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Opinion

Intelligent Ventilation Systems in Mining Engineering: Is ZigBee WSN Technology the Best Choice?

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Abstract: With the continuous development and progress of the mining industry, various technologies in mining engineering have gradually developed towards the intelligent stage, and the ventilation system is no exception. Since ancient times, mine ventilation has been a necessary part of mining engineering, and so the optimization of mine ventilation undoubtedly plays a great role in mining production. This two-part opinion paper briefly introduces the development of the intelligent ventilation in mining engineering and serves as a guide to the Tossing out a brick to get a jade gem, with implications for both the development and the future of the underground mine ventilation systems. Finally, in the second part of the paper, we explain why we think ZigBee WSN technology is the best choice in intelligent ventilation systems in underground mines at the present stage.

Keywords: intelligent ventilation system; mining safety; underground mine; mining engineering; ZigBee WSN technology

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1. Retrospective: The Development of Intelligent Ventilation Systems in Underground Mines

The word "intelligent mine" has been exposed to the public for a long time: since the 21st century, Raman, Nutter and Reddy [1] proposed that intelligent control systems would undoubtedly be used in various industries, and the mining industry in particular.

As an indispensable link in mining engineering, the ventilation system is also developing towards the intelligent stage. According to the available references, it is believed that the earliest intelligent mine ventilation was proposed in the 20th century.

Due to the "Third Technological Revolution" since the 1940s, the rapid development of computer science has brought many possibilities that can contribute to the realization of intelligent mines. Therefore, Nutter et al. [2] designed the Expert System for the underground mines based on computer control function in 1986. The Expert System was actually first developed for ventilation, emergency rescue and Power Peak Shaving. However, it seemed to perform better in the intelligent adjustment of ventilation because the computer simulation technology at that time enabled engineers to easily determine the impact of various ventilation configurations.

In fact, as early as in 1970, Wang and Saperstein [3] had already developed a simulation program which allowed for the free splitting of internal and external fans, and allowed for the calculation of natural ventilation pressures to regulate and control mine ventilation. Meanwhile, in 1977, Greuer [4] developed a ventilation simulator in order to simulate the operation of the ventilation system in any case. All of these achievements are due to the development and progress of computer science since the 1940s.

After the 21st century, while developing intelligent ventilation systems, experts also considered many problems, such as the cost consumption caused by different ventilation systems. In 2003, Kocsis and Hardcastle [5] compared the energy consumption of several ventilation systems, but, according to their results, none seemed ideal.

Therefore, some people thought that while the operation of manual ventilation systems would undoubtedly create many useless costs, the costs would be reduced by sophisticated computing through intelligent systems. As a result, an increasing amount of experts have been investing in the development of intelligent ventilation systems to reduce the cost, and more companies [6] are beginning to help the underground mines optimize the ventilation system and reduce their costs in order to make a big profit.

After 2005, more research on intelligent ventilation systems has gradually emerged. In 2006, Yan, Qian and Novozhilov [7] analyzed the intelligent regulation of ventilation systems in mine fire, and in 2007, Turchenko, Kochan and Sachenko [8] proposed to combine neural networks with mine ventilation systems in order to achieve intelligent control of the ventilation in mines on the 2007 4th IEEE Workshop on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications.

In particular, on the 2009 International Workshop on Intelligent Systems and Applications, Wang and Qian [9] published their research on the design of the wireless transmission system of mine video and temperature monitoring. This system can monitor and analyze the motion of the video and the temperature of the monitored object. When the temperature changes, the ventilation is controlled and the alarm call is issued.

In the same year, You et al. [10] developed an intelligent smoke exhaust and ventilation system based on fuzzy control. The experimental results showed that the system has the advantages of pulse function, high efficiency, safety, no gas emission and a good function of intelligent gas emission system.

During the 2010s, the intelligent ventilation systems developed very rapidly. Lin et al. [11] and Zhen [12] improved the system by using sensors.

The research of Zhen [12] is worth exploring further: they designed a small detection system through the single chip microcomputer Type 8031 and integrated circuit, which solved the shortcomings of the decentralized instrument and manual operation in the old fan detection system, and realized the centralized real-time monitoring of ventilation. However, the system still has the shortcomings of a limited number of monitoring nodes, short communication distance and low monitoring accuracy. Therefore, they have constructed a real-time underground ventilation monitoring system based on CAN field bus, various intelligent sensors and single chip computers, which has certain practical and popularizing value. Later experts did gradually magnify the role of sensors in mines, and his research was undoubtedly one of its pioneers.

