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Retraction

Retracted: UAV Tilt Photography Control for Numerical Simulation of High and Steep Rock Slopes

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] Y. Wang, Y. Zhou, and B. Wang, "UAV Tilt Photography Control for Numerical Simulation of High and Steep Rock Slopes," *Journal of Control Science and Engineering*, vol. 2023, Article ID 7489283, 7 pages, 2023.

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Research Article

UAV Tilt Photography Control for Numerical Simulation of High and Steep Rock Slopes

Yani Wang,[1] Yinpeng Zhou ,[2] and Bo Wang[3]

[1]*Xi'an University, Xi'an 710065, Shaanxi, China*
[2]*Institute of Surveying and Mapping Guizhou Geology and Mineral Exploration Bureau, Guiyang, Guizhou 550018, China*
[3]*Shaanxi Geomatics Center, Ministry of Natural Resources, Xi'an, Shaanxi 210019, China*

Correspondence should be addressed to Yinpeng Zhou; i17301129@stu.ahu.edu.cn

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In order to provide accurate image information for the analysis and treatment of dangerous rocks and rockfalls during the early investigation, a UAV tilt photography control method for numerical simulation of high and steep rock slopes is proposed. Based on the UAV tilting photography technology, the slope section was obtained through a real 3D modeling and poststage point cloud data processing. Numerical simulation is used to study the motion characteristics of dangerous rock falling in a high and steep slope of a railway station. This essay introduces the application of a UAV tilting photography and real 3D modeling technology in the process of rock fall analysis and realizes the real scene restoration of the site. The point cloud data of the site is obtained, and the processing process of the point cloud is introduced in detail. The slope section of the site was obtained based on the point cloud, and RocFall software was used to obtain the motion characteristics of dangerous rock falling (falling trajectory, bouncing height impact energy, and impact velocity). The simulation results show that because of the rugged slope, the falling rocks collide and rebound on the slope for many times. In addition, near the bottom of the slope, there is a steep cliff with a height of 136.21 m, which is approximately 54° from the horizontal line, causing the falling rock to bounce and eventually fall at a higher height. It moves to the bottom of the slope and bounces off the level of the railway line before finally settling on the railway road. The maximum bounce height of falling rock in the process of slope rolling motion reaches 30 m. When falling rock moves near the railway line (coordinate is on the right side of zero), the bounce height is 15~25 m, which threatens the safety of the railway operation. *Conclusion.* The UAV tilt photography technology can be well applied to the analysis of rockfall motion characteristics of dangerous rocks, and provide an accurate cross-section data information for the study of rockfall motion characteristics of dangerous rocks.

1. Introduction

With the continuous improvement of the level of economic development, transportation, logistics, and transportation have become major social problems that restrict the sustainable development of society. To this end, road, railway, water transport, aviation, and other transport infrastructure has been constantly improved, especially as the main forms of inland transport, highway, and railway plays an important role in the domestic transport. China has a vast territory and complicated terrain conditions, with mountainous terrain accounting for more than 60% of the total, resulting in the existence of high and steep slopes in the construction of highways and railways. On the one hand, the construction of high and steep slope promotes the construction of transportation in mountainous areas; on the other hand, it also becomes a major risk source of traffic infrastructure engineering. Slope instability occurs from time to time due to rainfall, earthquake, human factors, and other forms of instability mainly include landslide, collapse, debris flow, cracks, collapse, and subsidence. Slope instability may interrupt traffic, damage traffic infrastructure, or endanger people's lives. There are at least dozens of slope disasters in China every year. In addition to casualties, these disasters often also cause property damage such as roads, houses, and vehicles. Effective prevention and treatment of slope disasters are essential to promote social and economic development and

protect people's life and property safety [1, 2]. Slope monitoring is an important means to understand the development of slope disasters and the causes of disasters. Through long-term tracking and monitoring of slope, it can not only find the dangerous situation in time but also explore the law of its occurrence, which provides an important basis for slope prevention and early warning.

