Geological hazard interpretation and hazard evaluation of open pit mines based on Unmanned Aerial Vehicle images

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Abstract. Over-exploitation of open-pit mines has caused extensive development of geological hazards, posing serious threats to people and buildings in the area. Based on the UAV tilt-tilt photography technology, this paper generates a real-world 3D model of the study area, taking the molybdenum mine of Songshumao in Yangjiajiaozi, Xingcheng City, Liaoning Province as an example, and combines orthophotography, high-precision DEM data and field geological survey research to establish a geohazard interpretation marker for the study area and interpret various types of geohazards such as landslides, landslides, dangerous rocks, ground cracks and unstable slopes in the study area. Based on the hierarchical analysis method combined with the geological environment characteristics, the geological hazard risk evaluation model and index system were established, and five indexes were selected, including geological hazard range, stratigraphic lithology, slope, elevation, vegetation coverage, etc. The study area was divided into high, medium and low risk zones, and the geological hazard risk zoning map was obtained to complete the geological hazard risk evaluation of the study area.

1. Introduction
In recent years, social and economic development has accelerated the exploitation of mineral resources, but due to long-term improper exploitation, the potential geohazard hazards have gradually increased. With the acceleration of ecological civilization construction, the problem of geological hazards caused by mining based on mining has received widespread attention. Common geological hazard problems in mining areas include ground collapse, slope instability, ground fractures, landslides, and dangerous rocks, etc. The problems such as geological hazards induced by mines seriously hinder the sustainable development of national economy [1]. In the past, the geological hazards in mining areas were mostly monitored manually, which was limited by the spatial vision and often untimely prediction. The complex geological conditions of some open pits and the existence of many huge safety hazards in the pits have restricted the access of geological staff. In recent years, remote sensing technology has accumulated a large number of research results in mine monitoring, but there are some difficulties to be determined in mine geological disaster investigation based on satellite remote sensing due to the limitation of satellite image resolution and accuracy.

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UAV is a flexible, lightweight, terrain-independent and very excellent loading platform for near-ground remote sensing data acquisition. Coupled with the low cost, large scale and high accuracy of UAVs and the gradual maturity of image modeling technology, it has led to a gradual increase in its application in the fields of surveying and mapping, electric power, engineering, mining and homeland. Based on the characteristics of high flexibility, low influence by weather and high accuracy of UAV, UAV remote sensing can quickly obtain high-precision, high-resolution and time-efficient remote sensing images of geological disaster areas [2]. Through the technology of UAV tilt photography, a high-definition three-dimensional realistic model can be obtained, which can clearly obtain the production information of rock bodies and rock layers and better reflect the real spreading of rock layers [3][4], and get the basic data of geological disasters with high resolution, high timeliness, high precision and high accuracy [5]. For open pit mining, the orthophoto obtained by UAV technology can identify various types of geological hazards and obtain their types, scales and hazards, etc[6]. Through the data of multiple phases, the 3D model established by UAV tilt photography can clearly monitor the deformation modulus of the pile in the mining site and monitor the dynamics of mining[7].

In this paper, taking the molybdenum mine of Songshumao in Yangjiajiaozi, Xingcheng City, Liaoning Province as an example, a realistic 3D model of the mine area was established by using UAV tilt photography technology, and the realistic 3D geological model was used to decipher geological hazard information such as landslides, unstable slopes, dangerous rocks and ground cracks, and to make a comprehensive evaluation of the risk of geological hazards in the mine area.

2. Regional geological overview
The Songshumao molybdenum mine is located in Yangjiajiaozi Town, Xingcheng City, Liaoning Province, which is under the jurisdiction of Huludao City. In terms of tectonic position, the Xingcheng area is in the transition zone between the northern edge of the North China plate, the Shanhaiguan ancient uplift and the Mesozoic depression zone in western Liaoning [8], with the North China fault depression in the southeast and the Inner Mongolia geological axis in the north, and intraplate deformation in the Mesozoic under the influence of the Pacific tectonic domain. The area is rich in mineral resources, with large reserves of molybdenum, iron ore, lead-zinc ore, limestone, etc. [9]. Among them, Yangjiajiaozi Songshumao molybdenum mine is a large and medium-sized molybdenum deposit, and due to long-term molybdenum mining, the local ecological environment has deteriorated and there are a large number of abandoned sites, which destroy the local ecosystem, and there are many safety hazards such as landslides, mudflows, ground cracks, and dangerous rocks, which seriously threaten the living ecological environment of local residents.

