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The Recent Technological Development of Intelligent Mining in China

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ABSTRACT

In the last five years, China has seen the technological development of intelligent mining and the application of the longwall automation technology developed by the Longwall Automation Steering Committee. This paper summarizes this great achievement, which occurred during the 12th Five-Year Plan (2011–2015), and which included the development of a set of intelligent equipment for hydraulic-powered supports, information transfers, dynamic decision-making, performance coordination, and the achievement of a high level of reliability despite difficult conditions. Within China, the intelligent system of a set of hydraulic-powered supports was completed, with our own intellectual property rights. An intelligent mining model was developed that permitted unmanned operation and single-person inspection on the work face. With these technologies, the number of miners on the work face can now be significantly reduced. Miners are only required to monitor mining machines on the roadway or at the surface control center, since intelligent mining can be applied to extract middle-thick or thick coal seams. As a result, miners' safety has been improved. Finally, this paper discusses the prospects and challenges of intelligent mining over the next ten years.

1. Introduction

Intelligent mining, which is based on mechanized and automatic mining methods and which combines informatization with industrialization, has brought about a revolution in the coal industry [1]. This new technology can carry out mining automatically by intelligently perceiving the circumstances around the work face, intelligently controlling each mining machine, and automatically navigating mining equipment. Intelligent mining has three main characteristics: ① Mining machines have the intelligent ability to work by themselves; ② real-time data can be captured and updated promptly, including geological information, the changeable boundary line between the coal and rock, the positions of machines and of the mining process, and so on; and ③ machinery can be automatically controlled according to the conditions of the work face. When decision-making and machine operation can be conducted automatically, the work face is called an "intelligent mining work face" [2].

During the period of the 12th Five-Year Plan (2011–2015), several key technologies were achieved through active research. These technologies and achievements included: a set of intelligent equipment for mechanized mining; information transfers; dynamic decision-making; performance coordination; and the achievement of a high level of reliability despite the complicated mechanized procedures, large equipment system, and bad working conditions in China.

An intelligent system comprising a set of mechanized mining equipment was completed, with Chinese intellectual property rights. An intelligent mining model was built that permitted unmanned operation and single-person inspection on the work face. Using this model, the mining process can be monitored from the roadway or from the surface control center. In this way, our domestic technology has reached the international level; it can meet our coal production needs and provide direction for the future technological development of the Chinese coal industry. Fig. 1 shows the stages of intelligent mining technology development in China.

2. International intelligent mining

China's coal mining technology is still advancing toward the level

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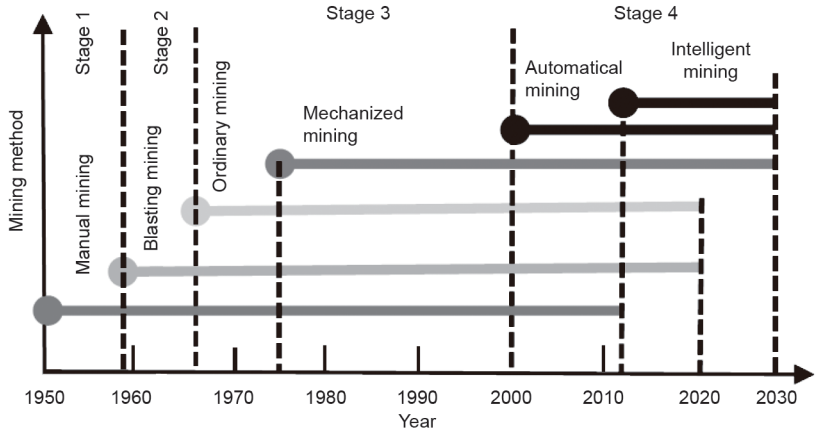

Fig. 1. Stages of intelligent mining technology development in China.

of the mining technology in Australia, Germany, and the United States. Therefore, we pay considerable attention to the Longwall Automation Steering Committee (LASC) longwall automation technology, which was developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO), and to the Intelligent Mining Service Center (IMSC), which was developed by Joy Global Inc. (now Komatsu Mining Corp.) in the United States. These applications are briefly discussed below.

