Chapter 1

The role of artificial intelligence in smart mining

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1 Industry 4.0 and smart mining

The paradigm shift occurring because of Industry 4.0 has led to the development of a new technology called smart mining in the mining industry. Smart mining technology improves productivity and safety through the digitization, intelligence, and automation of mining sites and mineral processing factories so that minerals required by the market can be mined, processed economically and safely, and delivered promptly. The scope of application of smart mining technology includes all processes, from ordering products from consuming companies to mining minerals in mines (ore production), processing minerals in factories, and product shipment. Smart mining improves productivity and safety through monitoring, analysis, prediction, diagnosis, optimization, and automation by connecting assets, processes, and people at mining sites based on advanced technologies of Industry 4.0. To realize smart mining sites, cutting-edge information and communication technologies, such as the Internet of Things (IoT), big data, mobile devices, artificial intelligence (AI), virtual/augmented/mixed reality (VR/AR/MR), and robotics, are being introduced to mining sites.

Building a smart mining site has the following requirements, as shown in Fig. 1: (1) technology that links space/state information of a physical mine site, including 3D modeling, smart sensors, and IoT, to a virtual mine model (Physical to Virtual, P2V); (2) intelligence technologies such as AI, big data analysis, and cloud computing to perform analysis, prediction, diagnosis, and optimization in virtual mine models; (3) automation technology, such as drones, autonomous driving, and collaborative robots for control (Virtual to Physical, V2P); (4) technology, such as mobile and wearable devices and VR/AR/MR, that links

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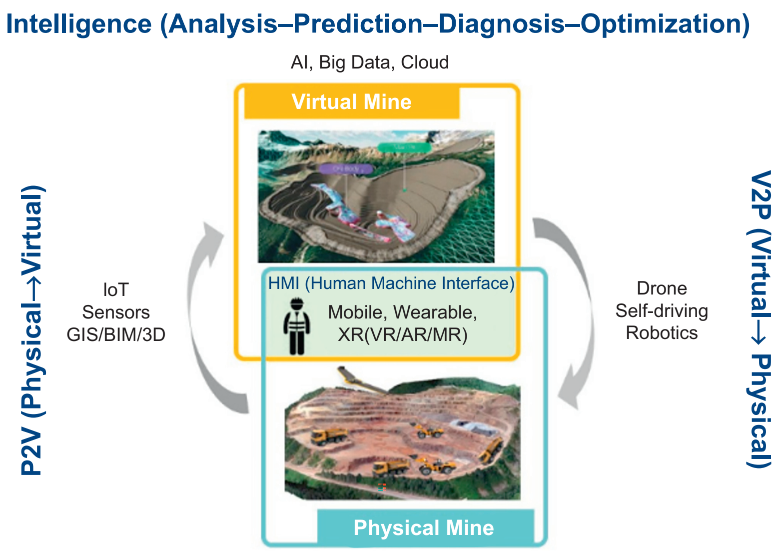

FIG. 1 Elemental technologies for building smart mining sites.

physical mine sites and virtual mine models centered on people should be combined.

2 Implementation levels of a smart mining site

The implementation level of a smart mining site can be divided into three stages. Level 1 involves constructing a digital spatial database of a mine site, inputting and visualizing attribute information, and performing preliminary simulations by changing the attribute information. 3D geology/mineral modeling technology and underground space surveying technology are used to construct a spatial database of a mine site (Fig. 2). Currently, unmanned aerial

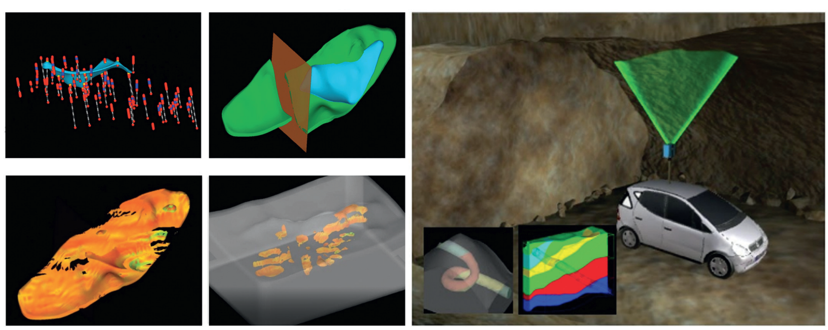

FIG. 2 Smart mining digital twin space database construction using 3D geology/mineral modeling technology and underground space surveying technology.

systems, such as drones, are used to build high-resolution spatial databases of mine sites.

Level 2 involves the one-to-one matching of the physical mine in the real world with the mine model in the virtual world, in addition to real-time monitoring. As shown in Fig. 3, a mine safety system corresponding to Level 2 of smart mining is developed and supplied to the field. In addition, recently, a technology that can implement smart mining digital twins at a low cost has been developed at a small-scale mining site using a low-power Bluetooth beacon and a smartphone with short-range communication technology (Fig. 4).

FIG. 3 Example of an ICT-based mine safety management system corresponding to smart mining digital twin <Level 2> [1].

