Intelligent Unmanned Mining

Subjects: Mining & Mineral Processing

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Intelligent unmanned mining is the application of new generation of communication technology, Internet of Things (IoT), cloud computing, big data, artificial intelligence and other advanced technologies, intelligent mining and transportation equipment are taked such as coal mining machine, hydraulic support, scraper conveyor, loader, crusher, belt conveyor with autonomous perception, autonomous decision-making and autonomous control execution ability, the comprehensive intelligent control system as the core, and uses visual remote monitoring or adaptive intelligent planning mining as a means, the safe and efficient comprehensive intelligent coal mining method can realize the intelligent operation process of working face mining, support, coal transportation (working condition adaptive and process collaborative control) or one-click start-stop operation mode (including unmanned follow-up operation and safe patrol).

Keywords: intelligent mine ; smart mining ; intelligent working face ; Intelligent Unmanned Mining

1. Introduction

The application of artificial intelligence, industrial Internet, cloud platform, big data, robot, 5G and other advanced technologies in the field of intelligent unmanned coal mining has promoted the innovation and development of intelligent unmanned coal mining in China's coal industry [1][2][3].

In order to implement *The guiding opinions on accelerating the intelligent development of coal mines*, jointly issued by the National Development and Reform Commission, the Energy Bureau, the Ministry of Emergency, the Coal Supervision Bureau, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Science and Technology, and the Ministry of Education [4], as of November 2020, five provinces in China have given specific implementation plans or opinions on the intelligent construction of coal mines. It includes *The Implementation Plan of Intelligent Coal Mine Construction in Henan Province*, *The Implementation Plan of Intelligent Coal Mine Construction in Shandong Province*, *The Implementation Opinions of Intelligent Coal Mine Construction in Shanxi Province*, *The Implementation Plan of Intelligent Coal Mine Development in Guizhou Province (2020–2025)* and *The Implementation Opinions of Accelerating Intelligent Coal Mine Development in Yunnan Province.* On 8 December 2020, Shanxi Provincial Energy Bureau issued the Evaluation Method for Intelligent Construction of Coal Mines in the Province (Trial) and the Basic Requirements and Scoring Method for Intelligent Construction of Coal Mines in the Province (Trial). The promulgation and implementation of the implementation plans or opinions for the intelligent construction of coal mines will provide policy basis for the development of intelligent unmanned mining [5][6][7][8].

Intelligent unmanned mining is a key process in the production of coal mines, metal mines, non-metal mines and other mining industries, which directly affects the safety, output and benefit [9][10]. However, although intelligent unmanned mining breaks the traditional idea of controlling the target with single machine position on the basis of manual operation, it improves the degree of automation of fully-mechanized mining, liberates workers from the working face, and realizes the reduction of personnel in working face mining. However, there are also limitations: the level of intelligent construction of coal mines is unbalanced; the level of regional intelligentization with good geological conditions in western China is higher; and the level of regional intelligentization with poor geological conditions in southwestern China is lower [11].

With the rapid development of intelligent unmanned mining technology, a large amount of real-time data and historical data will be generated during the coal mining process, how to collect and monitor those data and experience knowledge, how to realize a higher level of intelligent mining through key technologies, and how to realize unmanned mining of working face. These problems have gradually become research hotspots [12].

2. Key Technologies for Intelligent Unmanned Mining

The key technologies of intelligent unmanned mining are divided into intelligent automation technology, intelligent control technology, intelligent monitoring technology, intelligent precise positioning technology and other intelligent technologies.

Intelligent automation technology includes shearer memory cutting technology and intelligent automatic rapid tunneling technology. Intelligent control technology includes centralized control technology for fully-mechanized mining equipment, intelligent integrated liquid supply control technology, coal flow load feedback coal mining control technology [13] and remote-control technology. Intelligent surveillance technology includes intelligent video surveillance technology and intelligent video positioning and tracking technology. Intelligent precise positioning technology includes personnel precise positioning technology and equipment precise positioning technology. Other intelligent technologies include intelligent auxiliary transportation technology, intelligent ventilation technology, intelligent sorting technology and intelligent underground robot technology.