Furthermore, in 2014, it was reported [13] that three Chinese experts had developed an intelligent ventilation system for the coal mine environment and applied for a patent. In 2015, a new patent for the intelligent ventilation system [14] based on the director and sensor was proposed, and sensors have gradually become one of the most important tools for information transmission in underground mines.

In the same year, artificial intelligence (AI) was first proposed to be used in the ventilation system of mines in order to realize the intelligent ventilation mines; that is, Yin et al. [15] proposed an intelligent computer aided design method based on AI for an underground mine ventilation system. They explained that the intelligent mine ventilation design system is a highly intelligent mine ventilation design integration, including data management, graphics and design calculation, mutation process simulation and mine ventilation design decision analysis function, in order to solve structural assistance and semi-structured and unstructured problems in the system design.

The research of Yin et al. [15] is a successful practice of artificial intelligence in ventilation systems. In fact, the front of mine ventilation research lies in the integrated method. Although some progress has been made and some methods have been applied in practice to some extent, these technologies may not be fully applicable to practical engineering, which is a reminder that all theoretical bases should pay attention to practical engineering application.

After 2015, the systems such as GIS (Geographic Information System) began to be fully used in underground mines. Moridi et al. [16,17] carried out two studies in 2014 and

2018, reporting their achievements of the research, which was to apply the ZigBee WSN technology and GIS in the underground mines.

In fact, ZigBee WSN technology also used sensors as a tool for short-range information transmission. Besides GIS, an increasing number of systems for monitoring and control emerged, such as the WAMC (Wide Area Monitoring and Control) system.

For GIS, Liu et al. [18] proposed a model of an unsteady network based on the GIS, and developed a prototype web system called 3D VentCloud, which effectively integrates the proposed algorithm. Then, they verified the model and applied the system to the actual coal mine ventilation solution, which proved the rationality and practicability of the model.

The content of their research is also easy to explain; they combined GIS technology with the unsteady ventilation simulation model to provide a unified ventilation network model based on GIS, and the dynamic changes of the unsteady ventilation state and steady ventilation state were effectively simulated. Furthermore, a prototype web system was developed based on the proposed algorithm, which can provide fast simulation results and location-based information. The results showed that the simulation system can effectively simulate the unified ventilation results, and is expected to provide online and real-time decision support for the mine safety production.

Besides, Liu et al. [18] and Wang et al. [19] developed the Automatic Ventilation System Adjustment Software based on the requirement of ventilation change in the ventilation system, and Wei et al. [20] proposed a method for the accurate monitoring of tunnel wind speed by a long-span ultrasonic linear wind speed sensor based on a time difference method. Meanwhile, Watson et al. [21], Wang et al. [22] and Xu et al. [23] optimized the ventilation planning algorithm and finished the simulation process. What's more, Jo, Khan and Javaid [24] used the Internet of Things technology in order to improve the information transmission and monitoring function of mine ventilation in 2019.

Some of the research results are based on the original research, while experts have made some improvements, such as algorithm optimization or combination with advanced information transmission technology, such as Internet of Things technology. Furthermore, the development of some modeling tools, such as the aforementioned 3D VentCloud, also lays the foundation for the realization of intelligent mine ventilation.

2. Perspective: Is ZigBee WSN Technology the Best Choice for Intelligent Ventilation Systems in Underground Mines?

As previously mentioned, Moridi et al. [16,17] indicated that the narrow space of an underground environment significantly enhances the signal intensity, and as a result ZigBee WSN technology can have a great advantage in the underground environment.

In fact, in the narrow environment of the underground mines, short-distance transmission systems such as ZigBee WSN technology can play the greatest role and reduce energy consumption. As a result, ZigBee WSN technology is gradually used in monitoring and alarm systems in many mines. As early as in 2008, Yu et al. [25] applied ZigBee WSN technology to underground mine safety monitoring systems. They used the ZigBee WSN technology to collect temperatures, humidity and methane from underground coal mines. Then, the ZigBee WSN technology transferred data to ARM-based information processing terminals [26], and interestingly, Li, Zhao and Liu [27] designed a high-performance wireless robot network communication system for underground mines based on ZigBee WSN technology.

Evidently, the application of ZigBee WSN technology is becoming more and more popular for underground mines, as it has good information collection capabilities, such as harmful gas concentration and temperature, which can provide signals for intelligent mine ventilation systems.

As a result, in the future, ZigBee WSN technology is likely to become a medium for information transmission in intelligent mine ventilation systems because of its three characteristics: (1) suitability for the underground mines; (2) low energy consumption; (3) good performance for the information collection.

However, along with the continuous development of science and technology, the world has gradually entered the era of 5G technology.

