3D REPRESENTATION AND SIMULATION OF MINING SUBSIDING LAND BASED ON GIS, DPS AND GPS

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KEY WORDS: Mining subsidence, integrated data collection system, spatial simulation, hybrid data structure, 3D data structure

ABSTRACT:

Mining subsidence is a kind of familiar Geo-phenomenon, and creates serious damage to regional ecology and environment in mining areas. The monitoring, treatment and management of mining subsidence land have already got more and more attentions, and those are seemed as one of the fundamental issues on sustainable development of mining areas. Among all those studying fields, the collection of information about subsiding land, 3D representation and simulation may be the most important. It is proved that Digital Photogrammetry System (DPS) and GPS techniques can be used to capture information needed in representation of mining subsiding land with the assistance of conventional surveying technique and spatial forecasting model. By the Integrated Data Collection System (IDCS) information about subsidence, exploitation and land use in different time and position can be got. It is important and meaningful to realize 3D representation and simulation of subsiding land and its dynamic processing, and many key issues should be discussed.

In this paper, after and introduction, the mining subsidence phenomena and properties of subsiding land are discussed firstly, including the causes, features, and its impacts on mine production and human-settlement environment. In part III, an integrated data collection system (IDCS) formed by DPS, GPS, TS (Total Station), level and GIS would be proposed. In part IV, 3D data structure, especially 3D integrated data structure are analyzed according to practical situation, and some useful 3D integrated data structure are proposed, and then the integration of GIS and mining subsidence forecasting model is studied. Finally, some conclusions are given in part V.

1 INTRODUCTION

After underground mineral was exploited, the original stress situation in strata and rock was destroyed and would be distributed again. When the new stress situation formed, the rock would collapse and ground surface subside, that is mining subsidence. Mining not only bring damages to land resource and landscape, but also cause damages to water resource (including ground and underground water), forest, ground building and construction, at last the physical, chemical and ecological environment would be influenced. So mining subsidence has already become a kind of important human-settlement environment problem and got more and more attention from different fields. Among those, how to capture the spatial information about subsidence and represent and simulate the subsiding land is a very important issue, but relative achievements are few. With the development of Geomatics, which takes Remote Sensing (RS), Geographic Information System (GIS) and Global Positioning System (GPS) as its core, those problem can be solved by "3S" technology to great extent. In this paper we would give some discussions on the dynamic process of mining subsidence, spatial information capturing, representation and simulation of subsiding land and process and relative issues.
2 MINING SUBSIDENCE AND ITS PROPERTIES

As a typical damage to landscape and environment, mining subsidence has many important features, and those are the basis of further studies. In order to simulate and represent the shape and features of mining subsidence, its dynamic process and properties should be understood firstly.

2.1 The dynamic of mining subsidence

Mining subsidence is a typical spatio-temporal dynamic process. The mining activities were conducted underground and brought damage to rock directly, and then the stress change would spread in vertical and horizontal directions, finally, land over working space and goal would subside and create other problems, and this procedure can be demonstrated by Fig.1.

![Diagram of mining and subsidence](image1)

Fig.1 The relationship of mining and subsidence

From Fig.1 we can describe the dynamic process as follows: (1) before coal was mined, underground rock and ground surface is stable. (2) After mining begins, the balance of underground stress would be damaged and the force would spread to ground surface, but before point 1 was mined, no impact was created to point A on ground surface. (3) When 1 was mined, point A began to move at a low speed and with acceleration. (4) When point 2 was mined, point A would subside with biggest values and begin decrease, but continue to move. (5) After point 2 was mined, point A would continue to move with a lower speed until it reaches a stable situation. So we can know that this process is complex and dynamic.

We also can describe the procedure by Fig.2. From Fig.2, it can be known that the area of subsiding land is much larger than underground goal by mining, and it looks like a basin, so it is called subsiding basin.

2.2 The properties of mining subsidence

It is well known that GIS applications should be based on the properties of geo-phenomena and its demands, so we would give discussions on them.

(1) Mining subsidence is a three dimensional (3D) dynamic process, so if we want to express and analyze it in GIS, multi-dimensional and dynamic model and methods are necessary.

(2) It is influenced by several factors, including thickness of coal seam, mining depth, properties of rock and its force features, mining methods and others. When it is analyzed in GIS, different factor should be represent in different layer with different patterns, and the information should be easy to get and organize.

