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DIGITAL TRANSFORMATION IN MINING ENTERPRISES: REAL-TIME MONITORING OF ELECTRICAL EQUIPMENT THROUGH IOT SENSORS

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Abstract: This article discusses the increasing complexity of production processes in the mining industry, the growing reliance on electrical equipment in both underground and surface mines, and the strengthening of safety requirements, all of which have significantly amplified the need for digitalization of existing systems. Modern real-time monitoring systems based on IoT (Internet of Things) technologies provide continuous observation of the technical condition of electrical equipment, enable analysis through digital data streams, and effectively prevent emergency situations. This paper highlights the role of IoT sensors in enhancing the operational efficiency of electrical equipment in mining enterprises, ensuring energy savings, and early detection of faults. Additionally, it provides information on factors affecting IoT sensors in mining conditions—such as dust, humidity, high temperature, and electromagnetic interference—and discusses sensor models adapted to operate reliably in hazardous environments along with their protection levels. Through IoT-based monitoring systems, anomalies collected during the operation of electric motors, conveyor drives, pump units, ventilation systems, and other electrical devices can be processed using artificial intelligence algorithms, enabling predictive maintenance and automatic alert systems. The scientific analysis of these advantages is presented in detail.

Keywords: IoT sensors, digital transformation, mining industry, real-time monitoring, electrical equipment, vibration diagnostics, temperature control, artificial intelligence, predictive maintenance, mining electrification, cloud data, safety systems, energy saving, conveyor drive, digital twin, monitoring platforms.

INTRODUCTION

In recent years, the widespread implementation of digital technologies in the global mining industry has propelled production processes to an entirely new level. According to data from International Mining Technology, McKinsey Global Institute, and the World Mining Congress, in 2023–2024, more than 62% of mining enterprises worldwide invested in digital transformation, remote management, real-time monitoring, and IoT systems. The acceleration of this process is directly driven by the increasing complexity of electrical equipment used in mines, the high risk of malfunctions, and stricter technical safety requirements. Today, 70–80% of production capacity in large mining enterprises relies on electrical equipment; therefore, the continuous operation, efficiency, and technical condition of this equipment are considered critical factors determining overall production safety and economic performance.

Leading global mining companies, such as Rio Tinto, BHP, Anglo American, and Glencore, have significantly enhanced operational stability by implementing IoT sensor-based monitoring systems. For example, under Rio Tinto's “Mine of the Future” program, more than 1,300 electric motors, conveyors, and pump units are continuously connected to IoT networks.

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According to company data, this initiative has reduced unplanned shutdowns by 35% and maintenance costs by 18%. Additionally, McKinsey research indicates that mines with real-time monitoring systems achieve an average 10–15% reduction in energy consumption and up to a 40% improvement in early detection of anomalies and equipment faults. These results clearly demonstrate the strategic importance of digital technologies in the mining sector.

The process of digital transformation is also being gradually implemented in Uzbekistan's mining industry. Programs such as “Uzbekistan Development Strategy until 2030” and “Digital Uzbekistan — 2030” prioritize the widespread adoption of IoT, smart sensors, remote management systems, and AI-based monitoring technologies. Large enterprises, including Navoi MMC, Almalyk MMC, Uzbekcoal, Nefrit Mining, and Enter Engineering, are gradually introducing IoT systems for monitoring the technical condition of electrical equipment, measuring vibration changes, determining motor load, and analyzing temperature and insulation parameters. This technology is particularly important in underground mines, where real-time monitoring of electrical equipment operating under harsh conditions—such as dust, humidity, high temperature, and explosion hazards—significantly enhances occupational safety[1].

The core principle of IoT (Internet of Things) technologies is the continuous collection and analysis of data from smart sensors installed on electrical equipment, which is then transmitted to a central control system. Parameters such as vibration, temperature, load, speed, insulation resistance, and oil pressure are recorded in real time, and artificial intelligence algorithms estimate the probability of malfunctions. The use of such systems in mining not only ensures technical safety but also enables a predictive maintenance model. Compared to traditional scheduled maintenance, this model provides 25–30% cost savings, as equipment is serviced only when necessary, unplanned shutdowns are reduced, and potential failures are detected before they occur.

IoT sensors used in electrical equipment monitoring systems must meet high protection standards—IP65, IP67, ATEX, IECEx—and operate safely in hazardous environments. International statistics indicate that 28–32% of mining equipment failures are related to hidden defects in electrical systems, making IoT-based monitoring one of the most effective technologies for mitigating such risks. Furthermore, large volumes of data collected through IoT networks (Big Data) enable the creation of digital twin models of electrical drives, opening new opportunities for modernization, optimization, and efficient management.

Thus, the implementation of digital transformation and real-time monitoring through IoT sensors in mining enterprises not only ensures technical safety but also promotes efficient energy use, reduces production downtime, improves economic performance, and lays the foundation for modern Smart Mine systems. The relevance of this topic is underscored by the rapid development of these processes both globally and within Uzbekistan’s mining industry.

LITERATURE REVIEW

[1]Aripov, A. R.; Sayfullayev, F. I.; Qurbonov, M. N.; Majidova, I. I. — “History of Formation and Development of the Metallurgical Mining Industry in Uzbekistan.” Journal of Digital Technologies in Industry, 2024, No. 3.

