



Keywords: Mining automation; Robotics; Autonomous vehicles; Mining safety; Robotics in mining; Smart mining; Remote operations; Mining technology; Automation in mining

Introduction

The mining industry plays a pivotal role in the global economy, supplying raw materials essential for various industries. However, mining operations are inherently hazardous, with workers facing risks such as equipment malfunctions, exposure to toxic substances [1,2], and physical injuries. In addition, the remote locations of many mining sites present logistical and operational challenges. The advent of automation and robotics technologies promises to revolutionize the mining industry by improving safety, operational efficiency, and sustainability. By reducing human labor in high-risk environments, these technologies offer significant benefits, including cost savings, enhanced productivity, and more environmentally responsible mining practices.

Technologies driving mining automation and robotics

Autonomous vehicles: Autonomous vehicles (AVs) are among the most significant advancements in mining automation. These vehicles,

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distances is crucial. Additionally, robotic drilling systems enable faster and more precise drilling, ensuring a higher quality of ore extraction.

Underground mining: Underground mining operations benefit significantly from automation and robotics. Robotic drilling systems, autonomous loaders, and remote-controlled equipment allow for continuous operation in dangerous environments. By automating hazardous tasks, such as drilling and material transportation, mining companies can reduce the risk to human workers and ensure operations run smoothly. In some cases, these technologies can even assist in monitoring air quality, temperature, and other environmental factors, providing a safer working environment for miners.

Exploration and geophysical surveying

Automation also plays a crucial role in exploration and geophysical surveying. Drones equipped with sensors can gather data over large areas, mapping the topography and identifying mineral deposits. AI algorithms can then analyze this data to predict the location of valuable resources, enabling more efficient and cost-effective exploration.

These robotic systems reduce the need for human surveyors to work in potentially dangerous or remote areas, improving both safety and efficiency [7].

Benefits of mining automation and robotics

Enhanced safety: Safety is a primary concern in the mining industry, and automation is a powerful tool for reducing risk. By eliminating human workers from hazardous tasks and environments, automation minimizes the likelihood of accidents. Autonomous vehicles, for example, can operate in dangerous terrain, while robotic drilling systems can function in confined or unstable spaces without putting human lives at risk.

Increased productivity and efficiency: Mining automation boosts productivity by enabling continuous, 24/7 operations. Autonomous trucks and equipment can work around the clock without the need for rest, shift changes, or breaks. The integration of AI also helps to optimize the scheduling and execution of mining tasks, further enhancing efficiency. As a result, mining companies can achieve higher output with fewer resources, translating to cost savings and better profitability [8].

Environmental sustainability

Automation and robotics also contribute to more sustainable mining practices. By reducing human presence and increasing the precision of operations [9], these technologies help minimize environmental disruption. For instance, robotic drills allow for more accurate extraction of minerals, reducing the amount of waste material produced. Autonomous trucks can optimize fuel usage, reducing greenhouse gas emissions, and minimizing the carbon footprint of mining operations.

Cost savings: Though the initial investment in automation technologies can be substantial, the long-term cost savings are significant. Automation leads to reduced labor costs [10], fewer accidents, lower equipment maintenance costs, and higher efficiency. In the long run, these savings can offset the initial costs and deliver a

positive return on investment.