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Review article

A Review of the Utilization of Unmanned Aerial Vehicles (UAVs) in Open-pit and Underground Mining Design: Current State, Challenges, and Future Prospects

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English Extended Abstract

Summary

A digital photogrammetry has become a widely utilized technique for mapping geological features and characterizing rock masses in mining operations. Despite its advantages, challenges persist in capturing geotechnical data in remote mining areas, leading to incomplete models that could result in significant risks, such as collapses in underground excavations. Kinematic analysis of discontinuities can help predict potential failures, addressing data gaps. The integration of unmanned aerial vehicles (UAVs) has improved data collection, enabling high-resolution imagery and accurate topographic data even in difficult conditions. In this review study, an introduction to the significance of investigating jointed rock masses and the factors influencing their formation mechanisms is first presented. Subsequently, case studies of modeling jointed rock masses using aerial data collected via drones are provided. Additionally, the challenges associated with utilizing various types of drones in the mining industry for future studies are discussed.

Introduction

The integration of drone technology into mining operations has revolutionized the way geological surveys and resource management are conducted in both open-pit and underground mining environments. With the increasing demand for efficient and precise data collection, drones have emerged as a vital tool for enhancing operational efficiency, safety, and environmental sustainability in the mining sector. This review synthesizes insights from over 60 scholarly articles, highlighting the current state of drone applications in mining, encompassing various methodologies and technological advancements that have shaped contemporary practices. The primary objective of this study is to critically evaluate the existing literature on the utilization of drone technology in mining design and extraction processes. By examining both open-pit and underground mining contexts, this review aims to identify key challenges that practitioners face when implementing drone technology, such as regulatory compliance, data processing complexities, and operational limitations. Furthermore, it seeks to explore future prospects for drone applications in mining, offering recommendations for overcoming existing barriers and enhancing the efficacy of this transformative technology in the industry.

Methodology and Approaches

This review article utilizes a systematic literature review methodology to assess the current applications of drone technology in the design and extraction processes of both open-pit and underground mining. The research commenced with a comprehensive search for relevant scholarly articles published in peer-reviewed journals, conference proceedings, and industry reports. Academic databases such as Scopus, Web of Science,

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and Google Scholar were employed, focusing on keywords including "drone technology," "photogrammetry," "geospatial data," "mining," and "rock mass modeling ".

The selection criteria for the articles included relevance to mining contexts, recency—favoring publications from the last decade to capture the latest advancements—and peer-reviewed status to ensure credibility. This approach ensured that only high-quality studies were included in the review.

Key information was extracted from the identified articles and categorized thematically. The extraction focused on several critical aspects: technological innovations, including types of drones and sensors used; case studies illustrating practical applications of drone technology in various mining scenarios; challenges faced in implementing these technologies, such as regulatory compliance and the need for specialized training; and future directions that highlight potential advancements like artificial intelligence integration for enhanced data analysis.

The findings were organized into categories such as application phases (exploration, exploitation, reclamation), technological advancements (e.g., LiDAR and multispectral imaging), challenges related to operational training and regulatory compliance, and future directions emphasizing AI integration and real-time data processing optimization. This thematic analysis facilitated a structured synthesis of findings that underscores best practices for integrating drones into mining design and extraction processes.

Additionally, the review highlights the importance of accurate geotechnical data acquisition for effective rock mass modeling. It emphasizes that precise data collection significantly influences various aspects of engineering design, including slope stability assessments and resource estimation. The study also acknowledges limitations in encompassing all emerging technologies or regional practices due to the dynamic nature of the field. Future research should continue to explore innovative applications of drone technology as they evolve within the mining industry, aiming to enhance safety, efficiency, and accuracy in mining operations through advanced data collection techniques.

Moreover, this review aims to provide a comprehensive understanding of how photogrammetry can enhance rock mass modeling by integrating high-resolution aerial imagery with advanced analytical techniques. By addressing various methodologies employed in drone-based data collection, this study seeks to inform future research directions and practical applications in mining engineering.

Results and Conclusions

The findings of this review highlight the significant advancements in drone technology and its applications in both open-pit and underground mining. The analysis of over 60 scholarly articles reveals that the integration of drone-based photogrammetry has substantially improved data collection efficiency, accuracy, and safety in mining operations. The results indicate that drones facilitate rapid surveying of geological features, enabling the creation of high-resolution three-dimensional models that are essential for geotechnical assessments. The use of Structure from Motion (SfM) techniques has emerged as a particularly effective method for generating detailed point clouds, which can be utilized for various engineering analyses, including slope stability evaluations and resource estimation. The accompanying figure illustrates the comparative advantages of drone-based photogrammetry over traditional surveying methods. It depicts the time efficiency, cost-effectiveness, and data quality improvements achieved through drone applications. Notably, the figure emphasizes the ability of drones to access remote or hazardous areas safely, thereby mitigating risks associated with manual data collection. As a result, the review concludes that while challenges such as regulatory compliance and the need for specialized training persist, the future prospects for drone technology in mining are promising. Continued advancements in sensor technology and software development are expected to further enhance the capabilities of drones, making them indispensable tools for modern mining operations. This study underscores the importance of adopting innovative technologies to improve operational efficiency and safety in the mining industry while paving the way for future research and development in this rapidly evolving field

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