(3) Subsiding land can be expressed by different land use and land cover, and it can be identified by spatial and attribute information. So it should be represented by spatial and attribute information with different methods, such as shapes, DLM, images and other forms.

(4) It is a non-linear and non-even process, so the simulation can't be realized by GIS solely, and it should be based on the combination of spatial analyzing model and GIS. How to establish the model is a key issue, especially to non-linear and non-even process, the modeling methods based on statistics, experience, mechanism and rule should be used.

(5) It obeys some laws and can be forecasted, so GIS can be used to simulate and forecast the land subsiding situation, but how to realize it is an important and difficult problem, especially how to represent the laws by GIS.

(6) It will cause some further damages and problems, including water and soil loss, damage of construction, impact on water resource and land pollution. In GIS, mining subsidence would be integration with other problems, and it should be open to other field. Then, the data, information and model should obey certain standard and rules.

From above properties, we can know that if we want to study subsidence in GIS, several key issues should be given more discussions, and in this paper emphasis would be paid on the spatial information collection and 3D representation of subsiding
land and the dynamic process

3 SPATIAL INFORMATION COLLECTING BY IDCS

It is known that mining subsidence can be expressed by two means: spatial position (elevation of points) and attribute change (the land use and land cover change caused by mining subsidence). Spatial information is the basis of all studies, especially in GIS applications.

Nowadays, spatial information about mining subsidence can be captured from different means, including field surveying by theodolite, level, and Total Station (TS), cubic measurement and landscape reconstruction by photogrammetry and Remote Sensing, deformation monitoring based on INSAR technique, estimation by forecasting model, and dynamic monitoring by GPS technique.

Nowadays, forecasting model and field surveying are the main techniques used in practices, but each of them has inevitable shortages. Forecasting model depends on the geological, mining parameters and mechanical features of rock, and is variable with different environments, and some assumptions are applied in the model, so its precision is limited, even though different methods and theories are used. Field surveying is time-consuming, high cost and only results on some observing points can be measured, and other points should be interpolated by mathematical model, so the precision is not very high.

With the development of photogrammetry, GPS, and Remote Sensing (RS), spatial information of subsiding land can be collected by those techniques. Especially Digital Photogrammetry System (DPS), GPS combined with GIS can be used to realize the integration of information collecting, processing, 3D simulation and representation and spatial analysis in an uniform system.

3.1 DPS and its application

In recent years, DPS has become one of the most important means to get spatial information about terrain, landscape, building and other entities, and some software such as VirtuoZo can be used. Fig.3 is the flow of DPS to spatial information collecting of subsiding land.

Because subsiding land is low in middle and high at edge, it is convenient to do the fieldwork of photogrammetry, and some work had been done in this field. The further direction is to input the images into GIS, process them by professional modules compute spatial information and represent the results by DEM and contour.

3.2 GPS and its application

With its advantages of round-the-clock observation, high automation, 3D information collection simultaneously, easy work

Field reconnaissance Data collecting and pre-processing

Design of scheme and technique Image pre-processing

Field photogrammetry and image collecting Coordinate computing

Digital image processing Cubic measurement

Cubic reconstruction Generation of DEM

Applications of results Spatial analysis

Visual representation

Fig.3 Spatial information collecting and processing by DPS and so on, GPS technique has got more and more applications in surveying, deformation monitoring and navigation. GPS applications to mining areas have already got some progress, and one of them is to monitor subsiding land using its borders and 3D shapes. In GPS applications to subsidence monitoring, the most important issue is determination of elevation and differences in elevation. In order to use GPS to subsiding land monitoring, two schemes can be used, which are illustrated by Fig.4 and Fig.5.

We can know that the Scheme in Fig.4 is based on height interpolation and transformation between geodetic and normal height and the key is abnormal height, and scheme in Fig.5 is take the difference in geodetic height as subsidence quantity directly. It proved to effective to use each of the two schemes. GPS observing data should be process by special software before spatial information is got. Two methods can be used to input GPS information into GIS, one is importing 3D coordinates, that is X, Y and Z of each points computed by special software to GIS and the other is to develop GPS data processing module inGIS and raw observing data is input. At present, the former method is used mainly, but with the development of integration of GPS and GIS, the latter would be more convenient.

