Three-dimensional fine model construction of instability in dangerous rock masses

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Abstract. Rock collapse is a common geological hazard in mountainous areas, and the prediction of the stability of dangerous rocks has always been a difficult problem in engineering practice. In this paper, a dangerous rock body in Ritu, Tibet, was scanned and measured using UAV tilt photography and 3D laser scanning technology, and the high-precision data collected by the UAV were processed and constructed into a 3D fine model, and the movement state of the dangerous rock body when it is destabilised was numerically simulated using Unity3D. In order to verify the simulation effect, a field test was conducted on a slope around Lhasa and the field test results were fitted to the numerical simulation results. By comparing the data obtained, the 3D modelling data of the high and steep slope collected by the UAV was more refined and the model was more complete than that collected by the 3D laser. Comparing the field test results with the numerical simulation results, the fit between the two is good, indicating the feasibility of using the model data obtained by UAV tilt photography for hazardous rock investigation, which provides an important reference value for future investigations of hazardous rock on high and steep slopes.

Keywords: Critical rock mass; 3D fine model; Unity3D; Model testing

1. Introduction

A dangerous rock mass is an unstable rock mass that is cut by multiple groups of rock structural faces and is located on a steep slope or cliff. The sudden, dramatic and rapid nature of the rock formations makes them one of the most difficult geological hazards to prevent, often causing traffic accidents and casualties, damaging traffic routes and other hazards, and already posing a serious threat to human life and property. The construction of three-dimensional models is a common means of studying geological hazards such as rock hazards, and this method has been used to study the destabilisation, fracture characteristics and stability of rock hazards, with good results. Therefore, three-dimensional modelling will be more effective in the analysis and characterisation of geological hazards such as rock hazards.

In the early geological modelling process, instruments such as total stations, compasses and tape measures were often used to obtain 3D geological information data, but due to the large errors in the data obtained by such instruments, they cannot yet meet the requirements of high-precision modelling data [1]. To build a more detailed 3D model, it is important to obtain effective and accurate topographic data. With the development and improvement of laser ranging technology, infrared technology and wireless remote control equipment, 3D laser scanning technology and UAV photography technology have been widely used in the geological field. The 3D laser scanning technology has been widely used in building deformation monitoring [2-3], slope monitoring [4-5], tunnel measurement [6-7], etc. because it effectively overcomes the shortcomings of traditional measurement methods such as large errors, high costs and personal safety of surveyors. UAVs have been widely used in urban construction [8-9], disaster identification and analysis [10-11] and other fields due to their higher accuracy, smaller size and flexibility, and easier and more complete access to 3D data on the surface of objects. Therefore, when modelling high and steep slopes and complex terrain areas that are beyond human reach or lack of terrain information, the data collected by the two methods should be compared and analysed first in order to obtain more effective and accurate terrain data.

Born in 1953, numerical simulation technology is widely used in the field of emergency response to emergencies such as meteorology, engineering geology, social public safety and water resources due to its outstanding decision aid function. At present, there are also a variety of numerical simulation software for studying dangerous rock masses, such as Rockfall, STONE and Ebloul. However, such software often requires a lot of time for preliminary modelling works, resulting in low efficiency, and the simulation of geological conditions differs greatly from the actual conditions, and the simulation effect is extremely unsatisfactory. In order to solve such problems, previous authors have either sought to achieve the corresponding interface between various types of numerical simulation software pre-processing [12]; or devoted themselves to the coupling of 3D geological software and numerical simulation [13]; or started to try to combine existing geological software for modelling [14]. However, these methods can only compensate to a certain extent for the shortcomings of numerical simulation in 3D modelling. After exploration, it was found that Unity3D software, which has been widely used in system simulation and virtual reality, is more suitable for numerical simulation in the geological field because it has PhysX physics engine, which can simulate collision and free fall motions more realistically.

