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特　　集

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In this paper the author discusses the techniques and methods of monitoring coal mining subsidence using 3D laser scanning, respectively discusses data acquiring, data preprocessing, 3D modeling, data analysis, and damage forecasting. The author points out that DTMs are the foundation of data analysis and damage forecasting, the data of every period can build three kinds of DTM: Point cloud surface model, irregular triangular mesh surface model and regular grid surface model. Variation of elevation direction can be calculated through regular grid surface models, and variation of horizontal direction can be calculated through irregular triangular mesh surface models, combine variation in elevation direction and in horizontal direction, the regularity for change of the ground surface can be deduced and the variation in the future also can be forecasted. The aim of constructing point cloud model is to quest regularity for change of ground surface from another viewpoint.

Keywords : 3D laser scanning, Monitoring mining subsidence, DTM, Feature matching

1　INTRODUCTION

Ground subsidence caused by coal mining activity brings havoc for ecological environment, even becomes the decisive restraining factor of regional economies sustainable development. In order to minimize losses, variation and development tendency of ground surface above mining goaf must be monitored timely and accurately, and educe accurate forecast information, so for a long time, mining subsidence observation is considered as one of the most important research fields of mine survey. Traditional mining subsidence observation is set monitoring points in subsidence areas, and accurate survey these monitoring points regularly or periodically, then simulate the variation of the whole subsidence area according the monitoring information. Though traditional mining subsidence observation has proven technique, it has obvious disadvantage: high cost, high labor intensity, and limited monitoring information, and even more important is that monitoring points are easy to be destroyed and not easy to be recovered, the accuracy of monitoring and forecast must be influenced.

In order to make up the disadvantage of traditional mining subsidence observation methods, some new methods and techniques are used in monitoring coal mining subsidence: Close-range photogrammetric technique acquire digital image pairs of coal mining subsidence area, then work out the 3D coordinates of a

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series of feature points based on these image pairs, using these feature points construct DTM of different times, then contrastive analysis these DTMs, characteristic parameters such as shape, depth, and volume and so on of the subsidence area can be calculated [1,2] ; D-InSAR technique acquires satellite SAR data of different times and process them use differential interferometry method, and LOS deformation figures are got, then covert these LOS deformation figures into subsidence value, the extension and evolution discipline of the monitoring area can be analysed [3,4,5] . Robotic total stations as an efficient data acquiring equipment general used in landslide monitoring and strip mine side slope deformation monitoring [6,7] ; GPS-RTK technique is also used in coal mining subsidence monitoring [8] .

3D laser scanning technique has the advantage of high accuracy, high efficiency, and non-contact in data acquiring, it can direct acquire 3D surface information of the subject of study, there would be no doubt of that 3D laser scanning technique has distinctive advantage in monitoring mining subsidence [9,10] . There need no monitor points in using 3D laser scanning technique monitoring mining subsidence, and area-scan data can provide enough information for the monitoring and forecasting, 3D laser scanning can acquiring 3D surface information of the monitoring area of different periods, after contrastive analysis of these information, ground surface deformation of every differential regions can be accurately worked out, variation discipline of ground surface can be deduced and the deformation tendency of the future can be forecasted. However, the studying of monitoring mining subsidence with 3D laser scanning technique is still at exploration stage, no proven methods and techniques, no uniform operating mode, and no uniform technical manual. In this paper, the author will have a deep exploration on the methods and techniques monitoring mining subsidence using 3D laser scanning technique combine with practical experience, and point out practicable solutions and research ideas. This paper will have some promoting effect for the applying and developing of monitoring mining subsidence with 3D laser scanning technique.

