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EVALUATION OF THE EFFECTIVENESS OF OPEN-PIT MINE SLOPE DEFORMATION MONITORING USING UAV-BASED PHOTOGRAMMETRY TECHNOLOGY

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Abstract
This article investigates the effectiveness of using Unmanned Aerial Vehicles (UAVs) and photogrammetry technology for monitoring the condition of open-pit mine slopes. Continuous monitoring of the geomechanical state of mine slopes is essential for ensuring operational safety and for the early detection of potential landslides and slope failures. In this study, high-resolution Digital Elevation Models (DEMs) and three-dimensional (3D) models of mine slopes were generated using aerial images acquired by UAVs. The obtained data were compared with conventional geodetic monitoring methods to evaluate monitoring accuracy, time efficiency, occupational safety, and economic performance. The results demonstrate that UAV-based photogrammetry enables rapid detection of slope deformations, effective mapping of hazardous zones, and improved operational efficiency of monitoring activities. Furthermore, the application of this technology significantly reduces field survey time and associated costs while minimizing risks related to human involvement in hazardous areas. The findings provide a scientific basis for improving geotechnical monitoring systems in open-pit mines and for developing practical recommendations aimed at enhancing mining safety and slope stability management.

Keywords: UAV, photogrammetry, open-pit mining, slope deformation, geotechnical monitoring, digital elevation model, 3D modeling, mine safety.

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Introduction

The continuous growth of surface mining operations in the modern mining industry has led to increasing pit depths and higher slope heights in open-pit mines. As a result, ensuring slope stability and detecting potential landslides and failures at an early stage have become critical challenges for mining enterprises. Deformation of pit slopes can cause production interruptions, damage to mining equipment, and serious risks to personnel safety.

Conventional geodetic monitoring methods, including total stations, theodolites, Global Navigation Satellite Systems (GNSS), and terrestrial laser scanning technologies, have long been used for monitoring the condition of open-pit mine slopes. However, these methods are often associated with significant time consumption, high operational costs, and limited accessibility in hazardous or difficult-to-reach areas of large-scale mining operations.

Recent advances in Unmanned Aerial Vehicle (UAV) technology and digital photogrammetry have created new opportunities for implementing efficient monitoring systems in the mining industry. UAVs enable rapid acquisition of high-resolution aerial imagery over large areas, while photogrammetric processing allows the generation of Digital Elevation Models (DEMs), orthophoto maps, and three-dimensional (3D) terrain models. These products provide valuable information for continuous assessment of slope conditions and facilitate the early detection of deformation processes.

Today, leading mining companies worldwide actively employ UAV technologies for geotechnical monitoring, volumetric calculations, mine planning, production control, and safety management. Despite the growing adoption of UAV-based monitoring systems, issues related to evaluating their effectiveness in open-pit slope monitoring, assessing the accuracy of photogrammetric data, and scientifically substantiating their economic benefits remain insufficiently investigated.

Therefore, the objective of this study is to evaluate the effectiveness of UAV-based photogrammetry technology for monitoring open-pit mine slope deformations, analyze its capability for identifying deformation-prone zones, and justify its advantages compared with conventional geodetic monitoring methods. The results of this research are expected to contribute to the improvement of geotechnical monitoring systems and enhance operational safety in open-pit mining environments.

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Materials and Methods

In this study, a methodology based on Unmanned Aerial Vehicles (UAVs) and digital photogrammetry was developed for monitoring the condition of open-pit mine slopes. The research object was the slope system of an operating open-pit mine. Monitoring activities were conducted to assess the geomechanical condition of the slopes, identify deformation and displacement processes, and delineate potentially hazardous zones.

During the first stage of the study, aerial images of the mining area were acquired using a UAV platform. Flight missions were performed according to a pre-planned route designed to ensure complete coverage of the pit slopes and to provide image quality suitable for photogrammetric processing. Longitudinal image overlap was set at 80%, while lateral overlap was maintained at 70%. These parameters enabled the generation of highly accurate three-dimensional models through photogrammetric reconstruction.

In the second stage, the acquired aerial photographs were processed using photogrammetric software. The processing workflow included image alignment, point cloud generation, and surface reconstruction. As a result, a dense Point Cloud, a Digital Elevation Model (DEM), and a three-dimensional (3D) model of the pit slopes were produced. These models provided detailed spatial information and enabled comparative analysis of slope conditions over different monitoring periods.

The third stage focused on deformation detection and assessment. Digital models generated at different time intervals were compared to identify changes in slope geometry. Through this comparison, both vertical and horizontal displacements within the pit slopes were determined. The deformation magnitude was evaluated using the following equation:

$$D=\left|H_{2}-H_{1}\right|$$

where:

- D – deformation magnitude, m;
- H_1 – coordinate or elevation value of a monitoring point during the initial survey period, m;
- H_2 – coordinate or elevation value of the same monitoring point during the subsequent survey period, m.

To evaluate monitoring efficiency, the UAV-based photogrammetry approach was compared with conventional geodetic monitoring methods according to the following criteria:

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- duration of field survey operations;
- data processing time;
- monitoring accuracy;
- occupational safety level;
- economic costs.