2.1. Shearer's Memory Cutting Technology

Figure 1 shows the schematic diagram of the shearer memory cutting technology. When the shearer is located at A-A in the figure, it means that the shearer drum is normally cutting coal. When the shearer is located at B-B in the figure, it means that the position of the shearer drum is lower. Through the shearer memory cutting technology, the height of the drum is automatically adjusted to the normal coal cutting state C-C of the shearer drum. When the shearer is located at D-D in the figure, it means that the position of the shearer drum is on the upper side. Through the shearer memory cutting technology, the height of the drum is automatically adjusted to the normal coal cutting state E-E of the shearer drum. Through a variety of sensors in the body of the shearer to realize the shearer's mining height, speed and other data acquisition, the shearer self-positioning device was developed to achieve the shearer cutting process of automatic control. Additionally, the memory is carried out in the control program database to realize the learning of "demonstration knife", and realize the shearer automatically cutting coal according to the memorized curve and technology in the next cycle process, and finally realize the memory cutting [14]. Fan Qigao et al. [15] corrected the grey model by using the Markov chain state probability matrix, and obtained the adaptive adjustment value of shearer cutting height, which greatly improved the automation level of the shearer. Zhang Lili et al. [16][17] used a genetic algorithm or particle swarm algorithm to optimize the memory cutting path of shearer. The experimental results show that genetic algorithm or particle swarm algorithm can quickly and effectively realize the path optimization of the shearer under a complex geological environment, which is beneficial to the memory cutting and automatic control of the shearer.

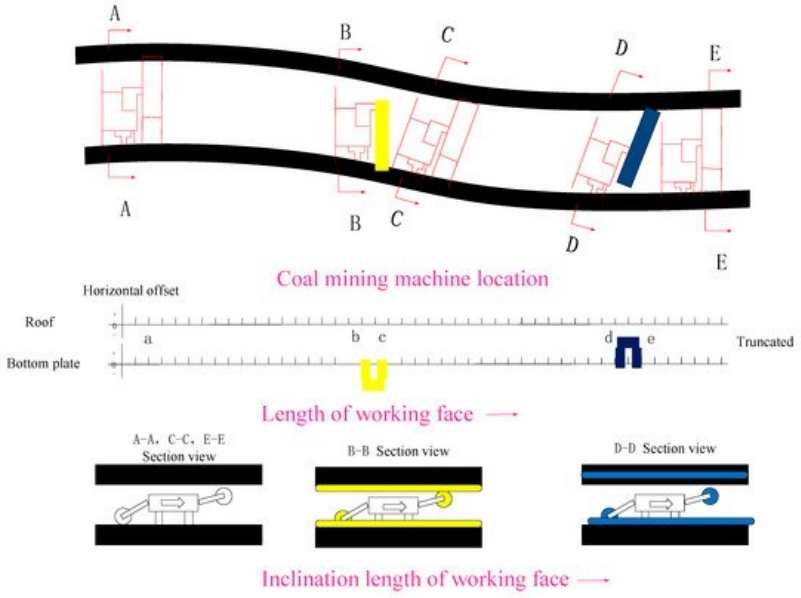

Figure 1. Schematic diagram of shearer memory cutting technology: A-A, C-C and E-E means that the shearer drum is normally cutting coal, B-B means that the position of the shearer drum is lower, D-D means that the position of the shearer drum is on the upper side.

2.2. Intelligent Control Technology of Hydraulic Support

Figure 2 shows the structure diagram of the Inertial Navigation Straight Finding System. **Figure 3** shows the schematic diagram of the automation of hydraulic support and machine. The left side of **Figure 3** shows the shearer that is cutting coal. At this time, the red line indicates that the scraper conveyor is in a curved state. The automatic follow-up of the hydraulic support is used to automatically straighten it, so that the straightening of the scraper conveyor on the working face is as shown in **Figure 3**. With the green line on the right, the working face has moved forward. At present, the intelligent hydraulic support with independent intellectual property rights in China has been equipped with the action of following the automatic advancement and automatic support of the shearer, and has realized some intelligent functions,

including automatic frame shifting, automatic follow-up, automatic incline adjustment, automatic straightening, intelligent liquid supply, self-testing mine pressure, automatic pressure compensation and centralized control of roadways, etc. [18]. The intelligent control technology of the hydraulic support is real-time control through remote intervention of the hydraulic support, using the monitoring data of the hydraulic support and the visual monitoring technology of the video follower to realize the automatic transfer of the hydraulic support, automatic follow-up, automatic incline adjustment, straightening and other functions.