2.1. The introduction of LASC

In Australia, LASC is engaged in automatic and intelligent mining technology for coal mines [3]. Three main achievements were obtained by applying a precision optical fiber gyroscope and a method of navigation and orientation. The first achievement is the fixing of the three-dimensional (3D) position of the shearer (deviation less than ±10 cm); the second is a system of straight adjustment (deviation less than ±50 cm); and the third is a horizontal level control system for the work face. In this way, the initial automatic controlling system was completed. The mining process can be monitored from a distant position, such as the roadway. These achievements were rapidly applied in the coal industry. By combining drill geological information with excavation information, the situation of a coal seam can be described; the 3D position of the shearer is then fixed on the seam via gyroscope. Thus, automatic mining is implemented and the difficult problem of how to distinguish the boundary line between coal and rock is solved.

The key technology of LASC longwall automation includes fixing the 3D position of the shearer, keeping the conveyor and supports straight and level, raising the shearer drum automatically, and providing 3D remote monitoring video feeds [4].

Fig. 2 shows the stages of development of LASC longwall automation technology. At present, the Tiandi Science and Technology Co., Ltd. is cooperating with the CSIRO. We have improved greatly as a result of our work with LASC, and our intelligent mining technology has been greatly enhanced.

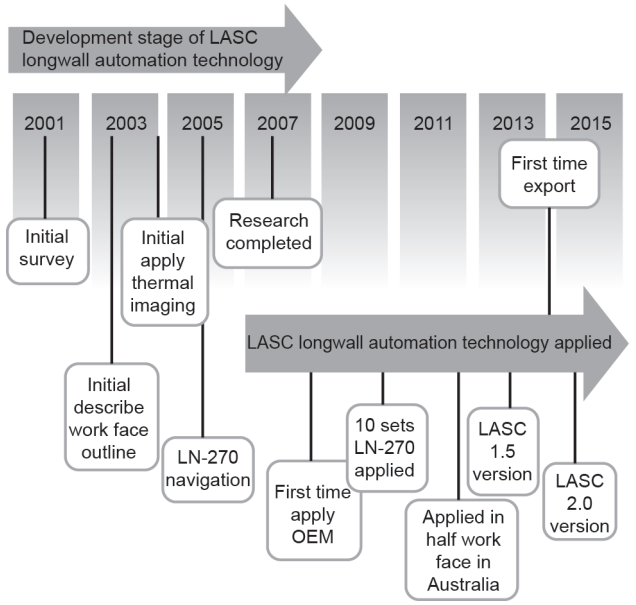

Fig. 2. The development of intelligent mining with LASC longwall automation technology. OEM: original equipment manufacturer.

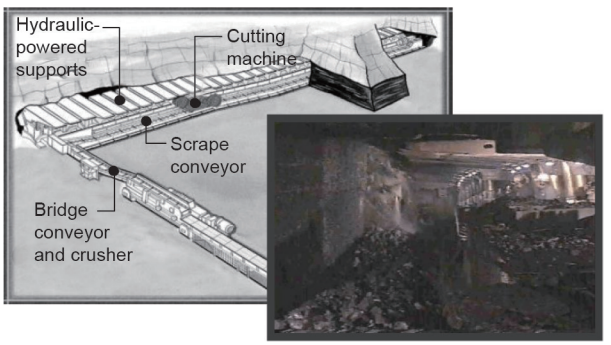

Fig. 3. Devices at the work face monitored by the IMSC.

2.2. The introduction of IMSC

The IMSC is a remote monitoring system that is applied to the longwall coal work face, which was developed by the American company Joy Global Inc. (recently taken over by the Japanese company Komatsu Mining Corp.). This system captures the real-time information and data of all mining machines at any time. It allows mining engineers to adjust coal production procedures according to information reported by the system regarding alarms or breakdowns (Fig. 3).

The IMSC provides a machine working analysis report of the coal mine by day, week, month, and season in order to guide the reasonable arrangement of a production procedure and machine-repair time. All the coal mines are monitored in real time at the general headquarters of the Anglo American company located in Brisbane, Australia. According to the equipment working parameters and monitoring data, engineers can adjust the production procedure at any time. Usage of this system led to an increase in production capacity of 15%, with greatly beneficial results [5].