When modelling the movement mechanism of dangerous rock masses, the previous work has not taken into account the influence of the terrain on the mapping technology and has used 3D laser scanning technology to collect data, resulting in large errors in the data; and when carrying out numerical simulations, the existing methods and software have a large gap between the simulated conditions and the field conditions, and the simulation effect is extremely unsatisfactory, resulting in some biased conclusions. It has been found that the slope data collected by UAV photogrammetry is more accurate than 3D laser scanning technology; and Unity3D can simulate collision and free fall movements more realistically, which is more suitable for numerical simulation in the geological field. In this paper, we will use UAV photogrammetry to collect data from the slopes where the rock hazards are located, and use Unity3D software to numerically simulate the movement of the rock hazards, and finally fit the field test results to the numerical simulation results to verify the fineness of the model built by this method.

2. High precision modelling

This paper presents an example of a dangerous rock along the G318 national highway in Niduo Township. The study site is located in the southeastern part of Mozhugongka County, Tibet Autonomous Region, with geographical coordinates 92°14′00"E, 29°41'30"N. The overall slope of the studied slope is about 35°, and the slope of the leading edge is 40°~45°. The surface is a loose accumulation of the Quaternary system, mostly sloping gravel block soil, and the underlying bedrock is mainly mica-quartz schist. In order to achieve high accuracy modelling of the dangerous rock masses, an unmanned aerial vehicle and a 3D laser scanner were selected to collect morphological data on the slope surface.

2.1 Data acquisition and processing

UAV tilt photogrammetry is the use of a UAV as a flying platform with a camera tilted at an angle to collect data from the study area in one vertical direction and four tilted directions. A DJI M210 industry-grade quadcopter equipped with a ZENMUSEX5S camera lens was used for the data acquisition, with an overlap of 80% in the heading and 50% in the side direction, and a course height of 150 m from the take-off point. 250 images were acquired, and 239 images were available after blurring and colour enhancement. Figure.1 shows the images of the Rideau Rock Danger obtained by the UAV.

In addition, the ILRIS-3D ground-based 3D laser scanner was used to collect data from the slope again, in order to verify the feasibility and accuracy of the data collected by the UAV. The ILRIS-3D ground-based 3D laser scanner was used to scan the observation body to obtain the 3D point cloud coordinates of the observation object. The data acquisition should be carried out in such a way that each station set up by the scanner can scan the entire area of the modelling target, while the overlap between stations should be 20%-30% to avoid point cloud loopholes. The internal data processing is to align the collected 3D coordinates with the data, data noise reduction and other processing, and finally use PolyWorks software to build a point cloud model of the region's dangerous rock body, as shown in Figure.2.

By comparing Figure. 1 and Figure. 2, it can be seen that although the 3D laser scanner has carried out a series of data processing when scanning the steep cliff and high mountain, the point cloud model established by the measured data still has more point cloud loopholes because it is easily blocked by the raised rock body and there are blind spots in the field of view, so the model established will not be fine enough, resulting in the dangerous rock body falling from the loopholes of the slope model, which cannot reflect the real movement scene of the dangerous rock body. Therefore, it has certain limitations when surveying and mapping terrain such as steep hills and complex slopes. The UAV has the advantages of small size, high mobility, high flexibility and good field of view, which makes the data collected more comprehensive and accurate, and the measured data can be more accurately modelled and better reflect the real scene. Therefore, it is more appropriate to use UAVs for data collection in the 3D modelling of slopes where dangerous rock masses are located.

2.2 Build high precision models

Due to the large size of the aerial survey data, the light effects and distortion of the image during the shooting process can make it difficult for the traditional feature point extraction algorithm based on geometric texture features to work effectively. Therefore, the data were first processed for feature point extraction and multi-view point matching to reduce the negative impact on the 3D modelling work [15]. Scale-invariant feature transform (SIFT) can quickly find the extreme points in the Difference of Gaussians (DOG) scale space and extract their position, scale and rotation invariants. feature point extraction. The formula for the difference of Gaussians numerator is:

$$COG=\frac{1}{\sqrt{2\pi}}=\left(\frac{1}{\sigma_1}\exp\left(\frac{x^2+y^2}{2\sigma_1^2}\right)-\frac{1}{\sigma_2}\exp\left(\frac{x^2+y^2}{2\sigma_2^2}\right)\right) \quad (1)$$

where x and y are the locations of the points in the image; σ_1 and σ_1 are the scale factors of the upper and lower Gaussian spaces。

