The Application Status and Development Trend of Data-driven Technology in Mine Engineering

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Abstract. With the rapid advancement of science and technology, data-driven technologies have found extensive applications across various industries, including mining. Traditional mining methods, which often involve significant safety risks, low operational efficiency, and high environmental costs, are increasingly being challenged by the need for more sustainable and efficient practices. This has highlighted the urgency of transforming the mining industry through the adoption of intelligent mining solutions. This paper reviews several commonly used data-driven technologies currently employed in mining production, such as 5G communication, Big Data Analytics, and Digital Twin Technology. These technologies enable real-time monitoring, predictive analytics, and virtual simulations, significantly improving operational efficiency, safety, and environmental performance. By examining the applications and integration of these technologies in both domestic and international contexts, this study analyzes the emerging development trends, key directions, and major challenges faced by intelligent mining systems. The goal is to provide valuable references and insights for promoting the digital transformation of the mining industry, contributing to the industry's sustainable development, and supporting the intelligent evolution of mining practices to ensure long-term viability and resilience in the face of environmental and market challenges.

Keywords: Mining Engineering, Coal Mining, Intelligentization.

1. Introduction

In the current society, science and technology along with artificial intelligence are developing rapidly. All industries are accelerating their progress towards intelligence. There is also a trend towards intelligence in the field of mining engineering. In recent years, data-driven technologies are profoundly transforming the traditional paradigm of mining engineering. Data-driven technologies include big data analytics, artificial intelligence (AI), machine learning (ML), digital twins (DT), etc [1]. These technologies are mainly used in mining engineering for data acquisition, intelligent decision making and optimal scheduling. For example, AI algorithms can perform predictive maintenance based on data collected by mine sensors to avoid lost downtime due to equipment failure [2].

5G, Internet of Things (IoT), sensors and other technologies are widely used in all aspects of mine development to realize the all-round design and monitoring of mine production, realizing the all-round design and monitoring of mine production, greatly improving the efficiency and safety of mine work [3].

2024, September 4, party committee member of the Ministry of Emergency Management, the State Mine Safety Supervision Bureau Director Huang Jinsheng said in the State Council Information Office held a series of themed press conference “Promoting high-quality development”, “up to now, the country has built 1,642 intelligent mining working face, with intelligent here are 1,642 intelligent mining working faces, 859 coal mines with intelligent working faces, 2,640 sets of robots of more than 30 categories, 1,328 sets of unmanned vehicles in popularization and application, and 17,000 fixed positions realized unmanned duty.” He also states that “as of the end of August, the number of mine production and safety accidents and the number of people killed decreased by 25.6% and 31.99% year-on-year, respectively.” This is a breakthrough in the application of digital drive technology in the field of mining engineering. This list of achievements proves the necessity and importance of applying data-driven technologies in mining engineering.

Although the application of data-driven technology in mine engineering has made significant progress, it still faces many challenges in the process of promotion and deepening. The main problems include data quality, technology integration, construction cost, and talent shortage, etc. And these factors affect the overall development of smart mines to a certain extent. This paper will follow the new trend of intelligent mine development, summarizing common data-driven techniques used in mining engineering. Exploring future directions and challenges. Provide reference for the intelligent development and application of coal industry.

2. Application of data-driven technologies in mining

2.1. 5G technology

5G technology is the fifth generation of mobile communication technology. It is the latest generation of current communication technology indicators. Compared to 4G technology, The 5G technology boasts higher rates, lower latency and greater link range [4]. 5G technology can support connecting more devices in mine production to the network at the same time, linking the various stages of production. and transferring data between individual devices with very low latency and very high rates. It can meet the demand for unified scheduling and deployment in mine production and solve the problems of low communication efficiency and many safety hazards in coal mine operation [3].

5G technology, as the latest generation of current communication technology, not only surpasses 4G in terms of speed, latency and connection range, but also can support parallel connection of many devices in the mine, which meets the high requirements of smart mines for real-time data transmission.

2.2. Big data analytics and machine learning algorithms

Big data analytics and machine learning technology, as the core driving force of the intelligent transformation of the mining industry, are complementary to each other and constantly integrated to jointly promote the intelligent development of coal mines. Through big data analysis and machine learning technology, comprehensive monitoring and analysis of all aspects of coal mine production can be realized [5]. And using big data analysis, mining companies can extract key trends from huge production data, while machine learning algorithms help the models to continuously learn and optimize, forming an intelligent decision support system with adaptive capabilities [6].

First, through 5G technology, linking various devices and sensors under the mine for real-time data collection, and uploading data into the database in a timely manner, providing the data foundation for big data analytics and machine learning. Then through big data technology to process and mine the massive amount of mine production data, distilling valuable information, used to support decision making. Finally, machine learning algorithms are used to further process and refine the data and to model, simulate, and analyze the various types of data necessary to achieve intelligent monitoring of the production process [5].

2.3. Digital twin technology

Digital twin technology is a technology that improves digital technology to build virtual mirrors for physical entities, realizing real-time interaction, simulation and optimization of the physical and virtual worlds. The use of digital twins is driving the transformation of mines from “experience-driven” to “data-driven”. Digital twin technology provides real-time feedback on the state of mine production by creating a virtual model of the mine's physical facilities, providing visual monitoring, early warning and optimization strategies to help mines carry out more accurate production scheduling and risk management [7].

Applying it to all aspects of underground equipment, tunnel structures, miners, environmental parameters, and so on. Various models such as equipment models, climate models, structural models, etc. are used to simulate the mine conditions in advance, and the mine design requirements are repeatedly verified and optimized. Through the digital twin technology can realize the coal mine production process of remote monitoring, intelligent analysis and other processes. Mining digital twin needs to go through several development stages, want to realize the real-time operation of the "complete body", but also to mine the further development of the intelligent process [7].