3. Domestic intelligent mining technology

The era of intelligent mining in China has now begun, based on strong achievements over the last 10 years, and especially during the period of the 12th Five-Year Plan (2011–2015). Intelligent mining technology was developed that allows the shearer to cut coal while depending on its memory function, and that moves supports forward automatically, following the shearer.

Software is the key of an intelligent mining system, as it allows all procedures along the work face to be controlled intelligently, including shearer cutting, pushing the scraper conveyor, moving supports forward, transporting, and dust capturing. With intelligent mining, a continuous, safe, and effective job can be done well.

3.1. New model of intelligent mining

At present, our domestic technology in some fields of intelligent mining is in a leading global position. This advanced technology particularly includes control systems and control modes, feedback time, and intelligent function. In addition, China is a world leader in number of miners and capacity of production. In fact, we have realized unmanned operation along the work face by means of monitoring by remote video on the roadway. In this kind of production, all equipment is operated automatically and is monitored by a remote-control center for safety, while procedurals are adjusted if necessary. This revolutionary method is greatly changing traditional production processes.

Intelligent mining depends on a general coordinate control system, rather than on individual pieces of equipment. The system connects all the equipment used along the work face through a web network, such as the shearer, hydraulic-powered supports, scrape conveyor, bridge conveyor, belt conveyor, crusher, hydraulic station, and power station. Each set of equipment is run by a central decision-making order, thereby utilizing intelligent mining software to centralize the work face production.

3.2. Intelligent mining technology

With intelligent mining technology, a miner sitting in the monitoring center can control and operate all the equipment by touching keys on a panel, and can communicate with other equipment to give various orders. The shearer, hydraulic-powered supports, conveyor, power station, and so forth are thus controlled and operated from a distant monitoring center on the surface, while all information (e.g., regarding safety and production) is transferred to the control center. We have thus fully realized remote-control coal production [6,7].

3.2.1. Intelligent mining procedures

The main intelligent mining procedures are as follows.

(1) The automatic shearer operation. The shearer is dependent on memory-cutting software to cut the coal wall. A position sensor is installed on the hauling part of the shearer by which the shearer position can be fixed from the remote-control center.

(2) The procedure of pushing the supports and conveyor to follow the shearer. Here, the key technical point is to coordinate the electro-hydraulic valve of the supports with the memory-cutting process. In addition, the shearer, supports, and conveyor must be surveyed in order to maintain optimal running conditions. All machine statuses can be monitored by the remote-control center on the roadway.

(3) The control procedure for the amount of coal via feedback information. The amount of coal on the scrape conveyor is surveyed in real time. The speed of the conveyor can be changed automatically according to the load distribution of coal on the conveyor.

3.2.2. Use of technology to distinguish coal from rock

At present, a high-definition mining camera is installed on one out of every six supports for remote monitoring. The direction of the camera is parallel to the work wall. A camera for capturing coal wall images (Fig. 4) is installed on one out of every three supports. The picture is transferred to the control screen via a web network to allow the monitoring miner to distinguish between coal and rock [8].

3.2.3. Remote-control technology

All action of the shearer and supports can be directed by a computer located at the roadway remote-control center. When the memory-cutting model order is sent to the shearer by the computer, the shearer can move forward, raise its arm, cut the floor, and automatically speed up or speed down. The status of the shearer can be changed at any time via computer, according to the changes of the work face conditions. The control panel, which is located at the roadway, is mainly used to operate, start, and emergency-stop three machines in the work face: the shearer, the supports, and the conveyor. This method enhances the work efficiency and the environment, and reduces manual labor.

3.2.4. Continuous cutting technology

It is very important for the conveyor to be laid down straight along the work face. However, it is difficult to visually survey the work face due to the unstable floor and the dust from the shearer. Laser orientation and transit instruments that are applied on the surface do not work well underground. A laser array measurement is used along the work face to keep the supports and conveyor straight; it restricts the deviation between two adjacent supports to less than 10 cm (Fig. 5).

3.3. The achievement of intelligent mining during the 12th Five-Year Plan (2011–2015)

Great research work was achieved in the field of intelligent mining during the period of the 12th Five-Year Plan (2011–2015). During this time, we achieved the following world-leading accomplishments.

(1) The number of operators along the work face was significantly reduced, from 30–50 persons to only 5–7 persons. Fewer miners result in safer and more efficient work along the work face.