2. Literature Review

Guo et al. studied the error of aerial photography caused by flight environment and aerial survey factors, and proposed an automatic correction model of remote sensing images without image control points [3]. Yu et al. studied the influencing factors of image matching and space-three solution in UAV photogrammetry, and proposed the realization method of automatic relative orientation of aerial photographs and automatic uniform distribution of model connection points [4]. Wu et al. combined aerial photogrammetry with land resource management, built a land resource monitoring and management platform based on the three-dimensional aerial survey model, and realized the concept of "one map" for local land resources [5]. Buhmann et al. discussed the setting of UAV flight parameters in the process of aerial photogrammetry operation, and on this basis completed 1: Zhang Guorong combined UAV photogrammetry technology with ground 3D laser scanner to monitor landslide deformation in alpine and steep slope areas [6]. Fu et al. proposed a calculation method of earthwork based on tilted photogrammetry technology, which solved the problem of time-consuming and laborious work in earthwork survey and improved the accuracy of earthwork survey to a certain extent [7]. Hu and Li carried out a study on the urban rainstorm water accumulation model based on tilt photogrammetry technology, and obtained a high-precision digital orthophoto map and digital elevation model of the city through tilt photogrammetry technology. On this basis, the SWMM model and storm water accumulation algorithm were used to simulate the urban storm runoff and calculate the urban inundation range and depth. Finally, the correctness and accuracy of the model were tested by comparing with the measured data in the city [8]. Meng et al. carried out the aerial survey accuracy analysis test and analyzed the influence of the number of control points and aerial photography height on the aerial survey plane position accuracy and elevation accuracy. On this basis, a surface collapse monitoring method based on UAV photogrammetry technology is proposed, and deformation monitoring is carried out in the western subsidence area of Chengchao Iron Mine, and the feasibility of this method is tested [9].

In this essay, based on a railway, the edge slope pattern was obtained by using UAV tilting aerial photography and a real scene three-dimensional modeling technology. To study the rockfall motion characteristics of the slope located in the station, we provide data support for the construction and transformation of the prevention and control measures of rockfall, and provide reference for the investigation and research of rockfall in similar projects.

3. Research Methods

3.1. Project Overview. The project along the large relief, steep rock wall, and bedrock outcrops. The strata are Quaternary Holocene slope silty clay and fine breccia soil and Holocene alluvial silty clay and fine (coarse) round gravel soil. The underlying bedrock is shale mixed with sandstone of the Lower Silurian Longmaxi Formation [3]. Geological disasters are prominent, among which the hazard of dangerous rock falling is more serious. The site is located in a station; the landform is a low mountain foothills and Lishui wide valley area. The slope of the hill is steep. Once rockfall occurs, it will bring serious threat to the railway safety. The small fold of rock strata at the working site is developed, and the tendency is mainly horizontal or inclined mountain, which is good for mountain stability [10]. The landform on the right side of the existing line at the site belongs to the foothills of low mountains, with large relief, steep rock walls, and bedrock outcrops. Its left side is Lishui wide valley area, and the terrain is relatively flat. The outcrop layer of the right side slope is the Middle Cambrian Huaqiao Formation limestone: dark gray, mainly composed of calcalite, cryptic structure, thin layer to medium thick layer structure, brittle and not easily broken by hammer, hard rock, joints and fractures developed, weak weathering, and V-grade subhard stone: 1000 kPa.

3.2. Drone Tilt Photogrammetry. The steep mountain at the work site made it impossible for personnel to ascend and investigate. Therefore, the sloping aerial photography method of UAV was used to investigate the mountain on the right side of the line [11]. The operating area coordinates of aerial photography are 29°10′25.75″ and 110°37′36.93″ and the area is about 1.1 km^2. Among them, it is necessary to control the flying altitude of the UAV.

3.2.1. Field Image Control Point Layout. By setting up the field image control point, the precision of 1 : 500 aerial surveys and mapping can be met, and the image control data can be provided for the internal industry data processing. The layout interval is about 200 m for one point, and a total of about 30 image control points are laid in the test area. The measurement method of Zhonghaida RTK combined with Chihiro Cors base station is adopted to obtain the real three-dimensional coordinate information of the image control points laid out in the field, which provides the precision basis for the data processing and modeling in the field.