3. Domestic and foreign intelligent mine analysis

3.1. Mining development abroad

Since the 1970s, the world's leading countries in mineral development, such as Australia, Russia and the United States, have begun to study intelligent mining technology [8]. In the 1990s, to gain a competitive advantage in the mining industry, these developed countries began to implement intelligent mine development programs [8].

For example, mining giant Rio Tinto Group is a global leader in automated mining and unmanned driving [9]. In 2018, Rio Tinto Group operated the world's first batch of unmanned vehicles on 1,700 kilometers of track, which increased the speed of unmanned vehicles transporting iron ore by 6% and reduced the impact of changing drivers [10]. The UK has a long history of developing and using VR technology in coal mine safety training. The VR products, such as SafeVR and Vroom, are very famous for open-pit truck operator training [11]. Canada Nickel has a longstanding commitment to automated mining technology and intends to have a mine free of people by 2050. All equipment at the mine is operated by satellite, allowing for automated mechanical mining [8]. Australian Micromine has developed a web-based online remote mining applications control system called PITRAM to reduce mining costs by 10% [12].

The intelligent development of foreign countries is developing towards "unmanned mine" and "intelligent mine".

3.2. Domestic mining development

In recent years, many domestic mining enterprises are also improving the level of intelligence, especially the popularity of big data, 5G and other technologies, but also to accelerate the progress of the domestic intelligent building.

Shanxi, Shaanxi, and Inner Mongolia, as China's major coal-producing regions, account for 70% of China's total coal production. The large coal bases in these regions have basically mechanized their working faces and are constantly advancing towards automation.

For example, the Shenmu Zhangjiamao coal mine of the Shaanxi Coal Group. Proposed upgrading and transforming to automation, intelligence in 2018. Develop a comprehensive sensory network, a high-speed data transmission channel, a big data application center and a commercial cloud service platform based on existing standard systems. Integrate the management of all aspects of mining, transportation, ventilation, and resource conservation and utilization [13].

After 2 years of construction, Zhangjiamao Coal Mine has set up a 5G network transmission system for underground roadways. The pioneering exploration tested underground applications of 5G networks, such as underground 5G transmission performance, fading characteristics, and real-world power consumption of 5G miniature base stations [13].

On this basis Xinyuan Coal Mine further investigated the use of 5G networks for underground HD video transmission and remote control. It proposed that the time slot allocation ratio between uplink transmission and downlink transmission used in underground coal mines should be 3:1. And the actual latency of 5G in the underground remote control was found to be less than 50 milliseconds [13]. These provide a valuable reference for applications with programs based on 5G technology.

Besides, domestic coal mines are still pushing forward the development of large-scale machinery and equipment. For example, Shaanxi Coal Group's Caojiatan coal mine applies the world's first 10-meter super-high mining equipment to the actual production of intelligent synthesized mining workings to adapt to the mining conditions of its extremely thick coal seams.

In general, China's intelligent mine research started late. However, with the rapid development and popularization of domestic digital drive technology, greatly advancing the development of China's intelligent mine construction, and even some of the technology as well as in the international leading.

4. Conclusion

Mine Intelligentization is the Core Technical Support for High-Quality Development of Coal Industry. In the future development, artificial intelligence, mechanical learning and other data-driven technologies will be deeply integrated with modern coal development and utilization to form an intelligent system with comprehensive perception, real-time interconnection and autonomous learning. Realizing the intelligent operation of coal mine development, mining transportation and other processes will be the development trend of intelligent mine.

The construction of intelligent mine is not only the improvement and upgrading of the original technology, but more importantly, it should fully reflect its technical status and role in the industrial field. Intelligent mining can be divided into four stages: mechanization, electrification, automation and intelligence. While automation refers to automatic execution according to certain standards and procedures, intelligence is proactive. Intelligent mining can not only do automatic execution, but also be able to accurately detect various conditions underground in real time, and actively respond to various emergencies. In terms of the current development of mines, has been basic mechanization, electrification process, and in the automation, stage has made considerable progress, but there is still a gap compared to the real intelligent stage.

1) Intelligence is not widespread in the production field. First of all, the various aspects of intelligence is not balanced, the current coal mining face automation technology has been quite mature, but the digging face is only able to complete the mechanization, electrification, far from reaching the automation, intelligent standards. Secondly, the core technology is not mature, and part of the intelligent equipment only applies to small coal mines, but cannot be used in large coal mines, which mean it cannot adapt to the current trend of large-scale coal mines. For example, motorized rollers to replace conventional rollers in belt conveyors. However, it cannot be applied to large coal mines at present because the problem of heat generation under high-power operation cannot be solved effectively. Finally, the high cost of intelligent equipment, such as permanent magnet motors, although the power balance, flexible control and other advantages, but due to the high cost of cost, also not popular at present.

2) Inability to adapt to local conditions. It is not possible to fully customize mine equipment for each mine's unique geological conditions, and there are cases where equipment selections are copied from mine to mine for use in actual production.

3) Staff capacity does not meet the demand for intelligence. At present, data-driven technology has some development and achievements in coal mines, but the staff engaged in the coal mining industry lacks intelligent awareness and ability. Problems such as unskilled operation of intelligent equipment and insufficient professional knowledge and literacy arise.

4) The analysis is not real-time. At present, coal mines have constructed six systems as well as a variety of sensor detection equipment, but on the one hand, due to the low connectivity between the various systems, they only serve as threshold alarms. Lack of ability to cope with emergencies in dealing with the actual production process

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