(2) Most of the miners now work at the roadway remote-control center instead of along the work face. In this way, working conditions

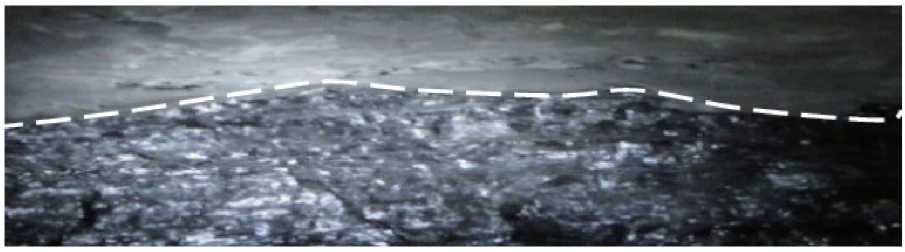

Fig. 4. The boundary line between coal and rock, as taken by monitoring camera.

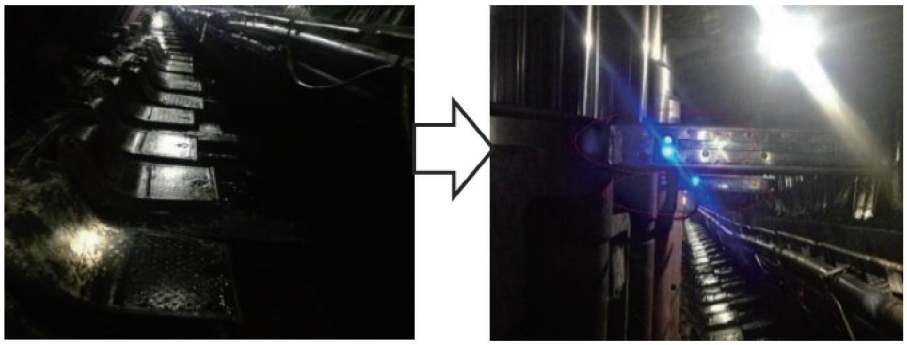

Fig. 5. Straight alignment of the supports using laser array measurement.

have become safer and more comfortable.

(3) The yield of coal and the economic efficiency were enhanced significantly, compared with normal work face procedures.

(4) The use of intelligent mining technology along the work face has grown in leaps and bounds, improving the safety and production of coal mines. This advance has been of great significance to China's coal industry.

Intelligent mining is a technical breakthrough for coal production. Automatic mining has been promoted to intelligent mining, in which more modern technology is applied. Fig. 6 shows the framework of intelligent mining in China.

3.4. Intelligent mining practice

Trial production of intelligent mining has been applied at more than 40 coalfields in China since the year 2000, including Shenhua Group Corporation Ltd., China National Coal Group Corp., Shaanxi Coal and Chemical Industry Group Co., Ltd., and Datong Coal Mine Group Co., Ltd. For example, intelligent mining was applied at Shenhua Ningxia Coal Industry Group Co., Ltd. to extract a middle-thick coal seam with complicated geological conditions. Great achievements in safety, production, and economic efficiency were made. Table 1 lists some production contents for a coal mine.

A trial production took place in August 2016, in which LASC longwall automation technology was applied at the Zhuanlongwan coal mine. This was a cooperative project between China and Australia. The straight level of the conveyor was described to a centimeter precision degree. LASC longwall automation technology was used 440 times to check that the conveyor was laid straight.

The 23303 work face at Zhuanlongwan was operated automatically and conveyor straightness was maintained by LASC longwall automation technology. The precision met requirements, and the expected result was obtained on 24 August 2016.

4. Problems and prospects

4.1. Tough problems for intelligent mining

Difficult problems that challenge intelligent mining are related to changes in ground pressure, the balance of stress, methane effusing, and water gushing during the shearer-cutting of the coal wall; these problems occur because the work face is usually located several hundred meters underground. It is necessary to develop new technology to solve these kinds of issues.

4.1.1. Intelligent detection of the geological rock stratum

Here, intelligent detection refers to the detection of an undisturbed area at the front of the coal wall. A 3D work face model can be established using the data from drilling and excavating the roadway, along with the information obtained by detecting the coal seam. The status of the coal seam, such as ups and downs, dips, faults, and corroded parts, can be seen clearly in the model, which can thus be used to easily control and run the shearer.