Statistical and comparative analysis methods were applied to interpret the obtained results. Based on the collected data, the advantages, limitations, and practical applicability of UAV-based photogrammetry technology for open-pit mine slope monitoring were assessed. The developed methodology provides a basis for improving geotechnical monitoring systems and enhancing operational safety in open-pit mining environments.

Results and Discussion

The effectiveness of UAV-based photogrammetry technology for monitoring open-pit mine slope conditions was evaluated during the study. As a result of the monitoring campaign, a high-resolution orthophoto map, a Digital Elevation Model (DEM), and a three-dimensional (3D) model of the mining area were successfully generated. These datasets provided comprehensive information on the spatial characteristics of the pit slopes and enabled detailed assessment of their geomechanical condition. Based on the analysis, several zones exhibiting signs of deformation were identified and mapped.

Monitoring surveys were conducted twice within a 30-day observation period. Digital models generated from each survey were compared to determine changes in slope geometry and to quantify displacement values at selected control points. The comparative analysis revealed measurable variations in elevation and position, indicating the presence of localized deformation processes within specific sections of the pit slopes.

Table 1. Displacement Values Recorded at Pit Slope Monitoring Points

Monitoring Point	Initial Survey (m)	Subsequent Survey (m)	Displacement (m)
N-1	425.84	425.79	0.05
N-2	417.36	417.28	0.08
N-3	409.12	408.98	0.14
N-4	401.55	401.39	0.16
N-5	394.20	393.98	0.22

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The data presented in Table 1 indicate that displacements ranging from 0.05 m to 0.22 m were observed in certain sections of the pit slope. The largest deformation was recorded at monitoring point N-5, suggesting the need for additional geotechnical monitoring and stability assessment in this area.

The analysis demonstrated that UAV-acquired data are capable of detecting even minor slope deformations. The high-resolution point cloud and three-dimensional (3D) model enabled rapid identification of potentially hazardous zones, allowing the implementation of additional engineering and stabilization measures where necessary.

Table 2. Comparative Indicators of Conventional Geodetic and UAV-Photogrammetry Methods in Pit Slope Monitoring

Indicator	Conventional Geodetic Method	UAV-Photogrammetry Method
Survey time (hours)	6–8	1–2
Personnel involved	3–4	1–2
Need to access hazardous areas	Required	Minimal
3D modeling capability	Limited	High
Data acquisition speed	Moderate	High
Monitoring costs	High	Relatively low

The comparative analysis demonstrated that UAV technology offers significant advantages in the monitoring process. In particular, the time required for field surveys was reduced by 3–4 times, risks associated with human involvement were minimized, and large areas could be covered within a short period of time.

Furthermore, orthophoto maps and three-dimensional models generated from UAV data enabled a comprehensive visual assessment of pit slope conditions. The identification of deformation zones and monitoring of their development dynamics contribute to improving geotechnical safety in mining operations.

The obtained results indicate that UAV-photogrammetry technology provides high accuracy, operational efficiency, and economic effectiveness in pit slope monitoring. The integration of this technology into geodetic monitoring systems expands the capabilities for early detection of slope instability and landslide hazards in open-pit mines, thereby enhancing the overall safmining operations.

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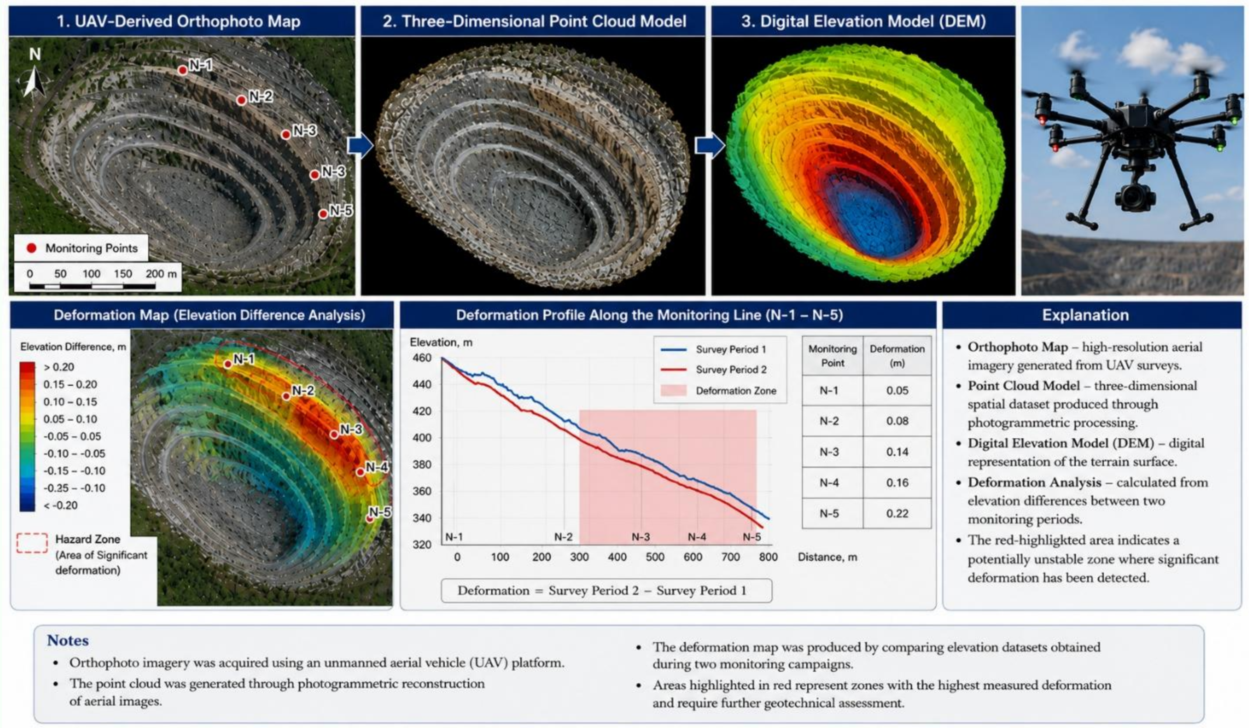