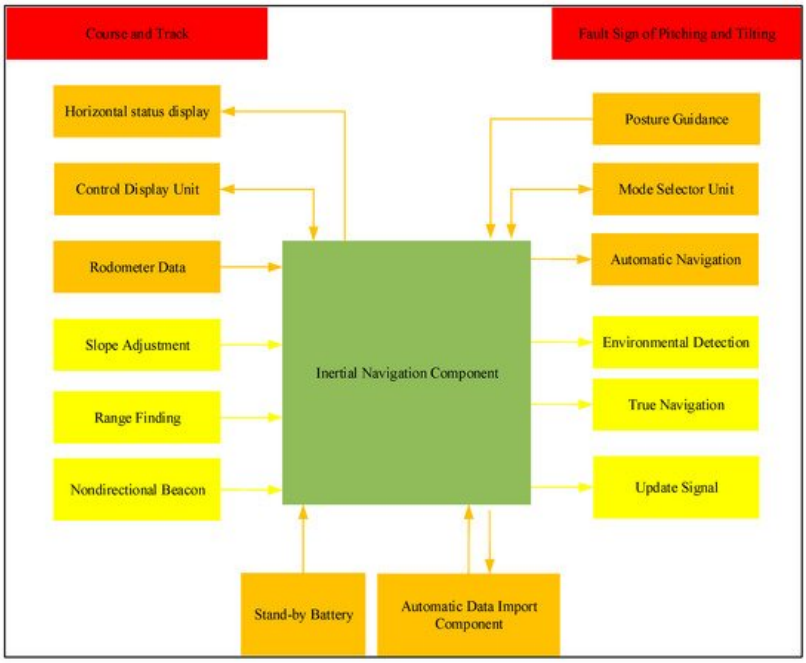

Figure 2. Structure diagram of the Inertial Navigation Straight Finding System.

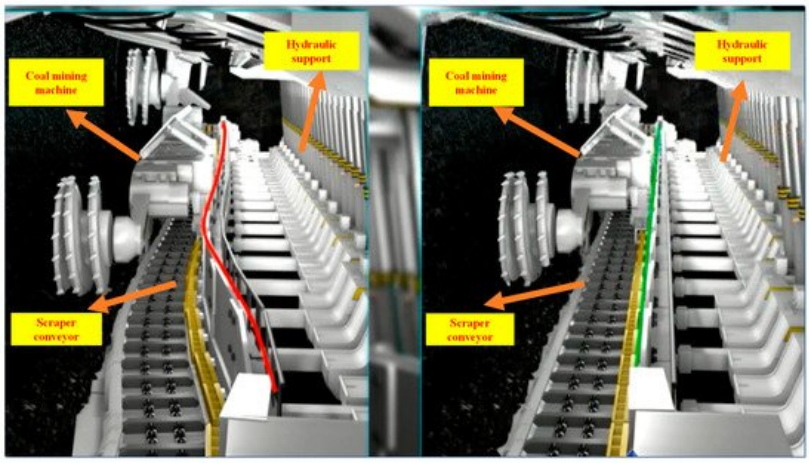

Figure 3. Schematic diagram of hydraulic support and machine automation.

2.3. Centralized Control Technology of Fully-Mechanized Mining Equipment

Figure 4 shows the process control model of fully mechanized mining equipment. **Figure 5** shows the picture of the centralized control software for fully-mechanized mining equipment. **Figure 5**a is the coal wall monitoring system, which collects coal wall conditions in real time through video; **Figure 5**b is the hydraulic pump monitoring system, which realizes the visualization of hydraulic data of the hydraulic support, and **Figure 5**c is the coal shearer monitoring system, which can monitor the shearer drum in real time. In the roof condition, **Figure 5**d shows that the shearer detection system monitors the relevant data of the shearer, such as shearer speed, traction current, load cutting temperature, etc., to clarify the normal value interval and early warning and alarm thresholds of various monitoring data. Various failures of the shearer equipment, including electrical control, mechanical transmission, hydraulic transmission, etc., are corresponding solutions to the failure; **Figure 5**e shows the statistics of the use of the shearer. The use of the shearer is recorded and the maintenance is designed. The arrangement of the plan is based on the relevant rules and requirements of the maintenance work. **Figure 5**f is a 3D scene model of the stope, which supports the location mark of the shearer equipment in the 3D scene and the fine modeling of the equipment, and realizes the three-dimensional visualization of the coal mining face. Through a set of centralized control system for fully-mechanized mining equipment, the centralized

