direction, the digging distance, the start time and the termination time for each digging phase. In addition, identification codes should be given to explain what plan digging area the data comes from. A part of the observation data tidied up is shown in **Fig. 9**.

code	start point	direction	distance	start time	termination time
WJLMA003	X:37472812.1	X:-32.72852	32.72852	2012.09.01	2012.09.31
WJLMA003	X:37472779.4	X:-81.67148	81.67148	2012.10.01	2012.10.31
WJLMA003	X:37472697.7	X:-45.298245	45.298245	2012.11.01	2012.11.31
WJLMA003	X:37472659.5	X:-164.6	164.6	2012.12.01	2012.12.01
WJLMA001	X:37470066.2	X:80.5	80	2013.01.01	2013.01.31
WJLMA003	X:37472505.6	X:-176.10000	176.10000	2013.01.01	2013.01.31
WJLMA001	X:37470141.1	X:105.587945	105	2013.02.01	2013.02.31
WJLMA003	X:37472334.6	X:-83.601333	83.601333	2013.02.01	2013.02.31
WJLMA001	X:37470237.8	X:162.2	162	2013.03.01	2013.03.31

Fig. 9 Cases of observation data

3.3 OPC Configuration

Current configuration:		Contents of alias group 'WJLMOPC001':				
		Name	Item Path	Data Type	R/W	Update Rate
Server Configuration		Direct		STRING	R/W	
Alias Configuration		Dis		REAL4	R/W	
WJLMOPC001		StartPoint		STRING	R/W	
WJLMOPC002		TimeEnd		STRING	R/W	
WJLMOPC003		TimeStart		STRING	R/W	

Fig. 10 The configuration of OPC Server

MatrikonOPC Server for Simulation [20] software was used as the OPC Server. Under the Alias Configuration node provided by the software for users, three own OPC Groups are defined mapping to the three plan digging areas. Under each OPC Group, five OPC items are defined each of which maps to one field of the observation data. It is shown in **Fig. 10**.

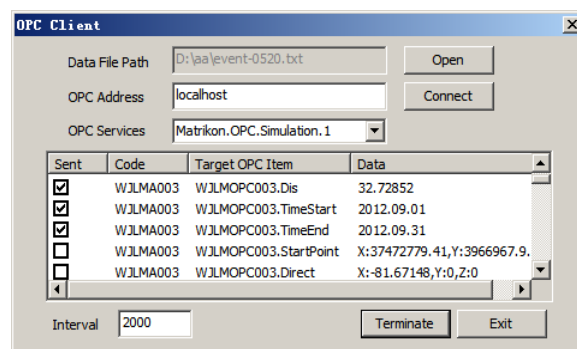


Fig. 11 The interface of OPC Client

Simple targeted OPC Client software was developed to transfer the observation data onto the OPC Server. The interface is shown in **Fig. 11**. The users need to specify the path of the observation data file, the address of the machine where OPC Server locates and the name of the OPC service. After setting the transmission interval, the observation data will be transmitted to the corresponding OPC Items one field by one field.

3.4 Observation Object and Geological Spatiotemporal Object Definition

In the system, observation objects and geological spatiotemporal objects are necessary. Each geological spatiotemporal object in use should have an observation object associated with, and responds the exploitation events transferred from the observation object. Each observation object in use should have an OPC Group associated with, meanwhile each observation field of the observation object has an OPC Item of the OPC Group associated with.

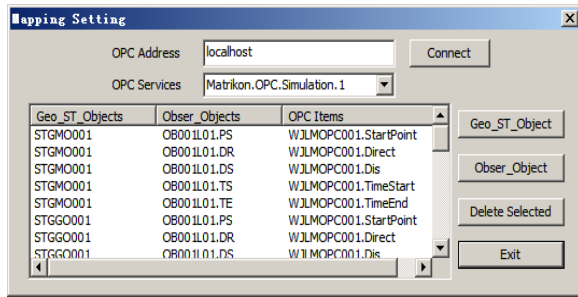


Fig. 12 The setting interface of mapping relationship

When the values of OPC Items change, the observation object gets and stores these values, which are followed by transforming exploitation events that will be sent to geological spatiotemporal objects. The mapping relationship among geological spatiotemporal objects, observation objects and OPC Groups is determined by the users. The configuration interface is shown in Fig. 13.

It is just for easy display that observation field is placed in the same row with a geological spatiotemporal object, instead of seeming like that a geological spatiotemporal object is associated with an observation field. Several geological spatiotemporal objects can be associated with the same observation object.

3.5 Experimental Results

After completing the preparations above, the coal digging simulation was started. For the convenience of viewing, only tunnel models and the coal seam models in plan digging areas are shown. The states of geological spatiotemporal objects change from details shown in Fig. 14 to details shown in Fig. 15 along with the expanding of the digging simulation process.