Conclusion

This study evaluated the effectiveness of unmanned aerial vehicle (UAV) and photogrammetric technologies for monitoring the stability and condition of open-pit mine slopes. The results demonstrated that UAV-based photogrammetry provides a rapid, accurate, and efficient approach for assessing the geomechanical condition of pit walls and identifying potential deformation zones.

The analysis confirmed that high-resolution orthophotos, point cloud datasets, digital elevation models (DEMs), and deformation maps can be successfully generated from UAV-acquired aerial imagery. Comparison of datasets obtained during different monitoring periods enabled the identification and quantification of slope displacement and deformation processes within the open-pit environment.

The calculated deformation values at the monitoring points ranged from 0.05 m to 0.22 m. The highest deformation was recorded at monitoring point N-5, indicating that this section of the pit wall represents a potentially unstable area requiring additional geotechnical assessment and continuous observation.

A comparative evaluation of monitoring approaches showed that UAV-photogrammetry offers several advantages over conventional geodetic surveying methods. In particular, field data acquisition time was reduced by approximately three

to four times, the number of personnel involved in monitoring operations decreased, and the need for direct access to hazardous areas was significantly minimized. Furthermore, the capability to generate detailed three-dimensional models and process large volumes of spatial data within a short period substantially improved the overall efficiency of the monitoring process.
The findings of this research confirm that the integration of UAV-photogrammetric technology into geotechnical monitoring systems for open-pit mines represents an effective solution for assessing slope stability, identifying potential landslide and failure hazards at an early stage, and enhancing operational safety. Future research should focus on the integration of artificial intelligence and machine learning algorithms with UAV monitoring systems to enable automated deformation detection, predictive analysis, and real-time geotechnical risk assessment.

References

1. Colomina, I., & Molina, P. (2014). Unmanned aerial systems for photogrammetry and remote sensing: A review. ISPRS Journal of Photogrammetry and Remote Sensing, **92**, 79–97.
2. Nex, F., & Remondino, F. (2014). UAV for 3D mapping applications: A review. Applied Geomatics, **6**(1), 1–15.
3. Turner, D., Lucieer, A., & Watson, C. (2012). An automated technique for generating georectified mosaics from ultra-high resolution UAV imagery. Remote Sensing, **4**(5), 1392–1410.
4. Shahbazi, M., Théau, J., & Ménard, P. (2014). Recent applications of unmanned aerial imagery in natural resource management. GIScience & Remote Sensing, **51**(4), 339–365.
5. Esposito, G., Fallavollita, P., & Tosti, F. (2021). UAV-based monitoring systems for slope stability assessment in open-pit mines. Mining Engineering, **73**(9), 42–49.
6. Niethammer, U., James, M. R., Rothmund, S., Travelletti, J., & Joswig, M. (2012). UAV-based remote sensing of landslides. Natural Hazards and Earth System Sciences, **12**, 1–15.
7. Casagli, N., Tofani, V., & Moretti, S. (2017). Landslide monitoring using UAV photogrammetry and remote sensing technologies. Engineering Geology, **221**, 76–90.

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8. Zhang, C., & Kovacs, J. M. (2012). The application of small unmanned aerial systems for precision agriculture and mining monitoring. Precision Agriculture, **13**(6), 693–712.
9. Hardin, P. J., & Jensen, R. R. (2011). Small-scale unmanned aerial vehicles in environmental remote sensing. GIScience & Remote Sensing, **48**(1), 99–111.
10. Pajares, G. (2015). Overview and current status of remote sensing applications based on unmanned aerial vehicles (UAVs). Photogrammetric Engineering & Remote Sensing, **81**(4), 281–330.
11. Aber, J. S., Marzolff, I., & Ries, J. B. (2019). Small-Format Aerial Photography and UAV Applications. Amsterdam: Elsevier.
12. Luhmann, T., Robson, S., Kyle, S., & Harley, I. (2018). Close-Range Photogrammetry and 3D Imaging. Berlin: De Gruyter.