3.2.2. UAV Aerial Photography. Determine the weather conditions on the day of operation, including light, visibility and wind speed, and conduct aerial photography flights in strict accordance with the design requirements. A total of 20 routes were laid in the whole survey area, which were completed in 5 flight sorties [12]. There are 3 sorties at the station takeoff and landing points and 2 sorties at the peak. Each flight sortie lasts about 30 min. The image resolution is 2-3 cm, which is better than 3 cm. A total of 10 528 images

were acquired in the whole flight. The images were clear, rich in layers, moderate in contrast, and soft in tone. It can identify the small ground object image which is compatible with the ground resolution; and being able to build clear dioramas. There is no cloud, cloud shadow, smoke, large reflective area, stain, and other defects on the image. The image preprocessing software is used to correct the image distortion difference, and output TIFF image data, GPS exposure point coordinates, and other related information. The inclination angle of the image is generally not more than 5°. The maximum is not more than 12°, and the number of pictures with more than 8° is not more than 10% of the total. Especially difficult areas are generally not more than 8°. The maximum is not more than 15°, and the number of slices with more than 10° is not more than 10% of the total. Three sorties will take off and land at the on-site station and two sorties will take off and land at the peak.

3.3. Key Technologies of Real Scene 3D Modeling. ContextCapture software was used to model the data collected by tilting aerial photography using the UAV. The real scene of the site is restored to provide a basis for the acquisition of point cloud data of the site.

3.3.1. Combined Adjustment of Multiview Images. The multiview images in ContextCapture include not only vertical but also tilt photography data. Therefore, the geometric deformation and occlusion relationship between images should be fully considered in the joint adjustment of multiview images [13]. Combined with the external position elements of multiview images provided by POS system, the pyramid matching strategy from coarse to fine is adopted to automatically match the same name points on each level of images and adjust the free net beam, and better matching results of the same name points are obtained.

3.4. Multiview Image Dense Matching. Multiview images have the characteristics of large coverage area and high resolution. Since it is often difficult to obtain the same name points required for modeling by using a single matching primitive or matching strategy, multiprimitive and multiview image matching has gradually become the research focus with the development of computer vision in recent years. For example, the automatic recognition and extraction of the side of a building, by searching the features on the multiview image, such as the edges and textures of the building, can determine the two-dimensional features of the building from different perspectives on the two-dimensional vector data image, which can be converted into three-dimensional features. The height and contour of the building are extracted by 3D reconstruction of the side. The tilted real scene 3D modeling principle is shown in Figure 1 [14].

3.4.1. 3D Digital Surface Model Generation and Texture Mapping. Digital surface model (DSM) with high-precision and resolution can be obtained by dense matching of visual images. After obtaining the high-density digital surface model, the filtering process is carried out, and the different units are fused to form a unified DSM. At the same time, the semantic information of image square is obtained by image segmentation, edge extraction, texture clustering, and other methods on multiview image, and then the corresponding relationship between object square and image square with the same name is established through dense matching. Then, the global optimization sampling strategy and the joint image correction taking into account the geometric radiation features are established, and the overall homogenization processing is performed to map the texture surface information to the model and realize the reconstruction of the real 3D model.

3.5. Obtain the Section of Slope at Work Point. Through the shooting of the station site UAV, the key technology of real scene 3D modeling is used to realize the real scene restoration of the site. The 3d real model can output STL format data, which can be transformed into dense point clouds, with high-precision 3d coordinate information [15, 16]. By importing the obtained point cloud into 3D Reshaper software, the section information can be extracted, and the shape, height, slope, and other information of edge slope can be obtained.

3D Reshaper is a software specially used for point cloud processing, 3D mesh, 3D detection, multiline, CAD surface, etc. After the point cloud is imported into 3D Reshaper software, the coordinates of the point cloud are not consistent with those in Rocfall analysis software, so some coordinate transformation is needed. 3D Reshaper software has a special ground extraction function, which can simulate the ground information of 3D slope and the steep rock cliff section. Then, the two-dimensional.dxf format slope section can be extracted by using the section extractor in the software, which provides a basis for the subsequent calculation of the rock fall trajectory of the slope.

