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Original scientific paper

OPTIMIZATION OF VENTILATION USING IIOT METHODOLOGY IN SERBIAN COAL MINES

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Abstract: The application of information technologies in the optimization of ventilation contributes significantly to the improvement of all aspects of mine operations. Coal mines face numerous challenges on a daily basis in terms of the organization, implementation and supervision of production activities. Some global mining companies have already implemented numerous technical solutions in the field of robotics, artificial intelligence and the Internet of Things (IoT). This article describes the basic principles of the Industrial Internet of Things (IIoT) and the configuration of the automation system for ventilation. It also discusses the opportunities and challenges of technology implementation in the coal mine. The advantages of applying modern software tools for monitoring mine air parameters and monitoring the operating characteristics of the main ventilation systems in real time greatly facilitate the control of working conditions in the mine. On this basis, it is possible to create a package of preventive and active measures in the event of equipment faults, fires or sudden gas outbursts.

Keywords: IIoT, coal mine ventilation, automation

1 INTRODUCTION

The mining industry is concerned with the production of raw materials. These are necessary for the functioning of other industries as well as for the functioning of a country's economy and its smooth development. In order to optimize their operations, companies must overcome numerous challenges related to safety, production organization, coordination of work tasks and management of business units within the company's organized work structure.

The automation of mining production processes optimizes the operation of the mine, which achieves outstanding business results at significantly reduced costs and in compliance with occupational health and safety standards. The current database, which

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is stored in real time, serves as the basis for classifying, interpreting, trending and visualizing the information collected on the monitored process.

The Internet of Things (**IoT**) is a term that unites the virtual world with devices of varying degrees of complexity and technical systems that surround us. The data in the virtual world is processed by software based on a variety of methods and algorithms. The Industrial Internet of Things is a further development of the **IoT**, the main difference being that the **IoT** focuses on the individual needs of users, while the **IIoT** aims to increase the efficiency, safety and profitability of industrial activities (POLIMAK).

The described technology is part of a broader concept called Industry 4.0, which is a new phase of the industrial revolution that promotes digital technologies, artificial intelligence, interconnectivity of devices and machines, internet-based communication and real-time data collection.

The integration of the information technology system into the operational industrial system is a complex process. This requires the introduction of industrial standards for the implementation of technical solutions for process automation in the industrial sector.

The introduction of uniform communication protocols is necessary to enable the standardization of the devices used. This will promote the further improvement and modernization of industrial technologies.

Based on the previous explanation, the basic components of the IIoT operating system can be distinguished (POLIMAK):

- Cloud Computing,
- Wireless Internet,
- Input/Output,
- Artificial intelligence (Machine learning, Artificial Neural Network, ...).

The basic structure of the Industrial System for managing the technological process in real time is shown in Figure 1. Communication within the individual blocks and between the blocks at different levels takes place through industrial protocols, as shown in Figure 2 (Singha, A. et al., 2018). The structures created in this way make it possible to shorten the operating time if the ventilation parameters deviate from the designed ones. Time to action is crucial in cases of sudden gas burst.