After the feature points are extracted, the Euclidean distance of the feature vector is used as the criterion for determining the similarity of the feature points in multiple images, and then feature matching is performed to find a pair of matching points with high reliability.

$$d\left(R_{\mathrm{i}},\mathrm{S}_{\mathrm{i}}\right)=\sqrt{\sum_{j=1}^{n}\left(r_{ij}-s_{ij}\right)^{2}} \qquad (2)$$

Where$R_i=(r_{i1},r_{i2}\dots,r_{in})$ is the feature point descriptor in the base image;$S_i=(s_{i1},s_{i2},\dots,s_{in})$; $d(R_i,S_i)$is the Euclidean distance between feature points.

To identify paired feature point descriptors for the feature point descriptors in the observed image, the ratio of the Euclidean distance between the nearest and second nearest feature point feature vectors needs to be less than a set threshold. The formula is defined as follows:

$$\frac{d(R_i,S_u)}{d(R_i,S_v)}<T \qquad (3)$$

Where S_u is the closest point to R_i in the observation map; S_v is the next closest point to R_i in the observation map; and T is the threshold value, usually set to 0.8.

Finally the processed UAV image data is built into a high precision model using Pix4Dmapper software. The modelling process consists of the following steps: selecting and adding images, adjusting image attributes, selecting output coordinate attributes, selecting processing option templates, adjusting output parameters and building the model. The generated 3D fine model is shown in Figure.3.

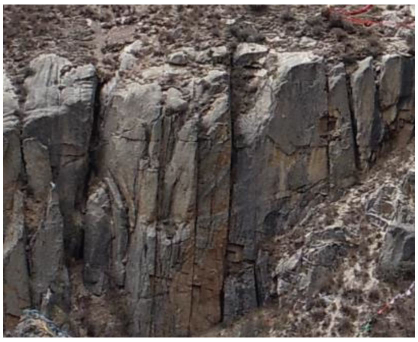

Figure. 1 Image model of the Nido Dangerous Rocks

Figure. 2 Point cloud model of the Nido Dangerous Rocks

Figure. 3 3D fine model of the Nido slope

3. Numerical simulation of the movement mechanism of a dangerous rock mass

3.1 Numerical simulation during movement of dangerous rock masses

The numerical simulation of the movement mechanism of the rock hazard is mainly to simulate the interaction between the rock hazard and the slope during the movement of the rock hazard, which may involve the rotation of the rock hazard itself, the collision, rebound and rolling of the rock hazard and the slope. In the process of numerical simulation of rock movement, firstly, the rock body and slope should be set as rigid body properties, and the physical parameters such as friction, mass and volume of the rock body and slope should be set to restore the real scene to the greatest extent; secondly, the slope and rock body should be set as collision properties such as mesh collision body, box collision body and spherical collision body, so as to restore the movement of the rock body on the slope to the greatest extent. Unity3D has the advantage of being multi-lingual and can be used to write C# scripts to export the motion parameters of the simulated rock hazard. Therefore, in this paper, we will simulate the instability characteristics of five different working conditions and analyse them through Unity3D。

In the analysis of the effect of the size of the rock mass on its movement mechanism, square-shaped rock masses with diameters of 0.2m, 0.4m, 0.6, 0.8 and 1.0m were used to roll down the slope of the same material in the same unstable manner.

3.2 Movement characteristics of dangerous rock masses

Due to the different forms of rock hazards, different slope material, destabilisation and other factors, resulting in the form of movement of rock hazards: or collision with the slope in order to do flying motion, or along the slope gently rolling, or smooth and gentle sliding along the smooth slope, etc.. The formulas for solving the motion of rock hazards differ from each other. The acceleration of dangerous rock body are used to find Newton's law, not to discuss in detail, only to analyse its motion in different states [16].