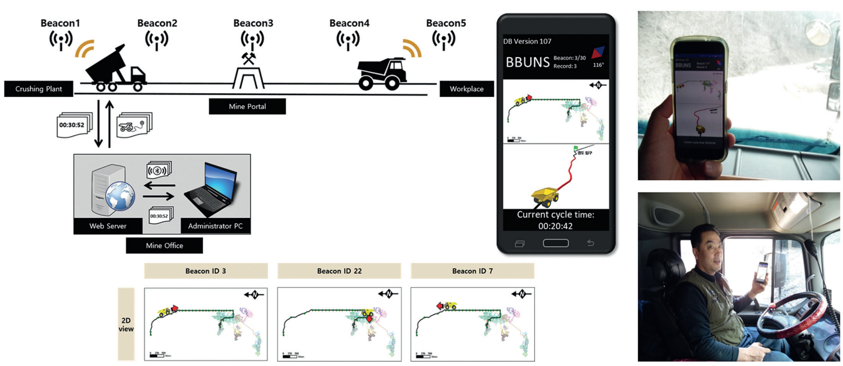

FIG. 4 Development case of underground mine navigation and production management system using low-power Bluetooth beacon and smartphone [2].

Level 3 of smart mining site implementation uses big data collected from physical mines to perform analysis/prediction/simulation in virtual mines and then optimizes site operation methods based on the results to apply it to real objects in physical mines. To this end, technology is required to reflect the optimization results of virtual mines in actual physical mines. Therefore, as shown in Fig. 5, self-driving robots driven according to the optimization results can be used to perform exploration, transportation, and environmental/safety management of smart mine sites. In addition, as shown in Fig. 6, VR/AR/MR technology and wearable devices can be used to effectively deliver the optimal simulation results of the digital twin to workers in physical mines.

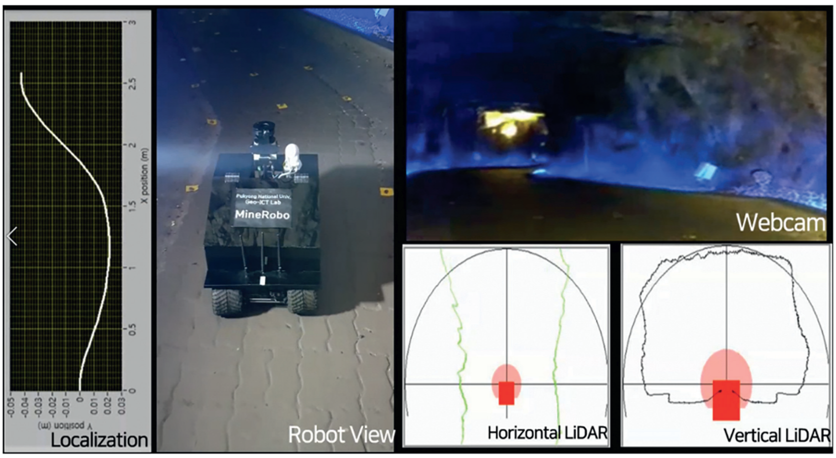

FIG. 5 Development case of a small self-driving robot for underground mine tunnel mapping [3].

FIG. 6 VR and AR technology application of smart mining digital twin using a wearable device [4,5].

3 Role of artificial intelligence in smart mining

To implement Level 3, the top level in the smart mining site, the roles of modeling and simulation (M&S) and AI are essential. M&S optimizes the performance of objects by analyzing/diagnosing the state of physical objects using data collected from the real world and predicting via simulations the conditions under which it is more efficient to operate or the circumstances under which problems may occur. As it is essential to analyze big data collected from physical mines, if M&S is performed for virtual mines, the working conditions of the mines over time can be predicted, along with the key indicators related to productivity and profitability. These prediction results are used as important data for determining the optimal mine operation method.

Recently, attempts have been made to combine the M&S technique, a system science approach, with the AI technique, a data science approach. M&S techniques based on physical theories or operating rules must secure detailed information and knowledge regarding the characteristics of the target object for model development. However, the verification of the reliability of the developed model is essential. AI techniques, such as databased machine learning, require a considerable amount of data on the target object, making it difficult to analyze causal relationships to identify the cause of the problem. Therefore, they cannot be applied to special situations or non-existent systems that have not been learned. Owing to the convergence of AI and M&S, research is actively conducted to address the limitations of each technique.

4 Future perspectives

Recently, smart mining technology has attracted increasing attention worldwide owing to its potential in realizing eco-friendly, highly efficient, low-cost, and accident-free mining sites. Zion Market Research [6] predicted that the smart mining market would expand from $8.6 billion in 2018 to $22.2 billion in 2025, owing to the digital transformation of the mineral industry, with an average annual growth rate of 14.5%. With the emerging necessity to create a new type of business through the convergence of advanced technologies in the mineral industry, the need for developing smart mining technologies is increasing. With the development of smart mining technology, large amounts of data are produced, collected, and shared in real time at mining sites. Accordingly, artificial intelligence technologies, such as machine learning, which can effectively analyze big data at mining sites, are attracting increasing attention. Therefore, the importance of artificial intelligence technologies will increase in the future mining industry.

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