Discussion on the remote visual control technology system of fully-mechanized heading face in mine

Gao Xubin\textsuperscript{1,2}

\textsuperscript{1} Tai Yuan institute Co., Ltd. of China coal technology and engineering group, Taiyuan, Shanxi, 030006, China

\textsuperscript{2} Shanxi Tiandi Coal Mining Machinery Co., Ltd., Taiyuan, Shanxi, 030006, China

*Corresponding author’s e-mail: wfgxb@sina.com

Abstract. According to the present status of the intelligent and informational level of fully-mechanized heading face in mine, the remote visual control technology system of fully-mechanized heading face is put forward on the basis of the analysis of the working requirements of fully-mechanized heading face and the necessary intelligent information technology support for individual equipment and complete equipment of heading face. The six key technologies of complete equipment cooperative control, intelligent cutting, intelligent anchoring, intelligent transportation, working face vision, fault diagnosis and prediction are expounded. The present status and technical feasibility of fully-mechanized equipment are analyzed in detail, and the technical route of remote visual control of fully-mechanized heading face is defined. The problems that need to be innovated according to local conditions in the aspects of accessory materials transportation and environmental safety monitoring are put forward to realize the integration of the intelligent system. At present, through the remote visual control technology system, the goal of reducing people and increasing efficiency, safe operation and production data accumulation in fully-mechanized heading face has been achieved.

1. Introduction

Adverse circumstances, high dust, strong humidity and loud noise around the fully mechanized mining face affect the occupational health of the manpower seriously. Roof falling and rib spalling, rock burst, coal and gas outburst and mine flood threaten the life security of the manpower. The fully mechanized mining face also involves various operations such as excavation, support, transportation, exploration, and communication. The number of manpower and work intensity cannot be reduced, therefore mining face becomes a high-incidence area of coal mine disasters\cite{1}.

With the rapid development of automation, intelligence and unmanned technology at the fully mechanized mining face, the coal mining efficiency has been greatly improved, which makes the contradiction between the coal mining and the drivage operation more prominent, restricts the safety and efficient production seriously.

To solve these problems that troubled the safe and efficient production of fully mechanized mining face, the general consensus is to rely on automation and intelligent technology to solve. In this regard, more explorations of the fully mechanized coal mining face have been made. There are more than 100 intelligent fully mechanized coal mining faces in China's coal industry. The relevant successful experience is worthy of reference for comprehensive mining face. Literature \cite{2-5} proposed new feasible technical routes, evolutionary stages and goals. Combined with the current objective technical
level, they are basically defined as "remote visual control", "visual remote intervention control", realize "manned patrol, unmanned operation", "less manpower working face", all in the literature [2-7] Embodied.

2. Fully mechanized mining face status
The geological conditions of the roadway are different, and the operation technology and equipment support of the fully mechanized mining face are also different. The drivage operation is particularly critical, and the drivage equipment is the key equipment of the fully mechanized mining face, and its performance plays an important role in improving the drivage efficiency and the drivage progress [9]. Once the drivage equipment is finalized, the back-up deployment of the fully mechanized mining face drivage equipment is basically finalized. At present, domestic drivage operations are mainly based on roadheader, continuous miner, and bolter miner, and their back-up deployment are shown in Table 1.

In terms of the randomness of movement, the supporting equipment with the continuous miner is the most complicated. Each single machine is an independent equipment, but the mobile crossover operation is frequent. Each equipment of the rapid drivage system has been restrained strongly, and easy to coordinate control. The working surface environment with the roadheader as the leader with high working intensity and low safety is tough.

