# APPLICATION OF DIGITAL TWINS IN HIGH PRECISION GEOLOGICAL HAZARD SURVEY AND PREVENTION IN BEIJING

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**ABSTRACT:**

Beijing is located in the northwest corner of the North China Plain, with a total area of 16410 km$^2$, of which mountainous area accounts for about 61.3 % of the total area. Due to the complex geological and geomorphological conditions, the development of fault structures, the spatial-temporal uneven distribution of rainfall and the influence of human engineering activities, there are many sudden geological hazards in Beijing, such as collapse, landslide, debris flow and mining collapse. As is known, Beijing is one of the capital cities with most developed sudden geological hazard in the world. With the continuous development of economy and tourism in mountainous and shallow mountain valleys and the further enhancement of human activities, the threat of sudden geological hazard to Beijing's social and economic development will continue to exist. This paper explores the application of digital twin technology in the survey and prevention of geological hazard in Beijing, mainly using tilt aerial photogrammetry, 3D model production, remote sensing interpretation, ground analysis, database management and other methods to carry out high precision survey, mapping and investigation research. Furthermore, we analyze the relevant features of geological hazard hidden danger points, deeply study their dangers, and establish a two-dimensional and three-dimensional information management system for geological hazard in Beijing's mountainous areas. It is proved that the information management system can effectively improve the management and prevention of geological hazard.

## 1. INTRODUCTION

Geological hazard is a common type of natural disaster in China. Mountainous areas are prone to geological hazard in China. The common geological hazards in mountainous areas include collapse, landslide, debris flow and so on. Geological hazards in mountainous areas have the characteristics of strong concealability, strong burstiness, strong destruction and complex causes, which greatly threaten the safety of people's lives and property. Monitoring and survey of geological hazards is the key to disaster prevention and control (Ao, M. , et al., 2014). The topographical and geological conditions in mountainous areas are complex, so simply relying on the field geological hazard survey not only takes a long-term, costs high and takes effect slowly, but also is difficult to accurately survey in some areas with steep elevation or inconvenient transportation. Using photogrammetry and remote sensing technology, we can complete the comprehensive interpretation, investigation and review of geological hazard hidden danger points in multi-angel accurately, intuitively and comprehensively, and improve the accuracy and efficiency of survey. In addition, the systematic management of geological hazard survey data and the improvement of early warning capability can also effectively prevent and control geological hazards.

This paper carries out the innovative application of digital twins based on oblique aerial photogrammetry technology in high precision geological hazard survey in Beijing, a city with a large area of mountainous areas and many geological hazards. The main application methods include the following five aspects:

1. Unmanned aerial vehicle (UAV) tilt photogrammetry of geological hazard hidden danger points. Based on location distribution data of hidden danger points, facing the complex terrain conditions, the UAV tilt photogrammetry considering the terrain was carried out. The route design method of changing the flying height based on digital elevation model (DEM) was realized, and the absolute flying height was changed on the basis of fixed relative flying height. The tilt images with a spatial resolution of 0.05 m and relatively consistent accuracy were obtained.
2. Digital orthophoto map (DOM) production and real three-dimensional (3D) model construction. The pre-arranged ground control points were used to complete UAV aerial triangulation, and stereo image pairs were generated to produce DEM. On the basis of the aerial triangulation results and DEM, DOM was produced through ortho-rectification, color balance, mosaic, subset and cutting, and 3D models were constructed through dense matching (Guo, J. et al., 2016), 3D tin construction, texture mapping, model repair, and partition model integration. DOM and 3D models were used as the three-dimensional working base map for high precision geological hazard survey (Jiang San et al., 2022). In image matching, considering the large oblique angle of UAV images and the difficulty in setting up ground control points in mountainous areas, the method of accurate image matching for large oblique angle images was used to realize the completion of aerial triangulation with a small number of ground control points on the premise of meeting precision (JiménezJiménez Sergio Iván et al., 2021).
3. High-precision remote sensing interpretation. Based on the visualization and measurability of the real three-dimensional scene, the remote sensing interpretation of the distribution area, source distribution, threat objects of each hidden danger point had replaced the traditional complicated geological survey methods to achieve accurate mapping (LIAN et al., 2020).
4. Auxiliary geological structure analysis. Using tilt aerial

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photography images, massive point cloud data were calculated through image-dense matching algorithm. The profile line extraction of point clouds and geological data were used to accurately analyze the geological structure of hidden danger points, which plays an important supporting role in the analysis of disaster occurrence.