4. Results Analysis

4.1. Numerical Simulation of RocFall Software

4.1.1. Working Principle of RocFall Software. RocFall software is a professional geotechnical engineering analysis software developed by Rocscience in 1996, which is used to simulate the statistical analysis of rock fall on steep rock slopes [3]. The calculation principle is as follows: the dangerous rock body in the upper part of the slope has greater potential energy than the middle and lower part of the slope. Under the action of natural gravity, the dangerous stone starts to move downward from static, and the dangerous stone becomes a falling stone. Velocity increases with the acceleration of gravity, and potential energy is converted into kinetic energy. When falling rock and slope contact rebound, according to the different normal elastic coefficient and tangential friction coefficient of slope contact point, the bouncing height of falling rock is also different. At this time, the contact slope produces energy dissipation effect on the falling rock, which causes the kinetic energy of the falling

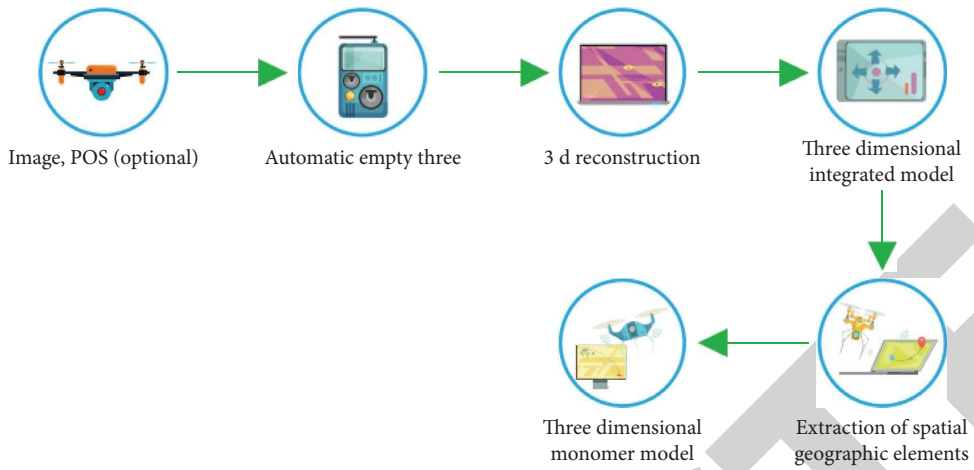

Figure 1: Tilted real scene 3D modeling principle.

rock to decay until the remaining kinetic energy of the falling rock is zero. The whole process follows the law of energy transformation and conservation.

RocFall software operation has three parts: point operation, bounce operation, and slide operation [17]. The operation of points determines whether the parameters involved in the simulation are correct, establishes the initial conditions for all the bounce operation and slide operation, and starts the bounce operation. The bounce operation is used to calculate the process of falling rock jumping from one point off the slope to another point in the air. The sliding operation is applied to the motion process of falling rock touching the slope. Most of the software calculations are parabolic motion in the air and falling rock and ground impact motion two processes. Where, the parabolic equation of motion is expressed in the following equations (1) and (2):

$$\frac{1}{2}gt^2 + (V_{Y0} - qV_{X0})t + [Y_0 - Y_1 + q(X_1 - X_0)] = 0, \tag{1}$$

$$q = \frac{Y_2 - Y_1}{X_2 - X_1}, \tag{2}$$

where X_1 and Y_1 are coordinates of the starting point of the line segment, m; X_2 and Y_2 are the coordinates of the end of the line segment, m; g is gravitational acceleration, m/s^2; V_{X0} and V_{Y0} are the initial velocity of falling rock, m/s, generally 0.

The impact time equation is as follows:

$$t = \frac{-b + \sqrt{b^2 - 4ac}}{2a}. \tag{3}$$

In the formula, $a = (g/2); b = V_{Y0} - qV_{X0}; c = Y_0 - Y_1 + q(X_1 - X_0)$.

4.1.2. Parameter Selection. RocFall software is used to simulate rockfall motion. RocFall program mainly displays the motion path, energy distribution, and height change of rockfall on the slope by inputting some basic parameters related to the slope and rockfall, so as to provide intuitive and effective basis for the design of protection management.

The slope section in DXF format obtained from 3D Reshaper software was imported into RocFall software, and the recommended restoration coefficient was selected according to slope surface characteristics and leaf four bridge. As shown in Table 1, the normal restoration coefficient, tangential restoration coefficient, and friction Angle of the slope can be calculated by input [18]. Because the slope of this project is mainly a hard rock surface with strong weathering and vegetation, the normal restoration coefficient is 0.35, the tangential restoration coefficient is 0.88, and the friction Angle is 30°. The horizontal subgrade surface is mainly loose gravel pavement. The normal recovery coefficient is 0.25, and the tangential recovery coefficient is 0. Section 2 input into RocFall software is shown in Figure 2.