3. Data Acquisition & Processing
3.1 Data Acquisition
The process of low-altitude image acquisition includes basic data preparation, technical preparation, and flight preparation (Figure 1). Preliminary survey and observation of the survey area should avoid airports, important facilities and densely populated areas, select the best window period according to the weather forecast, use the area with open view and good clearance conditions as the UAV takeoff platform, and judge and identify trees, mountains, pylons, etc. that may obstruct the UAV communication signals. When conducting flight operations, check and debug the UAV system's star search, GPS, magnetic declination, power, image sensor and propeller in advance to avoid the UAV from reporting errors and falling down, and conduct flight tests to ensure stable UAV flight. When conducting route planning, the flight height should be determined to avoid collision between the UAV and trees, mountains and other obstacles, calculate the time interval of the UAV image sensor shooting, and ensure that the overlap of the images obtained by the UAV flight heading and side shooting reaches more than 60%.
Figure 1. UAV low altitude image acquisition and modeling process

In this study, the DJI Phantom 4 Pro multi-rotor UAV is used as the flight load platform with a 20 megapixel image sensor. The ground control platform uses DJI's DG GS PRO route planning software. DJ GS PRO has an intuitive and easy interaction design, which can control the DJI aircraft to achieve autonomous route planning and flight, easily and conveniently plan complex route tasks, and perform fully automated waypoint flight photography. A day with good weather and low wind was selected for the flight operation. The overlap of images in the direction of the planned flight route reached more than 80% and the overlap of images in the side direction reached more than 60%, and a total of 700 high-resolution aerial images of the UAV were obtained.

3.2 Data processing
The data processing mainly includes pre-processing and post-processing, and the pre-processing process includes screening, correction, aberration correction, extraction and and formatting of UAV attitude parameters for the images [10], and the post-processing mainly uses Agisoft photoscan and ContextCapture software for dense point cloud generation, real-world model construction, and orthoimage acquisition (Figure 2).

3.2.1. Feature point matching
Based on the algorithm of finding the same features in the image collection from the motion recovery structure, the position and attitude of the UAV image sensor are obtained according to the corresponding feature points, and the GPS and image control point position coordinates of the camera are combined to obtain the real spatial coordinates of the feature points. Through the incremental algorithm, after several iterations of image calculation, these feature points gradually form the feature point cloud.

3.2.2. Dense point cloud
Based on the basic principle of aerial triangulation, the point cloud is dense by using the Multi-vision Stereo Vision (MVS) algorithm. The coordinates and poses of the existing cameras are searched systematically on the pixel grid to improve the matching accuracy to obtain more point clouds and generate dense point clouds on the surface.
3.2.3. Generating grid
Through the original aerial image data of the UAV and the generated dense point cloud data with coordinates, the 3D geometry of the model is lent to generate spatial geometric data such as points, lines, surfaces and bodies.

3.2.4. Real-world 3D model creation
Through the RGB information in the original image, the texture is given to the generated 3D grid. Obtain the digital elevation model, digital orthophoto and realistic 3D model in the flight area.

4. Geological hazard interpretation
By pre-processing the data from the aerial images collected from the Songshumao molybdenum mine in Yangjiajiaozhi and processing them through Agisoft photoscan software, we obtained point cloud data, high-precision real-world 3D models, digital orthophotos, and digital elevation model data within the mine area (Figure 2).

![Figure 2. Results of aerial image data processing in the study area](image)

4.1. Establishing geohazard interpretation markers
Through comprehensive analysis and comparison of the real-world 3D models, orthophotos, and digital elevation models obtained in the study area, and combined with field geological surveys to establish preliminary interpretation marks for establishing various geological hazards in the study area (Table 1)
### Table 1. UAV image interpretation signs in the study area

| Geological hazard categories | orthophotography | Live-action 3D images | Decode markers |
|------------------------------|------------------|-----------------------|----------------|
| Landslide                    | ![image](image1) | ![image](image2)      | The side slope section formed by the rubble fill area located around the molybdenum mining pit exhibits a fan and circular structure. |
| Collapse                     | ![image](image3) | ![image](image4)      | On the orthophoto, it appears as a nearly triangular, fan-shaped arc structure, which is lighter in color. On the real-world 3D image, the collapse products are irregularly piled rock dam-like. |
| Unstable slopes              | ![image](image5) | ![image](image6)      | Quarry pit rubble fill area, slope over 70 degrees, height over 15m fill slope lot. |
| dangerous rock               | ![image](image7) | ![image](image8)      | The dominant feature that shows a certain linear result in a vertical direction and a dark color is subject to structural surface cutting and the presence of multiple fissures. |
| Ground cracks                | ![image](image9) | ![image](image10)     | It exhibits dark linear features on the orthophoto, with a continuous dendritic distribution. |

### 4.2. Geological hazard interpretation

Based on the interpreted markers, the geological hazards in the study area were classified as landslides, avalanches, unstable slopes, dangerous rocks, and ground fractures.