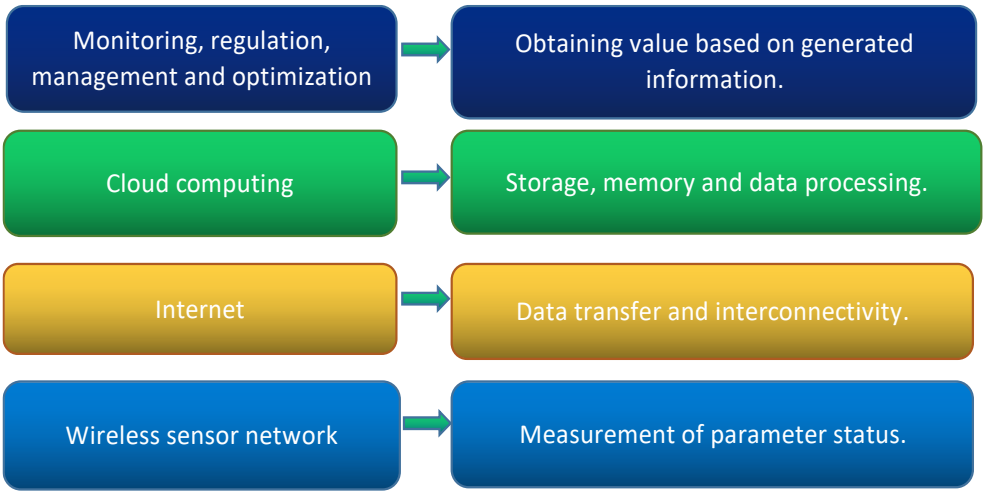

Figure 1 Structure of the Industrial Internet of Things system for real-time management

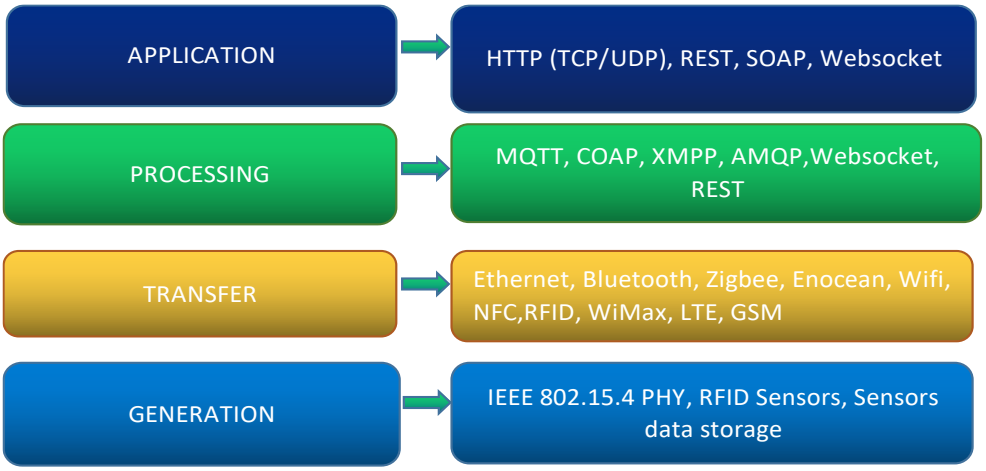

Figure 2 Industrial protocols for communication (Singha, A. et al., 2018)

The development of a high-quality ventilation system requires constant monitoring, recording, processing and re-implementation into the process. The use of suitable software enables rapid data processing and real-time action. The advantage of using such a system is very significant from a safety point of view, which eliminates the presence of workers in polluted mine air when the operating parameters of auxiliary fans in the mine need to be corrected and the air distribution needs to be regulated according to the conditions on site.

2 APPLICATION OF IIOT METHODOLOGY FOR VENTILATION OPTIMIZATION

The strategy of technological process management aims to monitor all influential process units, regulate input parameters, collect data on the state between input and output parameters and make timely management decisions that optimize the process itself. The data is updated in real time, which provides an insight into the status of working conditions on site. On this basis, it is possible to react in a timely manner and prevent the occurrence of potential risky situations.

The detection of possible irregularities in the operation of the machines, the functioning of the process or its component unit, is made possible thanks to the integrated sensors. The sensors record the values of the corresponding observed variables. The alarm system alerts the team in the control room to the presence of a possible malfunction in the equipment, and the user of the system takes management activities. Effective communication prevents situations that endanger the safety of the workers.

The development of optimized ventilation systems is a necessary prerequisite for safe working in mines. In order to ensure a sufficient supply of fresh air in all parts of the mine, it is important to develop a sustainable ventilation design. In addition, the work carried out must be consistent with the assumed design. Monitoring the working environment in real time is crucial to ensure safe working conditions. It is also important to modernize the technology of control and regulation of working parameters in the mine.

