

# Recent Advances in Smart Mining Technology

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Mining is a crucial industry for our modern society, providing valuable resources that fuel our economies and drive technological progress. However, traditional mining practices can be dangerous, environmentally damaging, and costly, and they often face challenges such as declining ore grades, increasing depths of mineral deposits, and complex geological conditions. The concept of smart mining, which combines traditional mining technology with information and communication technology (ICT), has become a representative keyword constituting the fourth industrial revolution of the mineral industry in the age of digital transformation. Smart mining technology offers a promising solution to these challenges, leveraging the latest advances in sensing, automation, and data analytics to optimize mining operations and improve safety, efficiency, and sustainability.

This Special Issue of *Applied Sciences* presents a collection of recent advances in smart mining technology, covering a broad range of topics from sensor design and data processing to machine learning and robotics. The papers in this issue highlight cutting-edge research and development in this field, as well as the challenges and opportunities that lie ahead.

One of the key themes of this Special Issue is the use of sensors for real-time monitoring and control of mining processes. Several papers describe novel sensor technologies for measuring various parameters such as temperature, pressure, vibration, and gas concentrations, and their integration into mining equipment and systems. These sensors enable operators to detect anomalies, optimize process parameters, and prevent equipment failures, thus improving safety and reducing downtime and maintenance costs. Park and Choi [1] developed a system to collect and analyze log data related to truck travel times in underground mines using Bluetooth beacons and tablet computers. The collected data were integrated and processed to calculate statistical values for each section of the transport route. The system was applied to a limestone underground mine in Korea to diagnose and analyze transport routes, classify them based on distribution and fluctuations in truck transport time data, and analyze the causes of stable and unstable sections. Such a system could be used to improve transport operations in mines.

Kim et al. [2] describe the development of a smart-helmet-based wearable personnel proximity warning system to prevent collisions between equipment and pedestrians in mines. The system utilizes Bluetooth beacons attached to heavy equipment and dangerous zones to transmit signals that are received by a smart helmet worn by pedestrians, providing simultaneous visual LED warnings to both pedestrians and operators. Results from a performance test in an underground limestone mine indicate that the system can detect Bluetooth low-energy (BLE) signals at a distance of at least 10 m and that the smart-helmet-based PWS has the lowest subjective workload among different types of proximity warning systems. Kim et al. [3] provide a review of the applications of the Arduino platform in the mining industry. The review is categorized into three types of Arduino applications: field monitoring systems, wearable systems, and autonomous systems. The study concluded that although most studies have been conducted in a laboratory setting, Arduino applications have the potential to be further expanded in the mining field due to their advantages of being cost-effective and easily combinable with various electronic products.

Another important theme is data analytics and machine learning, which are increasingly being used to process the large volumes of data generated by smart mining systems.



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Several papers present algorithms and models for predictive maintenance, anomaly detection, and optimization of mineral processing operations. These methods can help operators to identify and address issues before they cause downtime or production losses and to optimize the use of resources and energy. Wang et al. [4] propose a prediction model using gradient-boosting decision trees (GBDT) and particle swarm optimization (PSO) to analyze the uplift behaviors of helical anchors in sand. The dataset for the model was obtained from centrifuge tests, and the model used input parameters such as relative soil density, embedment ratio, helix spacing ratio, and the number of helices to predict output parameters such as anchor mobilization distance and ultimate uplift resistance. The model accurately predicted these parameters, with the embedment ratio being the most significant variable in the model. Jung et al. [5] used discrete event simulation to stochastically predict ore production in an underground limestone mine by using four different probability density functions for truck travel times. The results show that the predicted ore production was relatively consistent with actual ore production when using the normal and observed probability distribution of real data, whereas the uniform and triangular distribution underestimated it. The observed probability distribution showed the lowest root mean squared error for predicting ore production.

In addition, several papers focus on the use of robotics and automation in mining, which offer significant benefits in terms of safety, productivity, and efficiency. These papers describe the development and application of autonomous mining equipment, drones, and robots for various tasks such as drilling, blasting, ore transportation, and inspection. These technologies not only reduce the risk of accidents and injuries but also enable mining operations to be carried out in remote or hazardous environments that are difficult or impossible for human workers to operate in. Zhao et al. [6] propose a new autonomous walking training algorithm, called traditional control-based DQN (TCB-DQN), for underground load-haul-dump (LHD) machines using a reinforcement learning algorithm. The algorithm combines traditional reflective navigation and reinforcement learning deep q-networks (DQN) and does not require accurate positioning but senses the distance from the endpoint to determine how to reach it. Their experimental results show that after training with TCB-DQN in a simple and complex tunnel, the LHD machine achieved a walking effect similar to that of a human driver's manual operation and reached the endpoint smoothly.

Kim and Choi [7] propose a smart hopper system that automatically detects and removes rocks that cause obstructions in mining site hoppers. The system captures RGB-D images of hopper surfaces using a camera, transmits them to a computer, and uses machine-vision-based image processing techniques to identify rocks. Based on a simulation, a robot arm moves to the location of the rock in the real world and removes it from the hopper. The proposed system accurately recognizes rocks at all positions in the hopper, as confirmed by the evaluation results. Zhao and Bi [8] propose a path-planning method based on a high-precision digital map for open-pit mining that considers terrain factors. The method consists of constructing a high-precision digital map of the cutting zone and planning the optimal path based on the modified Hybrid A\* algorithm. The proposed method reduces the total transportation cost of the optimal path by 10–20% compared to the path without considering terrain factors and shows robustness. Kim and Choi [9] compared the accuracy of three location estimation methods for an autonomous driving robot in underground mines: IMU + encoder, LiDAR + encoder, and IMU + LiDAR + encoder. An indoor experiment was conducted in a laboratory and a field experiment was performed. The results showed that the IMU + LiDAR + encoder method had the highest accuracy, with an average estimation error of approximately 0.09 m in the indoor experiment and 0.11 m in the field experiment.

In conclusion, this Special Issue provides a comprehensive overview of recent advances in the field of smart mining technology and their potential to transform the mining industry. I hope that this collection of papers will inspire further research and innovation in this field and contribute to the development of more sustainable and responsible mining practices.

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