2 METHODS AND TECHNIQUES

The research of monitoring mining subsidence using 3D laser scanning technique covers a process of data acquiring, data preprocessing, 3D modeling, data analysis, and decision supporting. As every stage has different way, and emphasis is distinct, now we will discuss these methods and techniques respectively:

2．1 Data acquiring

Data acquiring of ground surface of the subsidence area is the first step of the research process. Data quality is in relation to the quality and effect of the whole research work, and even affect the final conclusion of the whole research work. The aim of using 3D laser scanning technique is of its advantage of data acquiring speed and data accuracy, so how to acquiring data of the research object accurately and efficiently is the first question to resolve. Data acquiring has three steps: data collection and reconnaissance trip, error estimate and control network set up, instrument install and scan. At the first stage, researchers should contact with mining unit and get necessary information about the monitor area, including mining position, geological condition, mining progress and so on, then have a serious investigation about the subsidence area, and work out a preliminary scheme about the control network. At the second stage, error estimate should combine the two sources of error: errors from control network and errors from 3D laser scanning data. The later not only related to instrument properties of the laser scanner, but also related to scanning range, data density, target reflectivity and so on. After finish error estimate, control network should set up on the spot. Control network mainly include two parts: reference points and observation points. Reference points are out of the monitoring area, they are inbuilt in stable foundation soil, The function is for spatial location basis reference. Observation points are set in monitoring area, the function is for set up instrument, provide reference for every observation station. During the monitoring, positions of observation points are constantly changing, so the positions must re-observed before setting up laser scanner. The setting up of observation points should keep on the following principles: (1) Uniform distribution as far as possible; (2) Reduce the number of observe points as far as possible; (3) Observation points should be set up at the places that fit for set up instrument and to acquire data; (4) There should have some overlapping among observation stations. At the third stage, the scanning work should be finished in the shortest time, and the data acquiring program should appropriate readjust. If the terrain of scanning area is flat and have much bare field, the density of scanning spot should be reduced; If the terrain of scanning area is complex and covered by superior vegetation, the density of scanning spot should increase; If the shielding is severe, there should add new observation station according actual situation.

2．2 Data preprocessing and 3D modeling

After the primary process, data acquired by the laser scanner mainly including three parts: 3D coordinate, textures and reflectivity information. 3D coordinate convert point cloud into image, which is the main study object, the other two kinds of information as auxiliary information. Primary point cloud data contains some noise, and also have many data holes, and the data distribution is not uniform, there needs data processing operation such as noise filtering, hole filling, spatial interpolation and so on, then construct precise digital terrain model, which is the basis of data analysis.

2．2．1 Data reducing and data merging

3D laser scanning acquiring data at a equal angle stepping mode, but the height of tripod, which is used for set up laser scanner, is limited. This kind of working mode leads to non uniform data density: The data density is very high near observation station, and exceed the requirement; As the distance increasing, data density is diminishing; At the marginal area, the data density is very sparse; Restricted by scanning angle, there have no data in a small area around the observation station. Not only non uniform data density, but also large data seriously influence the speed and efficiency of data processing. So it is necessary to appropriately reduce data. The emphasis of data reducing is the areas close to the observation stations. Some data can be removed directly according to some rule. After finish data reducing of every observation stations, then merge all observation stations data together, the data is stored in one file according to coordinate, or stored in several data block. After data reducing and data merging, some holes are filled, the data density also balanced as a whole.

2．2．2 Filtering

3D laser scanner records all the information that can be detectec without choice, including buildings, structures, vegetation, water and bare soil. The main task of data processing in prophase is accurately and effectively filter cluttered information and reserve bare land surface information. In laser point cloud image, buildings, structures, trees and bushes have distinct characteristic and easy to be recognized and filtered automatically or artificially; Because of reflected signal is very weak, water usually has no exploratory data and leave holes in point cloud image, now the texture information can be used to assist identify water; Low bushes and weeds information is a headache thing, low vegetation is of wide distribution and the configuration is varying as time varying, so low vegetation filtering is the emphasis and difficult point of 3D laser scanning data processing in prophase. Textures and reflectivity information can be used as ancillary information, deal with point cloud data similar to supervised classification of remote sensing image, research the texture and reflectivity of different kinds of vegetation at different distances, then extract vegetation from bare land according to sample value. Vegetation is grows on the ground, at a small region, vegetation point is higher than bare soil, so divide subsidence area into many small regions and project scanning points onto these small regions, every small region is considered as one unit and accept or reject the points lies in it following some rule, as a general rule, reserve minimum elevation point will get good result.