The numerical simulation of the rock movement mechanism should firstly ensure that it is the only variable, the same height of release, the same slope indicating the same friction, the same density of the same rock body, etc. Secondly, the velocity, acceleration and cumulative displacement data of the rock under two working conditions with different rock body sizes and different rock body forms are extracted by means of C# scripts respectively. The extracted data were then processed into comparison curves. Because of the problem of conflict and redundancy, the data were first processed for noise reduction, and the following is the movement of the rock mass in Unity3D under different conditions.

4. Experimental Study

4.1 Field model tests

In order to verify the fineness of the 3D model built by this method, this paper uses the field rockfall test to test it. The field model tests were divided into two groups: one group of 0.2m, 0.6m and 1.0m diameter square-shaped rock hazard models, and the other group of 0.5m diameter rectangular, spherical and square-shaped rock hazard models, which were released at the test site with coded markers attached to each face of the rock hazard models.
The movement data of the model at the test site was obtained by a monitoring system consisting of binocular camera stereo monitoring, a spatial 3D coordinate system for the slope, the Rocke TECH calculation system, a slope grid, spatial bounce markers and a power supply network [17]. The filming system consists of two Ac in the test site for releasing eutEye long time high speed camera system and CoaXPress high speed camera, using synchronous controller with 2 high speed cameras with high precision and synchronous filming.
Follow the tumbling orthogonal test protocol for rock movement at risk and synchronise with the binocular camera stereo vision monitoring system and save the video. Use the synchronous controller to synchronise the filming, taking care not to make any adjustments or movements to the calibrated footage and to ensure that the previous calibration results are correct before filming. To be on the safe side, take a video to verify that the whole system is working before starting the formal test process and start the field test after commissioning the equipment.

4.2 Goodness-of-fit analysis

In order to quantitatively describe the degree of fit between the field test and the numerical simulation, the test site is modelled in this paper and the numerical simulation is carried out with Unitu3D below the field conditions. The degree of agreement between the numerical simulation results and the field test results is also measured by the goodness of fit. The coefficient of determination is [18]:

$$R^2 = 1 - \frac{SSE}{SST} \tag{4}$$

SSE in equation (11) is the sum of squared residuals:

$$SSE = \sum_{i=1}^{n} \left(\hat{y}_i - y_i \right)^2 \tag{5}$$

SST is the sum of squared total deviations:

$$SST = \sum_{i=1}^{n} \left(\overline{y}_i - y_i \right)^2 \tag{6}$$

Where $\hat{y}_i$ is the fitted value; y_i is the test value; $\overline{y}_i$ is the average of y_i; The closer the value of R2 is to 1, the better the numerical simulation fit is. The results of the numerical simulation and the field test were substituted into the equation to obtain. It can be seen that the 3D model built by this method has a high degree of refinement.

5. Conclusions

This paper uses UAV and 3D laser scanner to collect slope and dangerous rock data, uses Pix4D software to generate high-precision 3D simulation model, uses Unity3D software in the analysis of various working conditions falling rock movement characteristics and accumulation position, and through the field test to verify the simulation analysis results, get the following conclusions.
(1) Comparing the data collected by UAV and 3D laser, it is found that the data collected by 3D laser has more point cloud loopholes, so the data collected by UAV is more suitable for this 3D modelling and the collected data is more accurate.
(2) By comparing the image observation of the calculation process of the high-precision 3D simulation model, the falling rock sphericity value changes from large to small, and the falling rock movement mode changes from jumping and rolling to sliding mode, so the high-precision 3D simulation calculation is more realistic and accurate than the ordinary numerical simulation software analysis.
(3) The numerical simulation fits well with the velocity, acceleration and displacement curves from the field test, thus verifying that the 3D model built by the method is more refined and beneficial to the design of highway slope rockfall hazard control projects.

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