The application of modern software tools for monitoring mine air parameters and monitoring the operating characteristics of the main ventilation systems in real time makes it much easier to control the working conditions in the mine. This leads to more efficient production management in compliance with the legal framework. An up-to-date database, the possibility of preventive measures and a complete insight into the state of the mine atmosphere are just some of the benefits offered by these software packages. Prior professional training of personnel is required to use this software.

2.1 Predictive maintenance of fans and related ventilation equipment

Monitoring of the technical correctness of ventilation devices and the timely elimination of equipment failures has a significant impact on improving safety. The company Zitrón offers a system for optimizing ventilation in mines, which leads to better working conditions, a reduction of carbon emissions and a reduction of mine energy consumption (up to 40%). These could be the highest energy costs that mines have (Zitrón, 2021).

Most mines do not have an optimized ventilation design. It is necessary to determine the actual required airflow for the entire mine as well as the required air volumes for certain parts of the mine in the appropriate period. Based on the relevant performance indicators of the ventilation systems and the sustainability of the adopted technical solutions, a plan for automating the ventilation of the mine can be created. Thanks to its flexibility and

practicality, the system can be integrated into the existing mine communication system. Figure 3 shows a display of fan operating parameters, which monitors air flow, power input, bearing temperature, and air temperature. Based on recorded data the preventive maintenance can be organized.

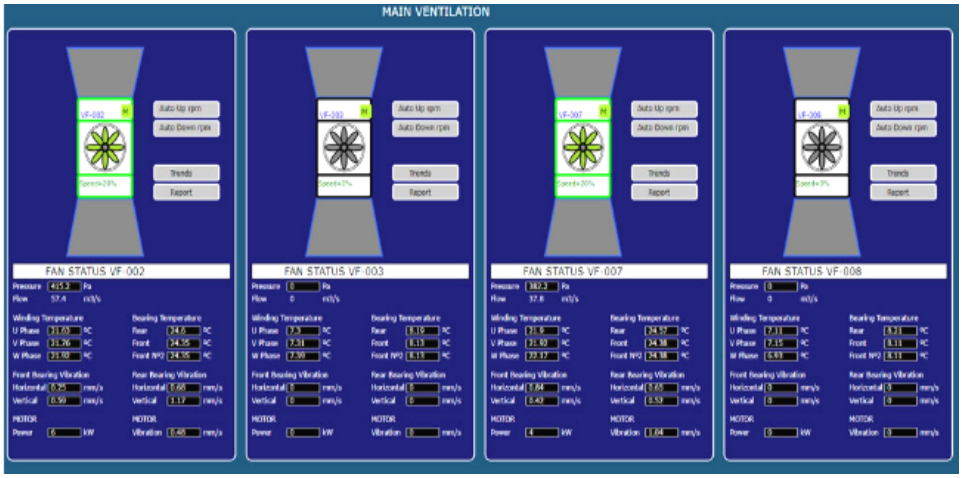

Figure 3 Monitoring of fan operating parameters in real time (Zitrón, 2021)

2.2 Wireless sensor network for gas monitoring

The gas concentration sensors are used to collect important data on working conditions. The data is transmitted to the main base in the mine via a wireless network. From there, it is sent to the main control station on the surface via wired network protocols. Based on the data obtained, useful information is generated about the production process and aspects of safety and efficiency of the realized production plans.

During blasting, a large amount of harmful and toxic gases are released and the oxygen concentration changes. The GuardIAN Intelligence Network from MineARC Systems offers a suitable solution for re-entry scenario after blasting. Based on the data obtained from the sensors, a decision is made on the safe time to return to the worksite after blasting is made. The sensors automatically confirm with a light signal that the conditions have been met for workers to return to the workplace. The lighting nodes warn the workers if the zone is unsafe for work. The previous practice was that checking the safety of the work zone required the arrival of workers who used detection devices to check the gas condition, often several times before the working conditions were met. This procedure takes too much time and is risky for the safety and health of workers (MineARC Systems, 2021).