![Table 1. Equipment matching and Feature of the fully-mechanized heading face.](https://example.com/table1.png)

| Drivage equipment deployment                  | Feature                                                                 |
|----------------------------------------------|--------------------------------------------------------------------------|
| Roadheader, single roof bolter, bridge conveyor, belt conveyor | It is suitable for rock roadway and semi-coal rock roadway with hardness less than f10. It has a wide range of application, and the supporting cannot be operated in parallel. |
| Roadheader, Mounted roof bolter, bridge conveyor, belt conveyor | It is suitable for rock roadway and semi-coal rock roadway with hardness less than f10. It has a wide range of application, improve support efficiency and operation safety. |
| Continuous Miner, shutter car, roof bolter, scraper, feeder breaker, belt conveyor | It is suitable for large-section dual-roadway drivage with good roadway conditions, cross-drilling and supporting operations, fast cutting speed, and less adaptability. |
| Bolter miner, Bridge conveyor, belt conveyor   | It is suitable for large cross-section single roadway with better roadway conditions, parallel operation of cutting and supporting, fast cutting speed and less adaptability. |
| Rapid drivage system                          | "Cutting supporting and transportation" trinity operation [9], the speed of drivage is fast. It has been successfully applied to roadways with better roof conditions in Shaanxi-Mongolia area. |

3. Remote visual control system
With the recovery of coal industry, whether it is the demand for continuous mining, or for safety and efficient production, it is imperative to improve the level of automation and intelligence of the fully mechanized mining. Including further improving the level of single machine automation of drivage equipment, improving the mechanization of supporting, research on the integration of automatic and intelligent systems such as raw coal transportation, material transportation, roadway ventilation, and dust removal at the heading face. Based on the successful experience of fully mechanized coal mining face, and taking the whole face as the control object, a "remote visual control" technical system that satisfy the current technical level and meets the needs of coal mine underground operations is proposed. As shown in Figure 1, it involves many professional fields and categories.
The "remote visual control" of the fully mechanized coal mining face is the integration of many technologies, and a complete remote monitoring system must be established. This means:

1. Real-time interaction of vision, status data, control commands, etc. between remote (surface or underground monitoring center) and each equipment around the heading face is required.
2. Each stand-alone equipment on the heading face has a certain automation and intelligent foundation to ensure automatic coordination and protection of field operations. It mainly includes six key technologies: coordinated control of complete sets of equipment, intelligent cutting, intelligent supporting, intelligent transportation, working face vision, fault diagnosis and prediction.

4. Discussion on key technical issues

4.1. Cooperative control technology for complete equipment

4.1.1. Heading face WLAN

The construction of the data channel of the heading face realizes:

1. Data transmission between the heading face and the monitoring center;
2. Data transmission between single machine equipment on the heading face.

The first problem is to solve the status quo of information islands in the fully-mechanized heading face. At present, the underground network construction cannot cover the fully-mechanized heading face, resulting in a large amount of equipment operation data, production data, and working condition information (including environment and video information) cannot be settled. These data can provide a data basis for users to analyze the cause of the accident afterwards, evaluate the efficiency of process supporting equipment, optimize production processes and other big data applications, making remote diagnosis and maintenance possible.

The second problem is to solve the present situation that there is no reliable transmission channel for cooperative control of the heading face equipment. The most typical is the double-lane tunneling technology with the continuous mining machine as the leading, multiple independent equipment cooperate with the operation and move frequently. Once one of the links of excavating, supporting, transporting, crushing, and cleaning coal is shut down, the equipment of other links cannot be informed in time and take the initiative to avoid harm. It is easy to cause coal stacking and traffic jams, and cause chaos in the heading face.
For the fully-mechanized heading face, the equipment has a large moving range and strong randomness. It is a relatively feasible and convenient way to access the underground ring network by wireless. Through the "equipment field bus network + heading face WLAN + mine industrial Ethernet" method, the data exchange and upload of the fully-mechanized heading face are realized. The WLAN in the heading face preferentially chooses the industrial 4G private network technology to meet the needs of high bandwidth, mobile access stability, network scheduling, and scalability.

4.1.2. Cooperative control technology
The automation control object of the fully-mechanized heading face is not only the single machine, but also the entire face as a whole to coordinate control. For example, in the rapid drivage system, it has been able to realize the cooperative control of linkage, blocking, walking, traction, posture, etc. of the complete equipment in accordance with the requirements of excavation, support, and transportation craftsmanship, and has solved specific problems such as heavy load start-up and tunneling mining transporting efficiency matching [10].