3.3 Integrated data collecting system and its applications

Several methods can be used to collect spatial information of subsiding land and each has its own advantages and shortages, so a useful choice is to set up an Integrated Data Collecting System (IDCS) to use the most effective methods for different
4.1 Surface Representation Using TIN and DEM

Subsiding land can be simulated by two means: one is expressing the land surface according to elevation of every point, and the other is simulating the dynamic process of mining subsidence including deformation of land surface and movement of rock from real 3D space. For the former, TIN and DEM can be used, and integrated data structure for the latter. Though TIN and DEM are not a real 3D representation, they are used widely to represent the surface by 2.5D because the algorithm is simple, data is easy to organize and collect, and use is convenient. By (x, y, z) of all the points collected by IDCS, TIN and DEM can be generated easily by GIS software, and they can be transformed with contour and each other. Based on DEM, some simple measurement and computation can be done.

4.2 3D Simulations Using 3D Integrated Data Structure

For complex simulation of mining subsidence, none of the data structure can be used effectively and 3D integrated data structure is necessary. According to the features of mining subsidence, two integrated data structures were proposed as follows:

4.2.1 Integrated data structure of 3D Raster and DEM

3D raster or Octree is used to represent the rock, coal seam and goaf after mining, and land surface is expressed by DEM or TIN. Firstly, the deformation and movement of land surface, rock and goaf is computed, and then the 3D cell is marked according to the generation rule of Octree. Octree and TIN are overlapped according to spatial coordinates of some control points in this scheme, the position and movement of rock should be computed by spatial model and perhaps it is not precise enough.

4.2.2 Integrated data structure of 3D vector, Octree and TIN

The goal by mining often is expressed by 3D vector data structure because it can be viewed as a regular 3D space composed by vertex, line, arc and face. The rock over goaf is represented with Octree and the movement of each voxel can be computed by spatial model, and the subsiding land surface is represented by DEM or TIN. These three different data
structures are overlapped by spatial coordinates of control points. With this integrated data structure, the goal can be represented more precisely by practical surveying data. The difficulty is how to compute the position of rock voxel, because the mechanical model is complex. A simplified method is to express the goal and land surface use DEM firstly and compute the height of low and high face of rock on all grids, and then the rock is expressed by its low and high face as a even body.

4.3.3 3D simulation based on CA model

How to simulate the process of mining subsidence in a read 3D space is a very difficult problem, and there is not a satisfied solution so far. With the development and applications of Cellular Automata (CA) model, we think 3D CA model based on 3D raster and Octree perhaps can be used to simulate the process. In this model, the situation of each cell is determined by a moving rule based on its former situation and properties of neighbors. So coal seam, goaf, rock can used different moving rules to determine their situation, and then subsiding land surface represented by DEM of TIN can be overlapped on the 3D CA. Because it is a new field and much work should be done further, we propose it as a future-studying theme.

4.3 Integration of GIS and Forecasting Model

No matter which kind of integrated data structure was adopted, the generation of DEM or TIN of subsiding land based on elevation of sample points is necessary. Two methods can be used to determine the elevation, one is by data from IDCS proposed in the former, the other is to compute the subsidence quantity of each points by forecasting model and then elevation can be got. For the latter, integration of GIS and forecasting model is key. Four means as follows can be used to integrate spatial analytical mode and GIS.

1. (a) Loose integration scheme by data transmission between GIS and forecasting model, in which parameters needed is got from GIS and transmitted to spatial model to compute the elevation, and results are input to GIS, and then DEM or TIN can be generated.
2. (b) External seamless integration based common interface, in which user can interact with a common interface and GIS and spatial model are conducted by messages, events and methods from interface.
3. (c) developing forecasting module in GIS by secondary development, for example, using Map Basic of MapInfo or AVENUE of ArcView to develop the processional model.
4. (d) including GIS functional module into forecasting model.

Fig.7 is the illustration to the four methods. All the four methods can be used according practice, and the former two are used mainly at present.

5 CONCLUSIONS

Mining subsiding land is one of the most serious environmental damages in mining areas, and it should be regulated and treated by land reclamation and ecology reconstruction. It is useful and important to manage the subsiding land based on GIS, and some important issues including data collection, 3D representation and simulation, 3D data structure used, and so on. In this paper, an IDCS based on GPS, DPS and GIS is proposed to collect the 3D and dynamic information about subsidence, and some useful data structures for 3D representation and simulation including DEM or TIN, integrated data structure are put forward, and the integration of GIS and forecasting model is discussed at last. It is proved effective to use those techniques and methods to solve practical problems. Of course, there are much work should be done in the future, for example, the 3D CA model, simulation of dynamic process of mining subsidence, and so on. We would like to do further studies in this field.

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