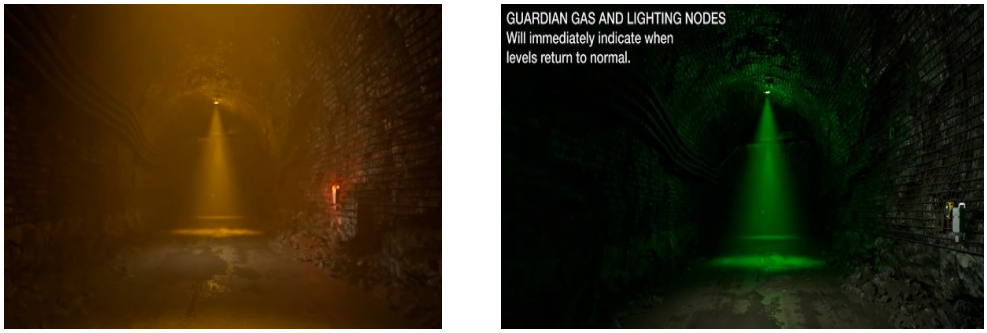

Figure 4 GuardIAN Intelligence Network sensors for gas concentration measurement and light signaling of safety conditions at the workplace (MineARC Systems, 2021)

In practice, sensors that register the gas concentration at workplaces (CO, CO2, CH4) or the air temperature provides data in real time, on the basis of which the ventilation system is automatically adjusted depending on what work is being carried out, how many workers are at the workplace, etc.

2.3 Interconnectivity and continuous communication

In underground coal mining, in order to maintain effective communication in complex working conditions it is necessary to adopt modern digital communication and connectivity technology. This ensures interoperability and the timely undertaking of management activities. A robust infrastructure of information technologies harmonized with the requirements of the industrial application enables effective communication between the different structural levels of the company. The acquisition of data from portable devices and wireless sensors at work sites, their interpretation and visualization significantly shorten the time for generating key information about mine production.

Unhindered communication is the basis for optimizing all technological phases of underground exploitation. This is the main reason for considering ventilation as an indispensable part of all other technological phases and not as an isolated unit in mine production.

ABB Smart Ventilation offers several levels of monitoring, control and optimization. The system is based on the 800xA platform. Some of the main advantages of the proposed system architecture are modularity, flexibility and scalability. The European metal company Boliden opted for the above-mentioned automation system, reducing costs by 30% (ABB).

2.4 Related work

Jo, B., and Khan, R.M.A. (2018) propose the application of the Internet of Things system for the monitoring and assessment of air quality in mines. In addition to data on the

current values of air properties, the system also has the ability to predict air quality based on machine learning. The most important elements of this system are:

- Sensors for measuring humidity, temperature, carbon dioxide (CO2), carbon monoxide (CO), methane (CH4), sulfur dioxide (SO2), hydrogen sulfide (H2S) and nitrogen dioxide (NO2),
- Machine learning platform (Azure Machine Learning Platform) that predicts air quality in mines
- Statistical methods for evaluating the most influential variables.

Ali, M. H. et al. (2018) presented an IoT dynamic system for monitoring workers' health through sensors attached to workers' helmets. Data on the condition of the air is always available. If the permissible values of the observed parameters are exceeded, the alarm system is activated. This is followed by appropriate feedback from the monitoring team to restore safe and healthy working conditions.

Wu, Y. et al. (2022) expanded the system of IoT technologies by adding a platform for processing a large package of diverse data (big data). In this way, a dynamic information platform for collecting, classifying, storing, processing and interpreting data on all aspects of mine safety was created.

Anani, A. et al. (2024) reviewed application of machine learning methods for the prediction of coal and gas outbursts in underground mines. Machine learning-based models use a data-driven approach. Data is collected using AE (acoustic emission), EMR (electromagnetic radiation) and gas sensors. Based on the processed data, a model with high prediction accuracy is selected. Numerous factors are taken into account for the prediction of eruptions. They can be classified into the following categories: geological, gas, coal seam and operational. The application of predictive models is important to reduce the risk of hazards in the mine. The implementation of a real-time monitoring sensor system will increase data quality.