In the double-lane tunneling operation with the continuous miner as the leader, shuttle car, roof bolter, forklifts, feeder breaker and other equipment need to be dispatched frequently, and the cutting supporting and transportation operations depends on manual monitoring. Operators cannot exchange equipment status information and surrounding working conditions, so they can't predict and adjust the operation of the machine in time according to the operating status of other equipment. For example, according to the presence or absence of coal flow, the size of the load to start and stop the equipment, speed control.

Now, Shendong Coal Group Co., LTD. has made many useful attempts to connect the local operations of continuous mining face equipment. For example, the coal unloading operation of the shuttle car and the feeder breaker realizes the linkage operation. The feeder breaker can automatically start and stop according to the position of the shuttle car to avoid idling idly. In the rapid drivage system, automatic connection operation, locking and dispatching of complete equipment are also tried.

4.1.3. Anti-collision technology
Collisions between mobile equipment, collisions and drags during the relative movement of front and back Overlap equipment, and dangerous proximity between people and equipment on the working surface can all cause production accidents. So far, a variety of anti-collision technologies have been tested underground, such as optical-based infrared detection, radar technology based on wireless signals, image-based human recognition technology, and ultra-wideband positioning technology based on wireless ranging.

These technologies have certain limitations. For example, infrared and radar technology can only recognize obstacles and cannot distinguish people or objects; image-based human recognition is subject to real-time performance and cannot be applied to fast-moving equipment; wireless positioning technology requires protected personnel to carry identification cards, otherwise unrecognized, the identification card and the personal location identification card cannot be used in common.

How to break through the rapid recognition of the human body and realize the active protection of mobile equipment is the focus of the next step.

4.2. Intelligent cutting

4.2.1. Positioning and orientation technology
The positioning and orientation of the tunneling equipment is to establish the relative coordinate space angle between the tunneling machine and the roadway by using various methods, and adjust the posture parameters of the tunneling equipment such as horizontal declination, horizontal offset, pitch angle, and roll angle in real time, and then Combined with the design parameters of the tunnel, it provides direct control parameters for the whole machine's walking control, so that the driving equipment is always in the ideal position required by the design of the tunnel.
The positioning and orientation of tunneling equipment is the basis of intelligent cutting control. The main technologies currently used are total station, gyroscope, electronic compass, laser guide, and visual measurement. At present, the main problem is how to overcome the harsh working conditions underground, including the harsh working environment such as machine vibration, dust, high temperature and high humidity, and apply the autonomous navigation technology successfully applied in other fields to coal mine equipment. At present, the inertial navigation system (gyroscope + accelerometer) has made progress in the application of fully mechanized face. It still needs to overcome the difficulties of low speed and drift to adapt to the working conditions of fully-mechanized heading face.

4.2.2. Adaptive cutting
According to the requirements of the tunneling technology, it can complete the circular cutting of the cross section independently, which mainly includes the section shaping control and automatic speed control of the cutting head to improve the cutting efficiency and cutting quality.

On the basis of accurate orientation, according to the technological requirements of the cross-sectional profile of the roadway, the cutting cycle path is automatically adjusted through the quantitative indicators to avoid over-excavation and under-excavation. The main implementation methods include memory cutting and setting boundary parameters.

Automatically adjust the cutting head speed and the cutting arm swing speed according to the rock hardness. For coal and soft rock, it is suitable to use the method of high rotation speed of cutting head and high swing speed of cutting arm to improve working efficiency; for hard rock, the method of reducing cutting speed and increasing cutting torque is adopted to increase rock breaking ability to reduce tool wear. The main task of drivage operation is to cut the roadway section that meets the design requirements, and adjust the cutting strategy according to the cutting load. The real-time identification technology of cutting head dynamic load is still in the theoretical exploration stage, represented by two modes of actual measurement and inversion calculation. The neural network is used to identify the information fusion processing of cutting current, cutting vibration, cylinder pressure, etc. [11-12], and the dynamic load calculation expression is derived by the reverse derivation of the cutting head vibration response [13].