5. Historical tracing and early warning simulation. By referring to the weather and geological conditions when the historical geological hazards occurred at each hidden danger point, combined with the latest climate and weather forecast, the mathematical model of geological hazard early warning was established to realize scientific early warning and assist the prevention of geological hazards in the way of "tracing history, combining the current situation and judging the new occurrence".

6. Scientific management. Based on all the above survey results, a three-dimensional analysis system was constructed to realize the integrated management of information display, analysis and early warning of each geological hazard hidden danger point. The system can provide scientific basis for geological hazard prevention and control, and provide decision-making support for functional departments.

## 2. APPLICATION OF DIGITAL TWINS IN GEOLOGICAL HAZARD SURVEY AND PREVENTION

### 2.1 Application of Digital Twins in Geological Hazard Survey and Prevention

In view of the fact that geological hazard hidden danger points in Beijing are mostly distributed in the high and steep slope or deep mountain forest area, UAV tilt aerial photogrammetry was applied with the advantage of presenting high-resolution three-dimensional models, which can assist investigators with a clear and intuitive judgment on the places where are hard to observe.

Firstly, the aerial photogrammetry range was determined based on distribution data of geological hazard hidden danger points, and the flight platform and aerial camera were reasonably selected according to the terrain conditions of the survey area. In order to obtain tilt aerial photogrammetry data with a resolution of 5 cm and meeting the requirements of industry standards, it was planned to use CW-10, a vertical take-off and landing fixed-wing UAV, and ZC-3C, an electric fixed-wing UAV, both equipped with high-pixel five-lens tilt camera. In special flight difficult areas, AC1600 six-rotor UAV was used to guarantee resolution.

Then, considering the aerial photogrammetry range and resolution requirements, the distribution scheme of “4+1” ground control points per square kilometer was adopted, that is, the four corners and the center points are evenly distributed in the quadrilateral area per square kilometer. The above scheme can ensure that the data accuracy in each square kilometer area is relatively average (Liu, J. and Xue, L., 2019), which is convenient for us to judge the geological hazard points in the later stage.

Lastly, the UAV tilt photogrammetry was carried out according to the terrain with the route design method of ground imitation flight, which the flying height was dynamically adjusted with DEM. As a result, the acquired images maintained the maximum consistency of resolution.

### 2.2 Digital Twin Production of Geological Hazard Points

**2.2.1 DOM Production:** The pre-arranged ground control points were used to complete UAV aerial triangulation, and stereo image pairs were generated to produce DEM. As each production process was closely connected, DOM was produced through ortho-rectification, color balance, mosaic, subset and cutting on the basis of the aerial triangulation results and DEM. In particular, the reference image was processed for uniform light and color, and the color of all original aerial images was calculated to close to the reference image. Then adjust the image color to be consistent through human-computer interaction. Figure 1 presents the whole specific processes.