Muduli, L. et al. (2018) investigated the application of wireless sensor networks for environmental monitoring in underground coal mines. In this study, WSN technology is also considered for monitoring mine hazards, personnel and equipment. In underground coal mines, there are many contaminants such as explosive gases, toxic gases, acute toxic gases, coal dust and water vapor. Changes in observed parameters such as gas and dust concentration, temperature, humidity and air pressure can increase the risk to the safety and health of miners. It is therefore necessary for mines to incorporate technologies such as the Internet of Things.

3 PROPOSED IIOT ARCHITECTURE

Effective control of parameters and indicators of air quality in the mine is achieved when the impact of other relevant factors of the technological process is taken into account, which primarily refers to the applied mining method, the transportation machines used, the coordination of workers, machines and accompanying equipment, the drainage system and other significant segments of production.

The automation of ventilation, the monitoring of the parameters of the substructure elements, the machines used for digging, loading and transportation of coal, as well as the health of the workers, significantly contribute to an informed management of the production and business aspects of the mine, better coordination and communication at the various management levels. In this way, the highest standards of occupational health and safety, maximum production capacity and economic operation of the mine are achieved. The energy efficiency and reliability of the sensors are the main characteristics that set them apart from other conventional technologies for monitoring the working environment.

Underground coal mining in Serbian mines is still characterized by low-productivity mining methods. Therefore, it is necessary to adapt the resources for the implementation of innovative technologies to the limitations that each mine has. This does not mean that coal mines should be excluded from the consideration of the possible digitalization of the business, but they should be approached with even greater attention and interest in order to find the optimal solution.

Traditional methods of data collection, management and regulation of ventilation do not provide optimal results. The isolation of individual subsystems within the business system has led to a significant delay in the transmission of information, resulting in significant deviations from planned production and business activities.

In underground coal mining, in addition to energy efficiency, maintaining effective communication under complex working conditions is essential. The use of modern digital communication and connectivity technology guarantees interoperability and the timely undertaking of management activities. The main advantage of such a system is its continuous improvement thanks to the constant flow of information and networking of all important aspects of the mine. The proposed IIoT architecture for the optimization of underground coal mine ventilation is shown in Figure 5.