4.2.3. Remote control
Operators in remote monitoring operations in underground monitoring centers or on the ground must consider real-time issues. The underground has bad electromagnetic environment, long data transmission line, and it must be converted through layers of networks during remote operation, so it's difficult to guarantee reliability and real-time. For underground monitoring centers, low-frequency and low-bandwidth data private network implementations can be considered. For ground operations that must be carried out via industrial Ethernet, efficient data transmission scheduling must be implemented at the network layer to avoid physical limitations such as access link congestion and communication competition.

4.3. Intelligent anchoring
In the fully-mechanized heading face, the contradiction between fast tunneling and slow support is becoming more and more prominent, and various data are no longer listed here. Intelligent anchoring operations mainly include automatic net laying, automatic drilling, automatic charging, automatic bolt loading and fastening, etc.

Some coal mining equipment companies have been working on intelligent anchor protection, and have achieved automatic control of the drill boom, automatic positioning of the anchor protection position in local areas, mechanized laying of anchor net and other technologies. The related products for the automatic control of the drill boom are being upgraded, and have the conditions for promotion and application. However, the key technologies that affect efficiency, such as automatic drilling positioning and real-time monitoring of surrounding rock conditions, must be
further explored. The related products for the automatic control of the drill boom are being upgraded, and have the conditions for promotion and application. However, the key technologies that affect efficiency, such as automatic drilling positioning and real-time monitoring of surrounding rock conditions, must be further explored.

4.4. Intelligent transportation
The key to intelligent transportation system lies in the intelligentization raw coal transportation, material transportation and Intelligent supply. The raw coal intelligent transportation currently has a feasible solution, and the intelligent material transportation and replenishment is difficult to achieve breakthroughs due to the limitations of fully-mechanized heading face space and automatic material handling. This requires the entire industry to optimize and innovate within the entire technological process of the fully-mechanized heading face to find a suitable complete set of solutions.

4.5. Working face vision
To achieve remote visual control, it is necessary to truly extend the vision from the remote to the working surface, provide an "immersive" visual experience, and guide remote production, which is the key technology for remote control.

At present, video capture (Various imaging principles), video compression / storage, video transmission (wired / wireless), video reproduction (platform software) and other products have been widely used in the rapid drivage system, roadheader, and continuous mining equipment, with intelligent basic conditions. In order to meet the needs of the intelligent working surface, it is also necessary to tackle the problems in video stitching, video identify, panoramic imaging, thermal imaging and other technologies, and even carry out preliminary research based on data-driven virtual reality technology (3VDR digital platform), in order to achieve less People and no one make good technical reserves. In addition, considering the harsh working conditions such as dust, water mist and vibration in fully-mechanized heading face, technologies such as image enhancement and anti-shake processing must also be integrated in engineering applications.

4.6. Fault diagnosis and prediction
Reliable operation of stand-alone equipment is the basis for continuous and efficient operation of the heading face. It comprehensively monitors the working conditions of the whole machine to obtain status data in hydraulic, electrical and mechanical aspects. Through signal processing, feature extraction and pattern recognition, online diagnosis and early warning of faults are realized forecasting is helpful for overhauling in advance, avoiding fault expansion or stoppage for overhaul.

According to the characteristics of complex working conditions, multiple fault sources, long mechanical transmission chain and other characteristics of the roadheader, the data of temperature, pressure, flow, liquid level, power supply, posture and other data are used for multi-sensor data fusion processing to study various state monitoring technologies and parameters data fusion to realize the safety assessment of roadheader components or the whole machine. At the same time, perform online vibration testing on key mechanical parts of the roadheader, diagnose and process vibration limits or significant changes in vibration, use spectrum analysis and other technologies to achieve fault determination and accurate positioning [14-16], and conduct fault trends based on monitoring data Analysis to provide support for fault warning and predictive maintenance.

