Application of UAV Photogrammetry in Mining Areas

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The geological environmental damage caused by coal mining has become a hot issue in current research. Especially in the western mining area, the size of the mining working face is large, the mining intensity is high, while the surface movement and deformation are more intense and wider. Therefore, it is necessary to effectively monitor the surface using appropriate means and carrying out research on the overlying strata structure of the stope.

mining subsidence UAV photogrammetry

1. Introduction

As an essential source of coal resources in China, coal mining in the western mining area has caused serious geological and environmental damage problems while meeting energy demands. Especially in recent years, with the rapid development of coal mining technology, large-scale, rapid, and high-intensity mining has become the norm. The mining area is mostly characterized by the continuous mining of multiple large-size (generally 150 m–400 m) adjacent working faces. The law of overlying strata and surface movement caused by mining is more complex than that of a single working face. Moreover, the surface movement and deformation show the characteristics of fast subsidence, large deformation, and wide influence range, which also brings specific difficulties and various challenges to the surface monitoring [1].

The monitoring technology of a mining area mainly includes conventional surface monitoring technology, unmanned aerial vehicle (UAV) photogrammetry technology, and InSAR (interferometric synthetic aperture radar) monitoring technology. Among them, conventional surface monitoring technology arranges “point–line” observation stations on the main section of the strike or inclination of the working face and carries out conventional measurements such as GNSS (global navigation satellite system), traverse, and/or leveling [2]. The observation accuracy of this technology is high; however it has the disadvantages of high cost, heavy workload, easy damage to measuring points, and ease of being limited by topography. Therefore, meeting the needs of surface damage monitoring for high-intensity and large-scale mining in the western mining area is challenging.

The application of UAV photogrammetry in mining areas has a long history. This technology was originally used for topographic mapping [3]. D-InSAR (differential interferometric synthetic aperture radar) is a technology that uses the phase information of synthetic aperture radar complex images to obtain surface subsidence information. It has the advantages of monitoring all times of day, over a large area and at high precision. Similarly, the structure of overlying strata is key to clarifying the law and mechanism of mining subsidence. The existing literature has discussed various proposals based on field measurement, numerical simulations, and theoretical analysis.

2. UAV Photogrammetry in Mining Areas

In terms of UAV monitoring, relevant scholars have also carried out a number of studies. In previous studies [4][5], UAV aerial survey technology was used to obtain DEM (digital elevation model) data on the surface of coal mining subsidence areas, which demonstrates and verifies that the data accuracy could reach to the centimeter level. Paweł et al. [6] used UAV photogrammetry technology to monitor the surface discontinuous deformation of the mining area and verified the practicability of the UAV in the domain of mining area monitoring. Ge et al. [7] used drones to observe the surface of the Tahmoor mining area in New South Wales, Australia, and plotted the subsidence curve of the surface of the mining area. Zhou et al. [8][9] used the UAV photogrammetry approach to monitor the surface subsidence of a coal mining area, inverted the subsidence prediction parameters, and verified that the accuracy of the subsidence basin was 81 mm. Puniach et al. [10] obtained high-resolution digital orthophoto images before and after surface deformation in the mining area using UAV photogrammetry. Furthermore, a weighted, normalized cross-correlation algorithm was used to constrain the matching results, and the obtained horizontal movement was compared with ground 3D laser observations. The authors observed that the accuracy can reach up to 1–2 pixels. Dai et al. [11] used UAV technology to obtain orthophoto images of tailings dams and monitored the maximum subsidence range within 0.16 m. However, UAV technology is still limited by factors such as cost and accuracy in mine monitoring.

In terms of D-InSAR monitoring, Gabriel et al. [12] first used D-InSAR technology to separate the deformation phase from the terrain phase in the interferometric phase and confirmed that the monitoring accuracy of surface deformation can reach centimeter or even millimeter level. In 1996, Carnec et al. [13] first used the D-InSAR method to monitor the surface subsidence of the mining area near Gardanne; the maximum subsidence value obtained was 42 mm, and the root mean square error of monitoring was approximately 459 mm. Moreover, it was found that the differential SAR interferometry was not suitable for monitoring large gradient deformation areas in a short time. Similarly, Yang et al. [14][15][16] monitored the surface deformation caused by mining in the mining area based on monorail InSAR, time series InSAR, and the combination of InSAR technology and leveling. The authors verified that the root mean square error was between the predicted surface subsidence value and the InSAR monitoring is 2.15 cm and analyzed its subsidence law. Zhang et al. [17] proposed the fusion of “D-InSAR measurement (space)” and “radon monitoring (ground)” to monitor surface mining cracks in mining areas. However, due to the influence of space–time decoherence, atmospheric delay, and orbital error, D-InSAR technology could not reliably obtain the large deformation in the central area of the subsidence basin.

Scholars have made some achievements in the study of overlying strata structure; these proposals and the obtained results are largely related to a single working face and multiple working faces are relatively unexplored. In addition to this shortcoming, all previous studies have collectively shown that there is vertical zoning and horizontal zoning in the mining strata of the working face [18]. In terms of rock mechanical structure, cantilever beam theory, pressure arch theory [19][20], hinged rock block hypothesis [21], and key stratum and voussoir beam theory [22][23] are the main contributions. Wu et al. [24] proposed the supporting plate theory in strip or room-and-pillar mining prediction theory. Aiming at the problem of mining pressure behavior in adjacent mining, Jiang [25] proposed four types of overlying strata spatial structure, i.e., (i) θ-shaped, (ii) O-shaped, (iii) S-shaped, and (iv) C-shaped.

He et al. [26][27] proposed the dynamic evolution process of overlying strata “OX–F–T” structure, and provided the mechanical conditions for the instability of key stratum in adjacent goafs. Yang et al. [28] studied the stability of a goaf roadway in adjacent working faces of the same coal seam. Based on the key stratum theory and 3DEC numerical simulation, Yu et al. [29] put forward their observations under the conditions of fully mechanized top-coal caving mining with large mining depth. The authors observed that with the increase in the total quantity of working face mining, the surface experiences the breaking form of the key stratum in the extremely insufficient–insufficient–sufficient process, which has a direct impact on surface movement and deformation.

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