automation of “three machines” (scraper conveyor, shearer, hydraulic support), transfer machine, crusher, pump station and other fully-mechanized mining equipment at fully-mechanized mining face is realized control. The centralized control technology of fully-mechanized mining equipment also involves multiple coal mine systems such as the power supply system, liquid supply system, monitoring system and communication system. Huang et al. [19] proposed and designed a set of centralized control systems for fully-mechanized working face equipment, which can integrate control, Ethernet, video, wireless, communication, monitoring and other technologies. It realized the centralized automatic control of fully-mechanized equipment in the roadway monitoring center, and was successfully applied in the 4109 working face of the No. 1 Mine of the Pingshuo Group. Based on the analysis of the necessity of developing electro-hydraulic control technology, Song et al. [20] reviewed the functional requirements and technical characteristics of electro-hydraulic control technology at different stages of development. Then, the current research status of electro-hydraulic control technology at home and abroad is introduced, and the development direction of electro-hydraulic control technology of hydraulic support in fully-mechanized automation working face is prospected. Taking Gaozhuang Coal Industry Co., Ltd. as the research object, Liu et al. [21] designed the integrated control system scheme of fully-mechanized mining equipment, analyzed the automation level of fully-mechanized mining equipment in working face, and studied the control function, data acquisition function, data storage function and alarm function of fully-mechanized mining equipment, which improved the labor efficiency of enterprises, ensured safe production, and increased economic benefits.

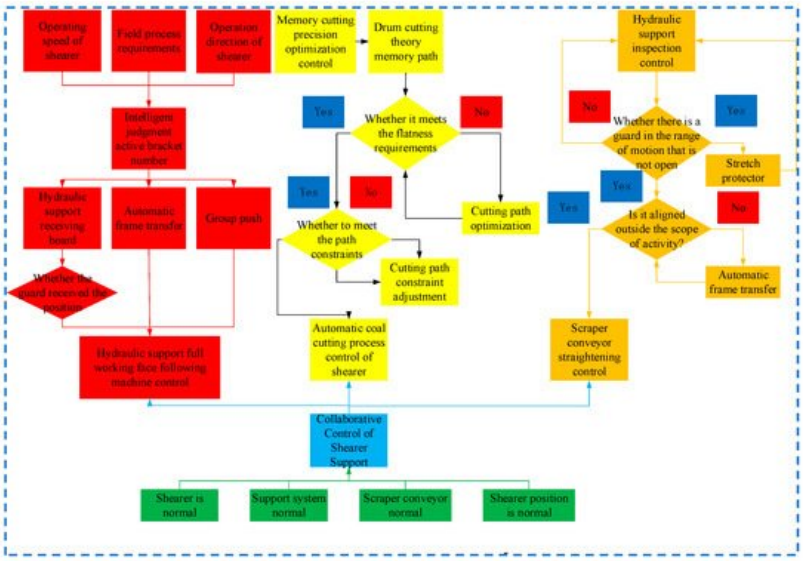

Figure 4. Process control model of fully mechanized mining equipment.