5. Conclusion
The coordinated control of the complete set of equipment through the wireless network of the comprehensive excavation face realizes the effective association and upload of various data and information on the face. It can realize the coordination, joint control of the working surface, and the precipitation of big data.
Objectively speaking, there is a lack of a complete set of solutions for the automation and intelligence of the exploration and anchor production operations. A large amount of research has focused on the intelligent control of the tunneling process, and effective progress has been made. There is a lack of complete solutions for the automation and intelligentization of tunneling and anchorage, environmental safety monitoring and auxiliary operations, it is necessary to carry out process innovations according to local conditions, and gradually apply intelligent information technology through new equipment and new processes to achieve the goal of reducing people and increasing efficiency.

As an important auxiliary method, video surveillance provides important support for the automation and intelligence of comprehensive excavation face. In the long run, to truly realize the "transparent comprehensive tunneling face", research on the 3DVR digital platform based on data must be carried out.

Fault diagnosis and prediction technology is an effective method to improve equipment safety, reliability, reduce accident losses, and reduce maintenance costs. It is also one of the technical ways to improve the safety, continuous and efficient production of comprehensive tunneling face.

References
[1] ZHANG Kexue. (2017) Study on intelligent mining technology of fully-mechanized heading face. J. Coal Science and Technology, 45(7): 106–111.
[2] WANG Guofa, ZHANG Desheng. (2018) Innovation practice and development prospect of intelligent fully mechanized technology for coal mining. J. Journal of China University of Mining & Technology, 47(3): 459–467.
[3] WANG Guofa, WANG Hong, REN Huaiwei, et al. (2018) 2025 scenarios and development path of intelligent coal mine. J. Journal of China Coal Society, 43(2): 295–305.
[4] GE Shi-rong. (2014) Key Technology of Intelligent Coal Mining Equipment. J. Coal Science and Technology, 42(9): 7–11.
[5] Ralston Jonathon R D, Hargrave Chad, Hainsworth David. (2014) Sensing for advancing mining automation capability: a review of underground automation technology development. J. International Journal of Mining Science and Technology, 24(5): 305–310.
[6] WANG Jinhua, Huang Leting, Li Shoubin, et al. (2014) Development of intelligent technology and equipment in fully-mechanized coal mining face. J. Journal of China Coal Society, 39(8): 1418–1423.
[7] HE Min. (2018) Important characteristics and realization ways of wisdom mine. J. Industry and Mine Automation, 44(3): 31–35.
[8] WANG Hong. (2010) Present Status and Development of Mine Roadway Heading Technology and Equipment in China Coal Mine. J. Coal Science and Technology, 38(1): 57–62.
[9] ZHANG Dongbao. (2018) Development status and key technology of intelligent rapid driving technology in coal seam roadway. J. Coal Engineering, 50(5): 56–59.
[10] HU Shouxin. (2017) Cooperative control of high-efficient and rapid excavation system. J. Industry and Mine Automation, 43 (4): 86–88.
[11] WANG Wei, TIAN Muqin, YAN Lin, et al. (2018) Dynamic Load Identification Method of Rock Roadheader Using Multineural Network and Evidence Theory. J. Coal Technology, 37(4): 228–231.
[12] WANG Wei, TIAN Muqin, SONG Jiancheng, et al. (2015) Dynamic Load Identification Method of Rock Roadheader Based on Wavelet Packet and Neural Network. J. Coal Mine Machinery, 36(3): 238–241.
[13] HE Yang, LI Xiaohuo. (2017) Identification of random cutting load on cutting head of longitudinal roadheader. J. Journal of Wuhan University of Science and Technology, 40(2): 138–143.
[14] LIU Xunan. (2014) Roadheader’s Dynamic Reliability and Its Key Technologies Research. D. Fuxin: Liaoning Technical University.

[15] YUAN Fengdan. (2017) Research on Prognostics and Health Management System of Tunnel Boring Machine. D. Shijiazhuang: Shijiazhuang Tiedao University.

[16] ZUO Qinglin. (2014) Research on Condition Detection and Fault Diagnosis of Shield Machine’s Key Equipment. D. Shijiazhuang: Shijiazhuang Tiedao University.