2．2．3 Hole-filling

Holes owing to obstruction during data acquiring and filtering needs to be filled with some proper way, and estimate missing data. There are many hole-filling algorithms, different feature of the landscape should select different algorithm. Subsidence area data acquired by laser scanning is very huge, it is almost impossible that all the data take part in calculation. So, global-based algorithms is impracticable and local-based algorithms should be opted, testing proves that local cubic-fit-surface algorithms can get better result.

2．2．4 Subsidence area modeling

After data preprocessing, digital terrain models should be built, they are basic data for data analysis and damage forecasting. There mainly three kinds of digital surface models: Point cloud surface model, irregular triangular mesh surface model and regular grid surface model. Point cloud surface model is made up by point cloud. It also has data structure, in addition to 3D coordinate, every point has topological relation with its surrounding points; Irregular triangular mesh surface model is directly built by points after data preprocessing according to some rules. It has the advantage of describe local detailed characterization; Regular grid surface model has simple data structure and topological relation. Every point of square control network is fixed. The elevation value is calculated by the interpolation of its surrounding points.

2．3 Data analysis and damage forecasting

The ground variation of mining subsidence area is a continuing and global process. In data processing, we should breakthrough the restriction of traditional mining subsidence monitoring pattern, and quest law of mining subsidence from the viewpoint of global and field, meanwhile, combine local and global. Surface model is the foundation of data analysis and damage forecasting: For any one period surface model, we can get crosshatching of arbitrary direction and arbitrary position, and also can get contour through data transformation; For different period models, local variation and global variation can be get through comparative analysis among them, the regulation can be deduced, and the variation in the future also can be deduced. Regular grid surface modes of different period have fixed horizontal coordinates. The difference of elevation coordinate describes the variation in elevation direction, the difference value between two models also of subside model. Comprehensive analysis of the models of subside and the regulation can be found. Irregular triangular mesh surface model can describe local detailed characterization of the surface model. Comparative analysis of two irregular triangular mesh surfaces through feature matching algorithm and horizontal variation can be calculated. Then combine variation in elevation direction and in horizontal direction, the regularity for change of the ground surface can be deduced and the variation in the future also can be forecasted. The aim of constructing point cloud model is to quest regularity for change of ground surface from another viewpoint.

3 CONCLUSION AND DISCUSSION

The author quest the techniques and methods of 3D laser scanning monitoring coal mining subsidence. The research mainly includs data acquiring, data preprocessing, 3D modeling, data analysing, and decision supporting.

The author points out that DTMs are the foundation of data analysis and damage forecasting. The data of every period can build three kinds of DTM: Point cloud surface model, irregular triangular mesh surface model and regular grid surface model.

Variation of elevation direction can be calculated through regular grid surface model, and variation of horizontal direction can be calculated through irregular triangular mesh surface models, as it is based on feature matching algorithm, and there has no efficient 3D feature matching algorithm, so there still need a breakthrough in theory. Using point cloud model to detect variation is a novel idea and needs further study.

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概要

本論文では，炭鉱の沈下を 3 次元レーザ走査を用いてモニタリングする技術と手法を議論する。ここで議論する技術は，それぞれ，データ収集，データ前処理，3 次元モデリング，データ解析，破壊予測等である。著者は，デジタル地形モデル(DTM)がデータ解析と破壊予測の基本であることを指摘し，時刻毎のデータから 3 種類の DTM を構成する。それらは，それぞれ，点群表面モデル，不規則三角形メッシュ表面モデルおよび規則的格子表面モデルである。垂直方向の変化は規則的格子表面モデルによって，水平方向の変化は不規則三角形メッシュ表面モデルによって計算され得る。垂直方向と水平方向の複合的な変化は点群表面モデルや地面の変化の規則性は推論され，未来の変化も予測される。点群モデルの構築の目的は，別の視点からの地表面の変化に対する規則性を探求することにある。

Keywords : 3D laser scanning, Monitoring mining subsidence, DTM, Feature matching