There are several loose piles in the mine area that have been mined for decades, and the main types of piles are slag and chert rubble, which are highly susceptible to landslides, and due to mechanical mining, the original rock fragmentation on the north side of the quarry pit is also susceptible to landslides. The landslides are mostly located on the steeply standing slopes within the quarry pit and occur on the inner side of the road around the quarry pit, and the products of the landslides are in the form of irregular pile rock dams, with the presence of huge blocks of collapsed rock, as well as rubble and broken powder. Through the digital elevation model obtained from the study area, several slope sections with slopes over 70 degrees and heights over 15m were deciphered in the study area, including the slope section of the debris fill area south of the quarry pit, with slopes over 80 degrees and some height differences over 30m. The dangerous rocks are combinations of rock masses cut by multiple groups of structural surfaces and less stable on the steep cliffs, which were observed by orthophoto and 3D geological model. The
dangerous rocks are mostly located on the cliff face of the mining pit. Ground cracks are mostly the result of the joint influence of natural and human factors, and show dark linear features on the orthophoto, mainly located above the road around the mining pit, with the width of cracks in the area about 20-30cm and the length ranging from 10m to 40m, which are continuously distributed in the form of dendrites.

Through field geological survey, combined with orthophoto, realistic 3D geological model, slope map, elevation map and other data, the remote sensing image interpretation of geological hazards in the study area is shown in Figure 3.

![Figure 3. Remote sensing image interpretation map of Songshumao area](image)

### 5. Geological hazard risk evaluation

#### 5.1. Evaluation Methodology

Hierarchical analysis is a common weighted decision analysis method, through in-depth analysis of the system and evaluation factors, the evaluation factors are divided into multiple interconnected and ordered levels, the relative importance of each factor is judged, and a judgment matrix is constructed. Because of the different geological environment characteristics and disaster types, the evaluation indexes selected for the evaluation of geological hazards vary in different regions. According to the geological environment characteristics of the study area, five hazard evaluation indexes, such as geological hazard range, terrain slope, vegetation coverage, surface lithology and elevation, are selected here. (Table 2)

| Table 2. Structural model of geological hazard evaluation |
|---------------------------------------------------------|
| Guideline layer | Indicator layer | Components |
| Geological hazard risk assessment | Deciphered geological hazards | Geological hazard scope | Geological hazard scope |
| Ground stability | Terrain slope | Vegetation cover | Terrain slope |
| | Vegetation cover | Surface lithology | Vegetation cover |
| | | Altitude | Rock type |
| | | | Elevation |

#### 5.2. Determination of weights and ranking

Geological hazards are the result of the joint action of many geological environment influencing factors, and different influencing factors have different degrees of influence on geological hazards on geological
hazards, and different influencing conditions and influencing elements within the same factor also have certain differences. According to the geological hazard evaluation model, the importance degree of different factors and the judgment matrix of hierarchical analysis method, the weights of various hazard shooting evaluation indexes were calculated (Table 3). The statistical results of geohazard development characteristics, the evaluation factors are divided into 3 levels such as high, medium and low hazard, and the values are assigned separately.(Table 4)

**Table 3. Geological hazard evaluation index weights**

| Target layer | Guideline layer | Indicator layer |
|--------------|-----------------|-----------------|
| Geology      | Geological hazard scope | 0.5 |
| Disaster     | Terrain slope    | 0.2721 |
| Hazard       | Vegetation cover | 0.0569 |
| Risk         | Surface lithology | 0.1444 |
| Nature       | Altitud         | 0.0266 |

**Table 4. Classification of geological hazard evaluation index levels**

| Evaluation Indicators | High Risk | Medium Risk | Low Risk |
|-----------------------|------------|-------------|----------|
| Geological hazard scope | High risk areas (<20m) | Medium risk areas (20m-50m) | Low Risk area (>50m) |
| Terrain slope (°)     | >40        | 20—40        | <20      |
| Vegetation cover      | 0-0.3      | 0.3-0.6      | 0.6-1.0  |
| Surface lithology     | Loess      | Gravel       | Rocks    |
| Altitud               | >300m      | 200-300m     | <200m    |

5.3. Results of hazard evaluation

The hierarchical analysis method is used to obtain the weights of each element layer and evaluation factors, and the indicator values of each evaluation factor within the element layer are weighted for superposition using the layer superposition function of GIS, while the element layers are superimposed again according to their weights, and the obtained raster result map and divided into high, medium and low hazard zones to obtain the geological hazard hazard zoning map of the study area. (Figure 4)
6. Conclusion

UAV tilt photography technology can provide safe, fast and efficient monitoring of geological hazard risk in open pit mines, with less factors influenced by climate and terrain factors. Based on the UAV live 3D model, combined with this precision DEM, point cloud data and orthophoto, the geohazard interpretation markers of the study area were established, and a number of geohazards such as landslide, collapse, dangerous rock, ground fracture and unstable slope were interpreted.

Based on the UAV tilt photography technology, and the basic principle of hierarchical analysis method, combined with the characteristics of geological hazard environment, the geological hazard risk evaluation model and index system were established, and five evaluation indexes such as geological hazard range, terrain slope, vegetation coverage were selected, and the geological hazard risk zoning map of the study area was obtained by weighted superposition.

UAV tilt photography technology is highly feasible, low-risk, accurate and reliable data in geological hazard research and investigation projects, and can be widely used in geological hazard monitoring and evaluation in mines. In today's increasingly mature artificial intelligence algorithms, the combination of deep learning, artificial neural network and other algorithms with drone technology will promote the application and development of drone technology in the field of geological hazards in a deeper way.

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