4.1.3. Calculation of Falling Rock Trajectory. Since the motion trajectories of the five sections are similar, only the motion trajectory of typical section 2 is selected as a schematic. Rockfall motion trajectory of section 2 was calculated by RocFall software, as shown in Figure 3.

As can be seen from Figure 3, due to the rugged slope surface, falling rocks collide and rebound on the slope for many times. In addition, near the bottom of the slope, there is a steep cliff with a height of 136.21 m, which is approximately 54° from the horizontal line, causing the falling rock to bounce and eventually fall at a higher height. It moves to the bottom of the slope and rebounds on the level of the railway line, and finally stays on the railway road [19].

4.1.4. Calculation of Bounce Height. There will be a peak height after the falling rock bounces on the slope. RocFall software was used to extract the maximum bounce height data of five sections, and the envelope of the maximum bounce height of falling rock was obtained, as shown in Figure 4.

Table 1: The selection range of the proposed restoration coefficient of Ye Si Bridge.

Slope characteristics	Coefficient of normal restitution	Tangential coefficient of restitution
Smooth hard rock surface, paving surface, shotcrete surface, and masonry surface	0.25~0.75	0.85~0.98
Soft rock surface and strong weathering hard rock surface	0.15~0.37	0.75~0.95
The slope is stacked with stones	0.15~0.37	0.75~0.95
Dense gravel accumulation, hard soil slope, vegetation development, mainly shrubs	0.12~0.33	0.30~0.95
Dense gravel accumulation slope, hard soil slope, no vegetation, or a few weeds	0.12~0.32	0.65~0.95
On the loose gravel slope and soft upper slope, the vegetation development is mainly shrub	0.10~0.25	0.30~0.80

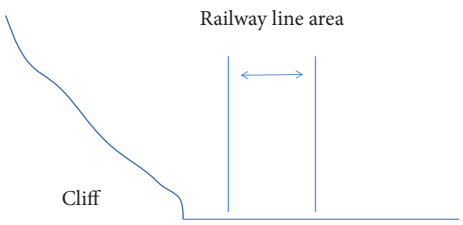

Figure 2: Section 2 in RocFall software.

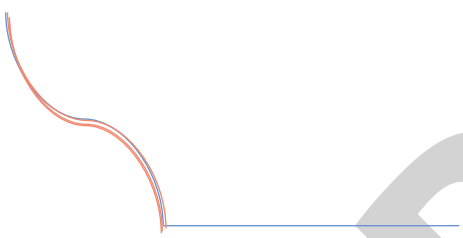

Figure 3: Trajectory of falling rock in Section 2.

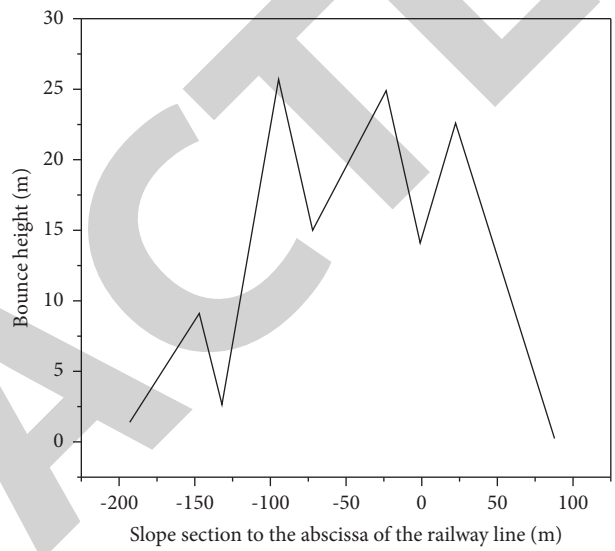

Figure 4: Bounding height envelope of falling rocks in Sections 1–5.

As can be seen from Figure 4, the fluctuation of the bounce height of the five sections varies greatly due to the different elevation and elevation of the sections. The maximum bounce height of the falling rock in the process of the slope rolling motion reaches 30 m, and the falling point of the falling rock is located near the upper cliff (coordinate is to the left of zero). When falling rock moves near the railway line (coordinate is on the right side of zero), the bounce height is 15~25 m. Rockfall may invade the railway area and threaten the safety of railway operation. Therefore, it is necessary to protect the slope from rockfall.