It is reported [28,29] that in 2019 Ambra chose Ericsson, as part of a global cooperation agreement, to provide 5G network solutions for automated ventilation systems, which shows that the 5G technology has been applied in underground mines in recent years. 5G technology has the advantages of being able to track vehicles as well as excavators in real time, monitor the underground environment and to remotely control machines such as vehicles, drilling rigs, ventilation systems and other equipment. At the same time, 5G technology [30] has an excellent performance in preventing underground casualties and post-accident (mine fire, traffic accident or gas poisoning) search and rescue. However, at this stage, the 5G technology is obviously not perfect. For example, its functional area coverage is small, so if we want to apply 5G technology to intelligent ventilation of the underground mines in the future, the 5G technology would need to be further optimized.

Generally speaking, ZigBee WSN technology is functionally similar to 5G technology, while the energy consumption and operating costs of ZigBee WSN technology are lower. Meanwhile, in the research of Moridi et al. [16,17], ZigBee WSN technology is often considered an economical, efficient and applicable option compared to other WSN in underground mines. ZigBee WSN technology, they argued, could improve the workplace health and safety for workers, cost-effectiveness, management of technical issues, energy conservation and real-time response to events. Therefore, ZigBee WSN technology is more suitable for underground mines in the monitoring and control.

However, in recent years, there has been a lot of research on underground communication. Around 2020, Basu et al. [31] and Muduli [32] carried out the research on the advanced technology for the underground monitoring. Furthermore, around 2021, some experts [33–36] have applied 5G technology, the GIS (Geographic Information System), the WAMC (Wide Area Monitoring and Control) system, the CBTC (Communication-based Train Control) system and other advanced technologies to underground mine monitoring.

Although there has also been a lot of research on wireless sensor networks and other technologies for underground monitoring in recent years, we believe that the ZigBee WSN technology and sensors are currently the most suitable for the underground monitoring and intelligent ventilation systems in most underground mines. The reasons are explained as followed:

- Although some advanced technologies can better solve the problem of mine fire monitoring, such advanced technologies are obviously not suitable for all mines, especially some backward mines in China. Furthermore, most of these advanced technologies have high operating costs, such as the operation of 5G technology, which requires the establishment of a large number of base stations.
- On the contrary, the operation of ZigBee WSN technology in underground mines does not require complex conditions, and the operating costs and energy consumption of ZigBee WSN technology are lower compared to other communications technologies, according to the related research [37,38].
- What's more, as a short-distance information transmission tool, ZigBee WSN technology is considered suitable for underground narrow environments. Both Moridi [16,17] and Bai [39] thought the ZigBee WSN technology was very suitable for underground monitoring [26], and Wei and Wu [40] revealed that most underground mines in China were equipped with ZigBee WSN technology as monitoring networks by 2015.

As researchers and engineers, we should not only pursue the research of frontier technology, but also choose the appropriate underground monitoring system for the suitable mines. Therefore, we believe that at this stage, ZigBee WSN technology still has the superiority in underground mine monitoring, and we believe that ZigBee WSN technology still has the potential for deep development. Therefore, in our previous work, we have emphasized the superiority of ZigBee WSN technology in environmental monitoring of underground mines.

3. Discussion: The Weakness and Future Work of the Application of ZigBee WSN Technology in the Underground Mine

Although ZigBee WSN technology has been used well in many underground mines, it still has many shortcomings.

In fact, the security of ZigBee protocol is a concern of many experts [41–44]. As Kim, Kim and Chung [41] thought, although ZigBee WSN Technology has a lower power consumption, the ZigBee protocol has some security weaknesses for newly added devices, while Lin et al. [42] argued that ZigBee, as a communications technology for building IoT systems, has weaknesses in its coverage and security.

However, at present, relevant experts, including us, are also actively improving ZigBee WSN technology in order to overcome its shortcomings. As early as in 2013, Choi, Kim and Chae [43] proposed a secure lightweight key distribution mechanism using ZigBee Pro for ubiquitous sensor networks, and enabled ZigBee WSN to consume a low power and provide security in wireless sensor networks. In addition, Pradana and Ardi Sumbodo [44] have improved latency and packet loss in the running of ZigBee WSN technology.

Despite the application of 5G technology in underground mines, and although an increasing amount of experts pursue the frontier and pay attention to the construction of 5G technology in underground mines, as experts in mining and safety fields, we obviously believe that 5G technology is not suitable for the application of underground mines at the present stage. Therefore, we will continue to push ZigBee's development and overcome its shortcomings in underground mines in the future.

Finally, we claim that the opinion article serves just as a guide to the Tossing out a brick to get a jade gem. During our future research, we will continue to develop the potential of ZigBee WSN technology and sensors in underground mine monitoring and intelligent ventilation systems, and we hope many more experts and scholars will be interested and engage in the research of this field.

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