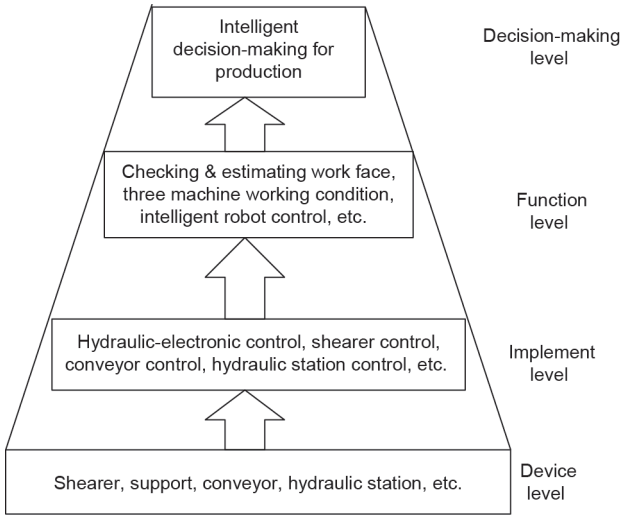

Fig. 6. A framework of intelligent mining in China.

Table 1
Statistics of intelligent mining work face at Shenhua Ningxia Coal Industry Group Co., Ltd.

Period	Miners	Producing days	Working hours (8 h per shift)	Numbers of cutting	Yield (t)
August 2013	3	31	62	16	400 500
March 2014	2	30	60	16	425 800
April 2014	1	31	62	18	465 000

4.1.2. Decision-making system

For current intelligent mining technology, the main function is the automatic control system. This control system is not particularly related to management; it cannot provide suggestions for the manager because it cannot integrate information and communicate with the operators [9]. Since the geological conditions are unstable and the status at the front coal wall cannot be predicted, intelligent mining cannot yet work well without human intelligence. At present, therefore, intelligent mining cannot be fully controlled without human assistance.

(1) The problem of equipment reliability. Intelligent mining cannot depart from highly reliable mechanized equipment, so perception, decision-making, and control functions must be added on to existing equipment. A single piece of intelligent equipment should be integrated into a set of equipment.

(2) The problem of visualization in poor conditions. It is difficult to get a clear visual picture due to dust thickness. Therefore, we need to develop new instruments with high clarity and a low time delay, which will provide real-time pictures for remote monitors in order to adjust machines.

(3) The problem of perception under complicated conditions. This is the biggest problem challenging intelligent mining, and is due to the limited space, constant changeability, difficulty recording accuracy data, difficultly analyzing real-time information, and difficulty reasonably using this information under complicated work face conditions [10].

To address these issues, an automatic expert decision-making system should be established for a mechanized work face. Data capture from human, machine, environment, and management processes must be integrated deeply. A decision-making system can be built based on data-mining technology that can realize pre-survey, pre-detection, and pre-control [11].

4.2. The prospects of intelligent mining

Information technology, and particularly optoelectronic technology, is accelerating the development of intelligent mining. It is necessary to upgrade intelligent mining by applying new technology.

4.2.1. Intelligent navigation technology for mining based on the real-time 3D geographic information system

Intelligent navigation refers to the use of navigation for persons and equipment at the work face by applying advanced automatic computer and optoelectronic technology for safe and accurate extraction (Fig. 7).

A real-time geographic information system (GIS) is combined with some necessary detection technology to establish a 3D geographic model of the work face. A visual 3D GIS can be established by analyzing model topology relations. This system is the scientific basis of intelligent mining decision-making and management. The core of research work in this field includes 3D orientation, scanning roadway technology at the work face, intelligent control technology, and 3D visual technology; these are the key foundations of intelligent mining applied at a mechanized work face.

4.2.2. The application of inspecting robots

Remote-control robots can be used to install mining machines to assist in intelligent mining management and maintenance by adding suitable light, vision, auditory, and vibration sensing capabilities. This is supplementary to intelligent mining, and permits robots to do dangerous jobs at the work face rather than having humans do them. Developments in key technology are still required in order to effectively utilize robots in intelligent mining at the work face.