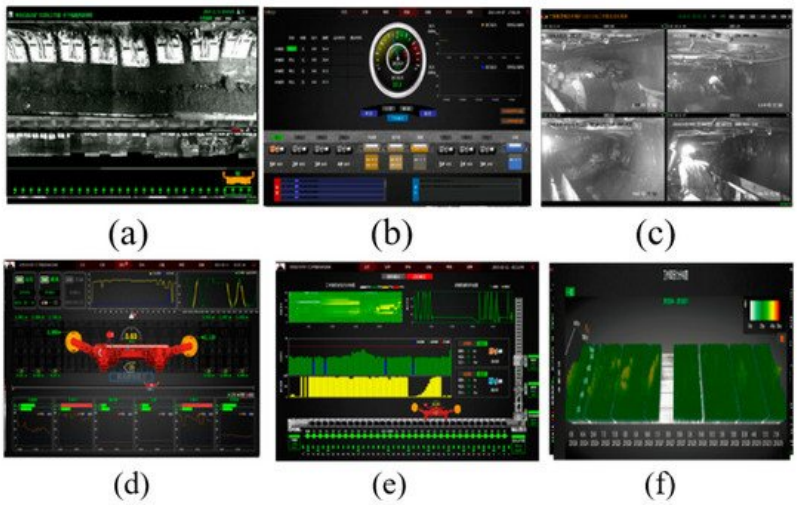

Figure 5. Centralized control software screen of comprehensive mining equipment: (**a**) coal wall monitoring system, (**b**) hydraulic pump monitoring system, (**c**) coal shearer monitoring system, (**d**) hearer detection system monitors the relevant data of the shearer, (**e**) statistics of the use of the shearer, (**f**) 3D cene model of the stope.

2.4. Intelligent Video Surveillance Technology

Figure 6 shows the schematic diagram of intelligent video surveillance technology. Intelligent video surveillance technology is the key technology to realize intelligent unmanned mining. In addition to the resolution of high-definition and above, auto-focusing function, and meeting the requirements of mine-used intrinsic safety design, the intelligent video

surveillance system should have the functions of target detection, target recognition, and behavior analysis. Chen Guiping [22] proposed the use of intelligent visual analysis and pattern recognition combined with intelligent analysis and early warning technology to achieve intelligent operation of coal mine video surveillance, through the analysis of abnormal monitoring screen to achieve active early warning, and effectively overcome the shortcomings of traditional video surveillance system. Cheng et al. [23] studied the structure and technical characteristics of PC and an embedded video server, analyzed the key technology of the video server, and prospected the development trend of the video server.

Figure 6. Schematic diagram of intelligent video surveillance technology.

2.5. Coal Mine Robot Technology

At present, underground coal mine robots mainly include coal mine intelligent rapid tunneling robots, intelligent coal mining robots in coal mines, coal mine intelligent transportation robots, coal mine intelligent inspection robots and coal mine intelligent detection and disaster relief robots.

The research of coal mine detection and disaster relief robots mainly focuses on power system, explosion-proof design, motion control, and information monitoring and transmission. The inspection robot should have basic functions such as video intelligent monitoring, data transmission and analysis. Inspection robots are divided into belt conveyor inspection robots and fully-mechanized mining face inspection robots. The main functions of the belt conveyor inspection robot include autonomous cruise, autonomous positioning, autonomous obstacle avoidance, autonomous charging and autonomous dust removal. The key to the inspection robot for fully-mechanized mining face [24] mainly includes flexible track technology, precise positioning and navigation technology, precise control technology, dynamic image acquisition technology and 3D stope model construction technology. Song et al. [25] reviewed the application status of five types of coal mine robots in China and abroad, including tunneling, coal mining, transportation, safety control and rescue, studied the application status of bionic robot technology in coal mine operations in China and abroad, and pointed out the development ideas and research directions of coal mine bionic robot technology and equipment. Intelligent coal mining robot in coal mines refers to the precise control of coal face shearers, scraper conveyors, hydraulic supports, transfer machines and advanced supports through integrated intelligent control systems, autonomous operation and multi-machine coordinated linkage operations.

3. Intelligent Unmanned Mining Technology Mode

3.1. Fully-Mechanized Mining Equipment Automation and Remote Visualized Intervention

The main technical support of the intelligent unmanned mining technology mode of “fully-mechanized mining equipment automation and remote visual intervention” at the working face is the automation of a complete set of fully-mechanized mining equipment [26]. Technicians observe and analyze the data collected by sensor equipment, and realize unmanned mining at the working face based on the automation of fully-mechanized mining equipment and manual remote visual intervention. Most of the existing intelligent mining working face in China adopt this kind of intelligent unmanned mining technology mode.