4.1.5. Impact Energy Calculation. The maximum impact energy envelope of falling rock in five different sections is shown in Figure 5.

It can be seen from Figure 5 that the curve trend of maximum impact energy of the five sections is roughly the same, and the maximum impact energy is near the upper cliff (coordinate to the left of zero). The maximum impact energy produced by the falling rock during the rolling motion of the slope reached 2 300 kJ, which occurred near the upper cliff of section 2. When the falling rock moves to the vicinity of the railway line (coordinate to the right of zero), the impact energy is 800~1 600 kJ, which still has a large impact energy. Rockfall may invade the railway area and threaten the safety of railway operation. Therefore, it is necessary to take protective measures on the slope to ensure the normal operation of the railway.

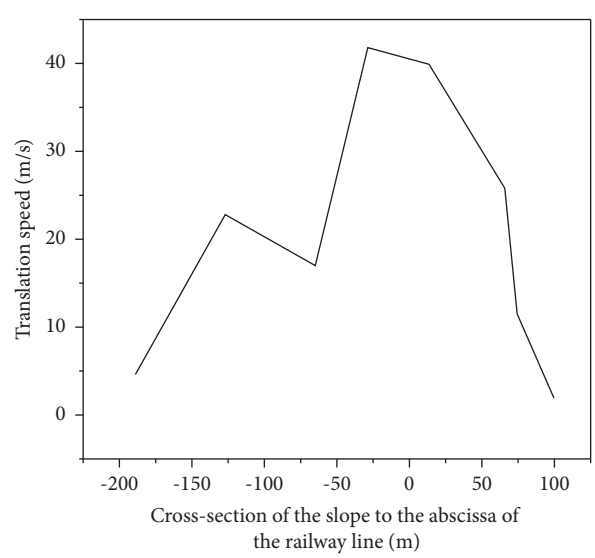

Figure 5: Translation velocity curves of falling rock from section 1 to section 5.

The RocFall software was used to calculate that the falling rock would have a large bouncing height during the movement on the slope. When the movement reaches the bottom of the slope, it still has large impact energy and movement speed, which threatens the normal operation of the railway [20, 21]. Therefore, it is suggested to set up an active curtain type protective net on the steep slope surface to limit the bouncing height of falling rocks, so as to reduce the energy of falling rocks at the bottom of the slope. In order to prevent individual rockfalls from jumping over the active curtain protective net and directly jumping into the bottom of the slope, threatening the safety of the railway, a stone wall can be built at the bottom of the steep slope to intercept rockfalls and prevent rockfalls from entering the railway line and affecting the normal operation of the railway.

5. Conclusion

The research of dangerous rock and rockfall is rarely combined with advanced engineering investigation technology. Based on UAV tilt photography, the application of real scene three-dimensional modeling technology and point cloud data information in the analysis of the motion characteristics of dangerous rock and rock fall is realized. The 3DReshaper software was used to process the point cloud, and the section slope pattern of the high and steep slope of a railway station was obtained, which was imported into RocFall software to analyze the trajectory, bouncing height, impact energy, and velocity of the falling rock, and the following conclusions were obtained:

(1) For high and steep slopes, UAV can be used for on-site photography and measurement. The key technologies of real scene 3D modeling are used to realize the real scene restoration of the site and extract the point cloud data. After processing the point cloud data, the real slope section information is provided for the simulation of rockfall motion characteristics, and the accuracy of the rockfall trajectory simulation is improved.

(2) RocFall software can well simulate the trajectory of falling rock and predict the risk of falling rock in the construction process. By simulating the trajectory of falling rock, we can judge the range of influence zone of falling rock rolling, analyze the bouncing height of falling rock, and impact energy and impact velocity generated.

(3) Through the simulation of rock falling trajectory of the high and steep slope of the station, it can be concluded that the falling rock still has high energy after falling to the bottom of the slope. In addition to the protective measures of the stone wall at the bottom of the slope, a curtain type active protective net should also be applied on the side slope to limit the bouncing height of falling rocks, reduce the impact energy of falling rocks by grades, and ensure the safety of the railway operation.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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