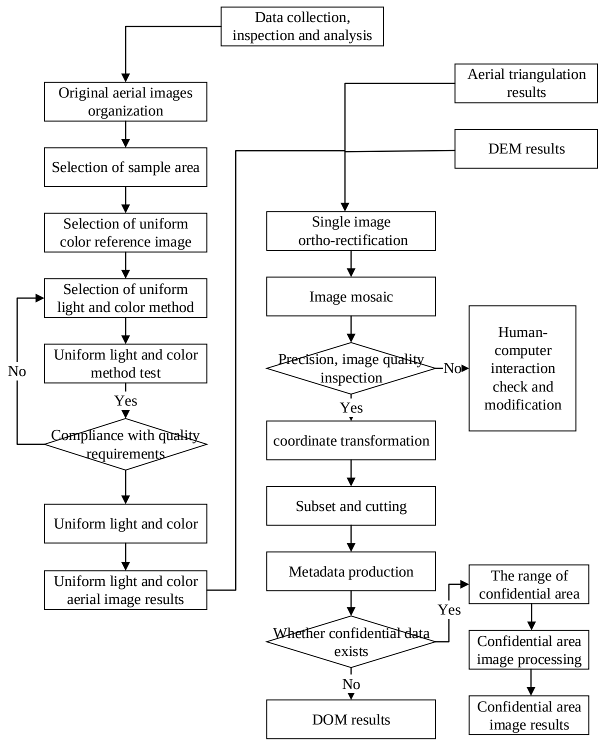


**Figure 1**. The process of DOM production.

**2.2.2 Real 3D Model Construction:** DOM and DEM can build 3D terrain sence, as shown in Figure 2. Based on large scene rapid 3D modeling, building model extraction and model refinement processing technology (Qiong Qi and Yu Wen Ju, 2015), using the current 3D modeling software, a technical solution for tilt photogrammetry data processing was formulated to construct real 3D model rapidly and precisely, as shown in Figure 3. When the camera shoots the ground target at a certain angle at high altitude, due to the dense distribution of ground targets, overhead structures of bridges, small target sections (such as billboards), etc., the occlusions are existed in the original aerial images, and the features of ground objects are difficult to distinguish. As a result, the generated real 3D model has the following situations: broken surfaces, flying points, texture errors, small holes, model deformation, etc., which requires editing the model. Real 3D Model editing includes geometric structure editing and texture editing, which can be done with different software, such as 3DMax, MeshMixer.


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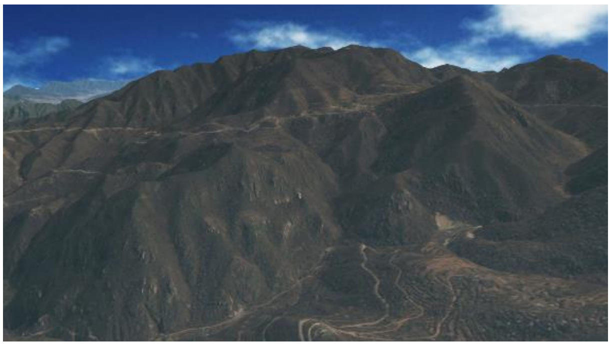

**Figure 2**. Terrain scene.

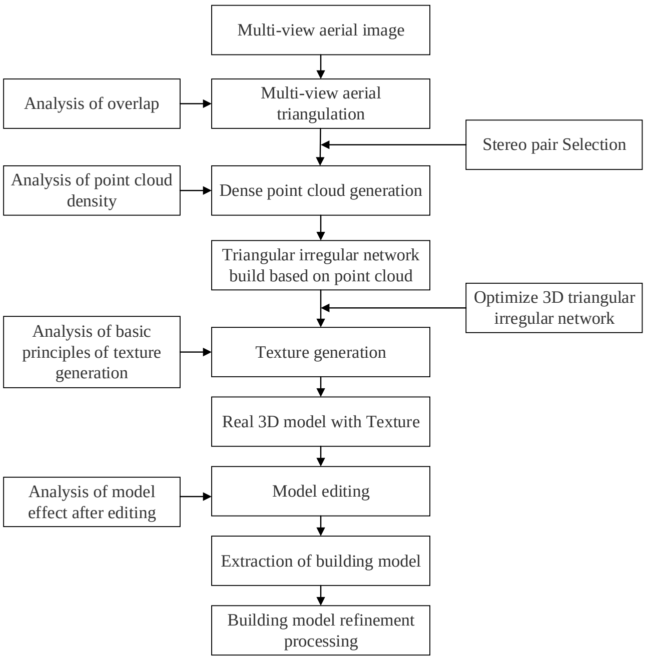


**Figure 3**. The process of Real 3D model construction.

## 2.3 Remote Sensing Interpretation

Remote sensing interpretation of geological hazard is a comprehensive, large amount of data, high-visualization 3D analysis and interpretation work. The main information sources are remote sensing data and 3D model data. Taking advantages of interpretation signs and practical experience and knowledge, the targets were identified and their relevant information such as the structure and function were extracted qualitatively and quantitatively. Thus, we analysed the geological background conditions and environmental development factors of geological hazards (Wang Wei Dong et al., 2009), which determined the type, scale and spatial distribution of geological hazards.