The automation of comprehensive mining equipment is mainly through the integrated control system software to control the main control computer software of the electro-hydraulic control system, the main control computer software of the integrated liquid supply system, the main control computer software for the centralized control of the slot, the industrial Ethernet network management software, the video management software, and the data integrated software, data communication software, etc., are integrated on a unified platform, and run on multiple explosion-proof computer

hardware platforms at the same time, to realize distributed integrated control, and complete the fully-mechanized mining equipment of the fully-mechanized mining face, including hydraulic supports, shearers and belts, centralized monitoring and control of machines, scrapers, transfer machines, crushers, belts, pumping stations and other equipment [27].

Remote visualization intervention is mainly through video visualization technology, remote real-time control technology, automatic data push technology, etc., to achieve remote monitoring and control of comprehensive mining equipment in the monitoring center.

3.2. Intelligent Adaptive Mining Technology Mode

In recent years, with the development of new technologies such as the Internet of Things, 5G, and artificial intelligence and their application in the coal industry, a higher level of intelligent unmanned coal mining mode has gradually formed an intelligent adaptive mining technology mode [28]. The intelligent adaptive mining technology mode is based on “integrated mining equipment automation and remote visualization intervention”, making full use of machine vision, multi-source information fusion and three-dimensional physical simulation technology to achieve intelligent analysis of collected data, and automatically make it based on the analysis results; for example, the self-adaptive height adjustment, self-adaptive adjustment and self-adaptation of the shearer drum, so as to truly realize the small and unmanned mining in the coal industry [29].

On 12 September 2020, the “Transparent Intelligent Fully-Mechanized Face Adaptive Coal Mining Key Technology and System” project of Guotun Coal Mine of the Linkuang Group passed the appraisal of scientific and technological achievements by the Appraisal Committee. It is reported that the project has achieved the first time in many coal industries, including the first application of 5G technology to the normal production of underground intelligent and adaptive fully-mechanized mining faces, the first development of a TGIS management and control platform including a digital twin system, and the first development of a full-scale control platform. The dynamic and precise positioning system of the automatic measuring robot makes the intelligent unmanned mining technology move from memory cutting to intelligent adaptive cutting, laying a solid high-tech foundation for the development of intelligent unmanned mining technology, and the social and economic benefits are significant.

3.3. Theory and Technology of Intelligent Unmanned Mining Overall Design System

Figure 7 shows the overall design framework system diagram of intelligent unmanned mining. A unified 4DGIS, virtual mine and configuration software platform was used to manage the spatial data and attribute data of the entire safety production process of “mining, excavation, machine, transportation, and communication”, using a unified GIS, three-dimensional visualization or virtual mine platform [30]. For the integrated automation system, a unified configuration software platform is adopted; production mine operation management, safety production online inspection management, safety production technology comprehensive management, and decision support adopts a unified management platform to achieve the height of the software and hardware system integrated operation, analysis and management; unified data transmission, underground enterprise management, integrated automation, online inspection, and integrated management of safe production uses a unified network for transmission; unified data warehouse, production mine operation management, integrated automation, safe production online inspection management, comprehensive management of safety production technology, and decision support adopt a unified data warehouse to realize data sharing [31][32][33].

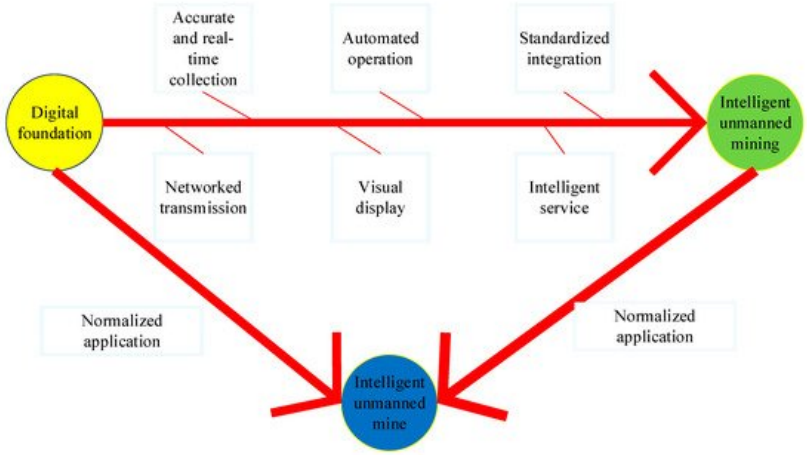

Figure 7. System diagram of the overall design architecture of intelligent unmanned mining.

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