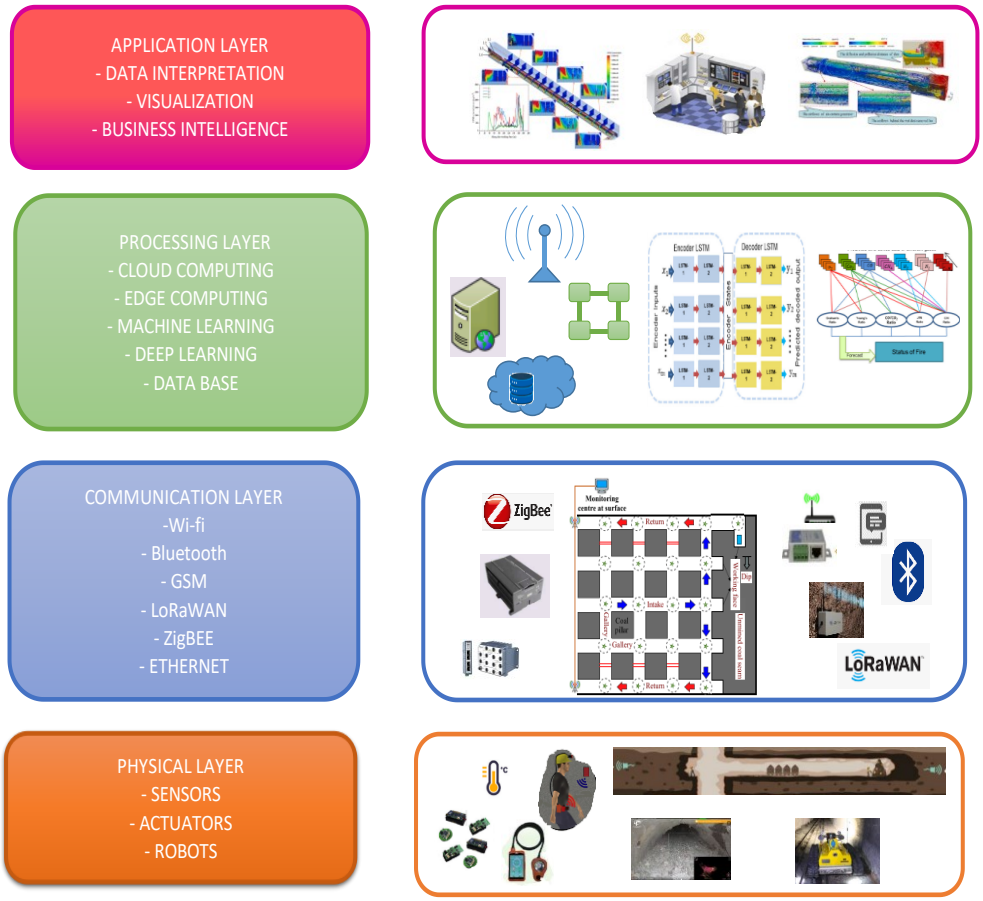

Figure 5 Proposed IIoT architecture for a coal mine ventilation optimization

The real-time management structure presented can be implemented in the existing mine production system. In this way, it is possible to monitor the operating parameters of the fan, the quality of the mine air and compare the values obtained with the data from other processes in the mine. In addition, by using smart devices information is obtained about the position, health and safety of workers.

4 DISCUSSION

In order to maintain the functionality of the system, the devices must withstand the difficult working conditions in the mine, which are reflected in a wide range of changes in operating temperature, high humidity, vibrations, noise and dust.

The lack of standardization of IIoT architecture has a negative impact on the security of network operations and threatens the security of critical mine operation data. In addition, difficult working conditions call into question the correct operation of the components

of the communication system. Considering the above-mentioned shortcomings, it is crucial to design equipment that can withstand large fluctuations in temperature, humidity and other variable parameters in the mine.

Complex conditions, which are also reflected in the frequent changes in the position of the workplace, make the development of the communication system particularly difficult. These factors hinder the functionality of the system. This manifests itself in interrupted data transmissions and poor connectivity between devices.

The challenges in the implementation of IIoT technology are expressed in the methodology of finding a technical solution which will harmonize the industrial requirements of the mine and the requirements of information technology. To successfully design a system that ensures the optimization of production, a team of experts from the fields covered by the industrial concept of the Internet of Things is required.

The establishment of such a system would significantly improve the System safety. It would also increase productivity by reducing the time spent away from the workplace. The energy savings would be considerable as other phases of the operating process could also be harmonized based on the ventilation parameters. The end result would be a reduction in operating costs.

5 CONCLUSION

The implementation of modern digital technologies offers numerous benefits and enables the further improvement and development of sustainable mining. By integrating information systems into the business structure of the mine, the basic concepts of automation are fulfilled. They are implemented through management, supervision, regulation and optimization of the technological process. The highest standards of occupational health and safety are set, and maximum productivity is achieved. Resource utilization is also achieved, encouraging further improvement of existing exploitation technologies and examination of the possibilities of new approaches to the exploitation of mineral resources.

The introduction of the real-time monitoring, control and action system for the ventilation system as one of the most important activities in coal mining creates the conditions for optimizing other phases of coal production. There is an opportunity to expand both the transportation and dewatering systems. In this way, the entire mining system would be monitored in real time, which would avoid production losses and increase productivity.

By investing in adequate resources for the design and development of communication systems in the mining industry, an optimized business model is created. This implies a

timely and informed management of the company's business based on information about the production segments observed.

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