## 2.4 Application of Geological Structure Analysis Based on Digital Twin Study Results

Because geological hazard points are mainly distributed in mountainous areas with complex terrain and large altitude difference, high-precision terrain data are very important basic data in both the survey of geological hazard hidden points and the prevention and control of geological hazard in the later stage. In this paper, the high-precision DEM data is obtained by calculating aerial photogrammetry images results through dense matching algorithm to output high-density discrete point clouds data, and then automatic filtering of the point clouds supplemented with some human intervention. On the foundation of these results, we realized three-dimensional visual browsing, mountain profile line extraction (Weidong Wang 2008), slope and aspect calculation of fine terrain and so on in complex mountainous areas. The above topographic factors are closely related to geological hazards, which effectively improved the evaluation accuracy of the risk level of geological hazard hidden danger points.

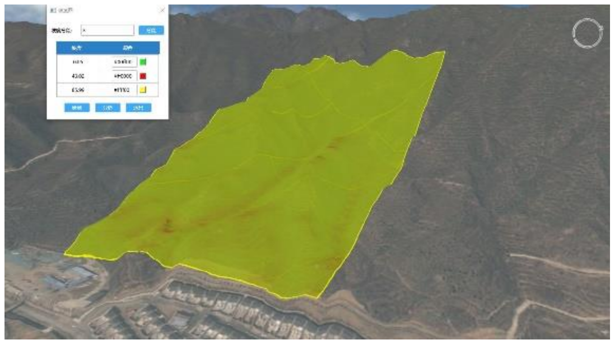

**Figure 4**. Slope maphe.

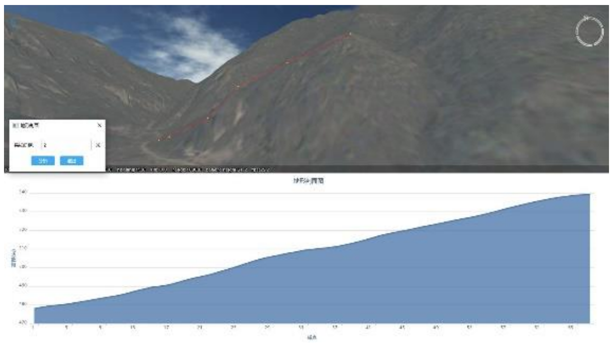

**Figure 5**. Topographic profile.

## 2.5 Historical Tracing and Early Warning Simulation

The digital twin processing results of the geological hazard hidden danger points in different time periods were permanently stored in digital forms, which were convenient to use anytime and intuitively analyze the change information such as topography and landforms before and after the occurrence of geological hazards. The analysis parameters of the geological hazard hidden danger points included the area and earthwork volume of the accumulation area, the area of the affected area and the earthwork volume of the terrain change area etc.
Combined with the different hazard types classification, hazard levels, and local climatic conditions, early warning models (Xiu Cai Guo and Xiao Peng Li, 2013) (Yang, B. et al., 2022) for some hazard types were established. Taking historical accumulated data as reference and latest weather forecast data as variable conditions, we realized scientific early warning simulation before the occurrence of geological hazard, which provided a certain reference value for the prevention and control of geological hazard.