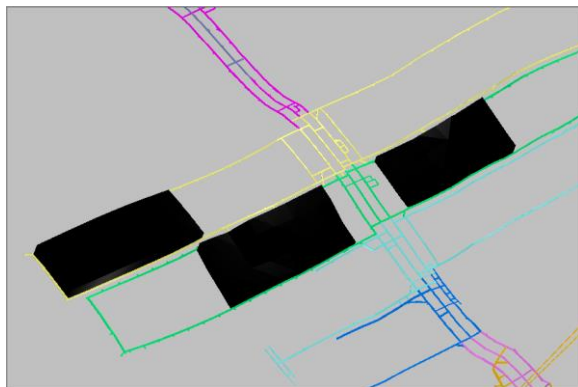


Fig. 14 Object states at an earlier time

The model index list of a coal geological spatiotemporal object is filled according to the scope of the plan digging area, the model index list of a digged-out-area geological spatiotemporal object is empty at the beginning, and an observation object is defined for each one of the three plan digging areas. The response function of geological spatiotemporal objects should be opened before the observation data sending starts in order to avoid observation data loss.

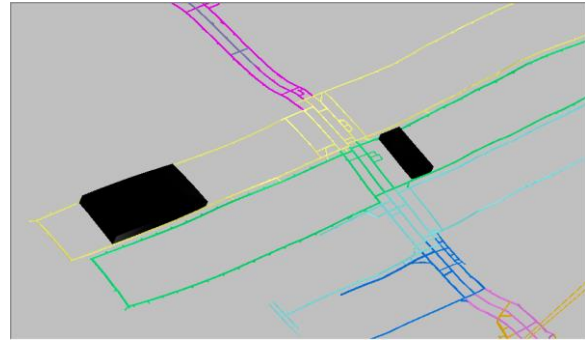


Fig. 15 Object states at a later time

The observation data is sent to OPC Items one field by one field through OPC Client software. When OPC Items are updated, the observation objects get the values to store immediately and combine them into exploitation events. Exploitation events are sent to coal and digged-out-area spatiotemporal objects and used to calculate the influence range.

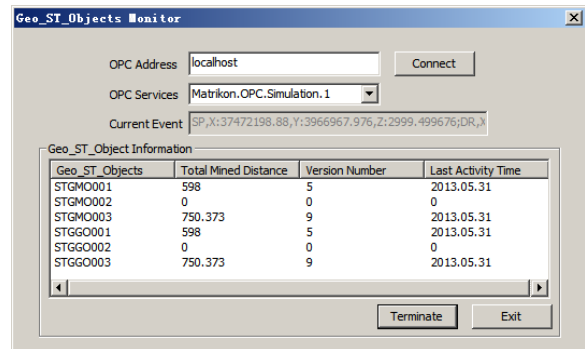


Fig. 16 The monitor interface of Fig. 14

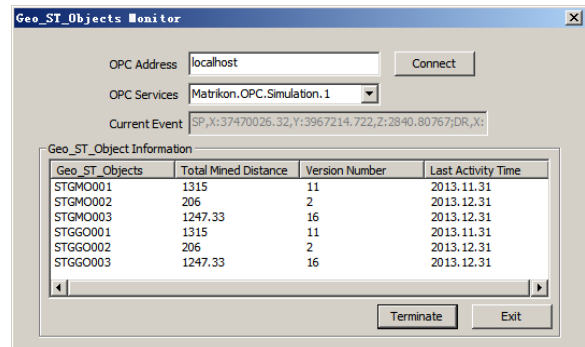


Fig. 17 The monitor interface of Fig. 15

The spatiotemporal objects find out the 3D geological models whose index is stored in the objects' index list and whose border intersects with the influence range. New geological spatiotemporal versions are created using the 3D geological models found which will be marked by display module with digged-sign meaning hidden.

Users can synchronously monitor the states of every geological spatiotemporal object including total digged distance, the number of generated versions and the last activity time through the monitor dialog, as shown in Fig. 16 and Fig. 17.

This experiment achieved the goal of simulating coal digging process which verifies the feasibility of the theory and method presented.

4. Conclusion

The present research is established on the exploration demand of the theories and methods of spatiotemporal mine information system and aimed at promoting the management of 3D geological models in spatiotemporal data model. Then three levels of technology are formed including the 3D geological model management using geological spatiotemporal object and geological spatiotemporal version, the access of observation data and the response of exploitation events. At last, an experiment was carried out with actual coal mine survey data and the effect is quite good.

The research is successful in a certain degree and is beneficial for related works. It proves spatiotemporal geological information system become possible. 3D geological solid models can be managed much more efficiently and dynamically by method presented here. In addition, this paper tried a new mind to simulate the digging process in solid mine and it can be extended in many details to make the simulation more realistically and smoothly.

Inevitably, there is some optimizing work need to be done. Firstly, on expectation real-time data can be accessed instead of historical data through the building of hardware environment to simulate the state of the mine in real time. Secondly, it is necessary to study the algorithms of real-time cutting of 3D geological model to extend the scope of application.

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