Fig. 8 shows the framework of one kind of inspecting robot installed at a work face, through which more instruments will be replaced. Robot technology is the future direction of intelligent mining development.

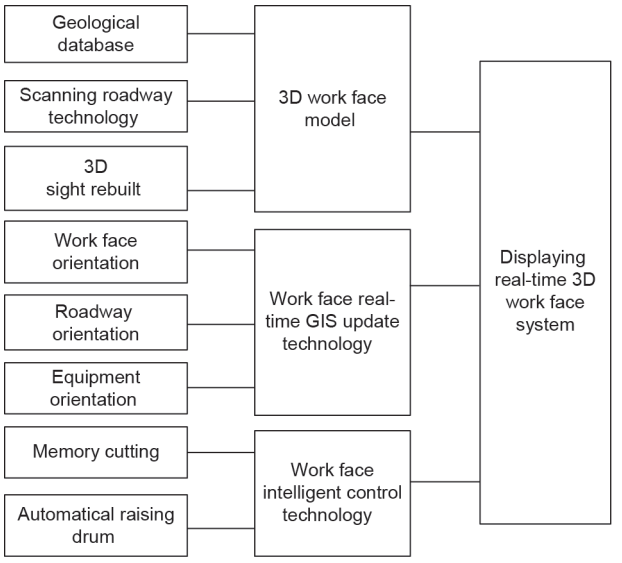

Fig. 7. Intelligent navigation based on a 3D geographic information system (GIS).

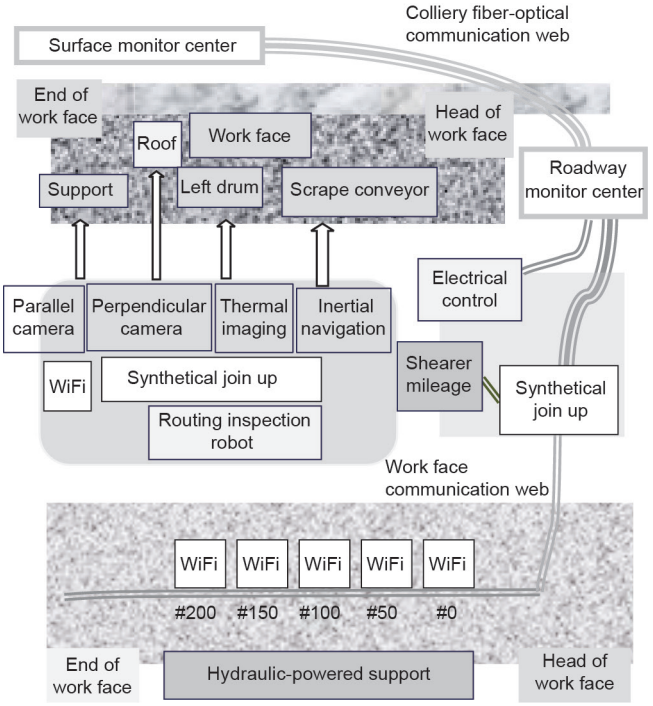

Fig. 8. The framework of an inspection robot at the work face.

5. Conclusions

China's coal industry has been significantly enhanced and breakthroughs in technology have been achieved by researching and practicing intelligent mining in China. However, some technical problems are still left that must be solved soon. Our conclusions are as follows.

(1) It is an important advancement in coal mine safety to move miners from the dangerous work face to the safer roadway.

(2) Intelligent mining is a revolution for coal production because of its high ratios of investment and profit, energy conservation, safety, fewer people, and greater efficiency.

(3) The level of China's electromechanical manufacturing industry and intelligent control technology has been greatly promoted by research into intelligent mining equipment.

(4) The current advances are just the beginning for intelligent mining in China. Problems remain to be solved in management, procedures, and technology. Difficult research work is necessary in the fields of sensing, control, the Internet of Things, and mining robotics.

(5) Since the roof and floor conditions of a coal seam are unstable, ground pressure exists everywhere throughout the mine, and methane is continually effusing, our key research work in future will focus on an intelligent mining technology that is suitable under these complicated conditions.

Compliance with ethics guidelines

Jinhua Wang and Zenghua Huang declare that they have no conflict of interest or financial conflicts to disclose.

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