**Figure 6**. Earthwork analysis.

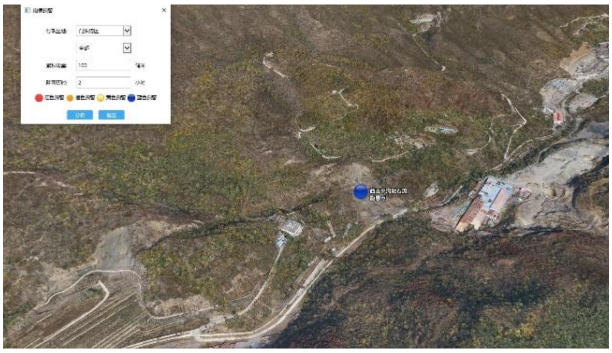

**Figure 7**. Rain warning.

### 2.6 2D and 3D Information Management System of Geological Hazard

These research data results include various types, which have the characteristics of multi-source and multi-dimensional. More specifically, multi-source data includes not only real 3D model data, DOM, DEM, but also basic geospatial data, such as Beijing's administrative divisions, road and village boundaries, geological hazard survey related vector data. Multi-dimensional data includes 3D data such as real 3D model of 、geological hazard hidden danger points, high-precision DEM; high-resolution DOM, vector data and attribute information data of geological hazard survey results, etc. The geological hazard spatial information system can unify the management of 2D and 3D data, and integration the geospatial and geological survey information data (Zeng, T. et al., 2009). Moreover, the information system has many functions such as all data display, accurate query and statistics, spatial analysis, and information release etc.

Through establishing digital 3D models of terrain and ground objects and collecting, integrating and excavating the 3D information of geological hazard points and their surrounding areas, the information system breaks through the limitation of traditional 2D map and realizes the transformation of modern management mode of geological hazard from 2D to 3D. A virtual environment similar to the reality is available for users to get information services about early warning, prevention and hazard evaluation of geological hazard, leading to a unified and standardized management mode formation (Zhenwen He et al., 2012). Thereby the sharing and utilization of city space information and the overall information management level of hazard are improved greatly.

## 3. EXAMPLES OF RESULTS

This paper takes the hidden danger point of debris flow in Xiwangping gully, Wangping Town, Mentougou District, Beijing as the sample application. This hidden danger point covers an area of about 6.23 km$^2$, located in Yongding River system, with a relative height difference of 579.79 m, where the quantity of people that a debris flow can threaten is 525. This area is a typical representative of northern mountainous areas. The UAV aerial photography technology was used to obtain oblique images with a spatial resolution of 0.05 m, and DOM production and real 3D constrution were carried out. The mean square error of plane position in DOM was 0.36 m. The mean square error of plane position and elevation in 3D models were 0.73 m and 0.98 m respectively.

**Figure 8**. Real 3D model.

（a）Debris flow basin (b) Gully

**Figure 9**. Debris flow basin and gully.

（a）Lithology (b) geological boundary

**Figure 10**. Lithology and geological boundary.

All data were stored in the 3D analysis system to realize the panoramic roaming of hidden danger point and real-time query of geological survey data. Combined with the 3D scene and data information, we analyzed the location relationship of debris flow deposits, threatened buildings and emergency shelter in the 3D scene, and judged that the emergency shelter confirmed by the field geological hazard survey was surrounded by the threat buildings, and located in the extension area of debris flow gully, which had a certain risk. Using the real 3D scene, combined with the terrain profile analysis, we interpreted that the northwest side has a high terrain and some open spaces. Therefore, the location of emergency shelter in this danger point was adjusted to the appropriate position in the northeast side.


**Figure 11**. Location relationship of debris flow deposits, threatened buildings and emergency shelter.


**Figure 12**. Location relationship between threatened buildings and emergency shelter.


**Figure 13**. Location movement of the emergency shelter.

## 4. CONCLUSION

In this paper, a high-precision geological hazard survey and prevention method using digital twins and UAV tilt aerial photogrammetry technique, is applied to realize the three-dimensional visualization, measurement, analysis and traceability of geological hazard hidden danger points in Beijing. Based on the application of digital twins in high precision geological hazard survey and prevention, this paper realized the three-dimensional visualization, measurement, analysis and traceability of geological hazard hidden danger points in Beijing. Combined with professional geological survey data, we had carried out "scientific physical examination" for each geological hazard hidden danger point, so as to truly achieve "one geological hazard hidden danger, one policy" and accurate early prevention. This method also provides valuable experience for the digital and systematic development of geological hazard survey and prevention in China.
Furthermore, by referring to the digital twins approach described in this paper, various following-up relevant work can be carried out in Beijing in all-round way. Such as, to conduct the various types of geological hazard survey and prevention in the whole city, establish a real 3D database of geological hazard, evaluate its stability and danger scientifically, build and improve the threat and early warning model. It is expected that all these efforts will lay solid foundation for scientific and accurate survey and prevention of geological hazard and optimization of early warning system.

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