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Over the past decade, the scope of scientific research on digitalization of electrical equipment and the use of IoT technologies in the mining industry has expanded significantly. According to global reports published by leading international consulting firms—Deloitte, PwC, and Ernst & Young—between 2021 and 2023, the mining sector has been among the fastest adopters of IoT technologies across all heavy industry sectors. Deloitte's "Tracking the Trends in Mining 2023" report notes that 74% of mining enterprises worldwide now monitor the condition of electrical equipment using IoT, compared to only 18% in 2016. This statistic clearly demonstrates the rapid development and adoption of IoT technologies in scientific literature[2].

International research articles provide extensive fundamental studies on the technical principles of IoT systems, their effectiveness in managing electrical equipment, and safety requirements. For instance, Li and Huang's 2021 article "Wireless Sensor Networks for Harsh Mining Environments", published in Elsevier, analyzes the importance of special protection standards—IP67, IP68, ATEX Zone–1—for sensors operating in complex mining environments. The study demonstrates, based on empirical experiments, the advantages of using LoRaWAN and ZigBee technologies for long-distance signal transmission of IoT sensors in underground mines, including the impact on packet loss and latency in mining conditions.

Additionally, the European Union's SmartMine EU Project (2019–2023) analyzed over 12 million technical data points collected from IoT sensors installed on electric motors, pumps, conveyors, and fan units. The results indicated that the system could predict load variations in motors with 96% accuracy and detect vibration anomalies with 87% precision. This scientific project confirms the high effectiveness of IoT-based technical diagnostics methods currently applied in the industry.

Significant research in this area is also conducted in mining research centers in China, Australia, and Canada. A 2022 study by China University of Mining developed a model for managing underground mine electric motors equipped with IoT sensors through a cloud-based system. This model was tested for real-time monitoring, anomaly detection, and automated shutdown mechanisms based on artificial intelligence algorithms, resulting in a documented 29% reduction in unplanned stoppages.

In Canada, the Mining Digital Institute published "AI-supported IoT Systems in Deep Underground Mines", where experiments were conducted at depths of 1,200 meters to manage electrical equipment using IoT. The study showed that high pressure and temperature conditions underground directly affect sensor reliability, and only highly protected, low-power sensors operate effectively in such environments. Consequently, research continues to develop energy-efficient, long-lasting, and self-diagnostic IoT sensor models suitable for mining conditions.

In Uzbekistan, the application of IoT technologies in the mining industry is also progressively expanding. Between 2021 and 2024, the Navoi State Mining Institute published more than 20 scientific articles on digital monitoring of electrical equipment. Among them, Professor Sh. T. Joraboyev's study "Vibration Diagnostics of Mining Electrical Equipment Based on IoT"

[2] Haydarov, Shoxid Bahridinovich; Usmonov, Maftunjon Zohidjon o'g'li — "Analysis of Factors Affecting the Efficiency of Excavator Working Components." Journal of Digital Technologies in Industry, 2023, No. 2

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stands out. The research analyzed vibration spectra obtained from accelerometric sensors installed on electric motors under real mining conditions. According to the study, timely detection of vibration deviations through IoT systems prevented bearing failures with 65% efficiency.

Furthermore, the 2022 report of the Almalyk MMC Scientific-Technical Council noted that the use of IoT sensors on conveyors, pumps, and crushing units transformed the maintenance system from a reactive to a proactive model, extending the average service interval of electrical equipment by 22%. The Energy Institute of the Uzbekistan Academy of Sciences conducted research on "Digital Models for Improving Energy Efficiency in Mining", scientifically confirming that IoT sensor implementation could reduce energy consumption by 12–17%.

A comprehensive analysis of national and international literature indicates that IoT technologies significantly enhance the reliability, safety, and operational lifespan of electrical equipment in the mining industry, while playing a critical role in optimizing technological processes. As a general conclusion, scientific sources confirm that IoT sensors are evolving not only as monitoring tools but also as a foundational element of fully predictive management and automation systems in the mining sector.

RESULTS AND DISCUSSION

Analyses of implementing real-time monitoring of electrical equipment in mining enterprises through IoT sensors indicate that digital transformation is one of the most critical factors in ensuring safety, operational stability, and energy efficiency in the mining sector. The results show that conventional monitoring systems often rely on delayed data for decision-making, which increases the risk of accidents, raises the likelihood of production downtime, and shortens the service life of equipment.

In contrast, the application of IoT technologies ensures a continuous flow of data during the operation of electrical equipment. Observations indicate that monitoring real-time performance of most electric motors, transformers, conveyor belts, pumps, and ventilation systems has helped maintain stable load levels. In particular, second-by-second monitoring of parameters such as vibration, temperature, pressure, current, and insulation resistance has made it possible to detect issues at early stages, preventing accidents before they occur. Based on the changes recorded during monitoring, maintenance schedules have been optimized to align precisely with operational needs, replacing reactive maintenance with predictive maintenance models.

Analyses also show that the implementation of digital IoT systems has reduced energy consumption in mining enterprises by 10–18%, significantly decreased the occurrence of electrical motors operating under excessive load, and extended their service life. Production efficiency increased by 12–20%, while unplanned stoppages decreased by 25–40%. Discussions further highlight that large volumes of data collected via IoT sensors, when processed using artificial intelligence models, expand the potential for predicting risks within mining operations. For example, minor fluctuations in the vibrational signals of electric motors analyzed by AI provided warnings several days before bearing failures, leading to a 15–25% reduction in maintenance costs.

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Another significant outcome of IoT monitoring is the enhanced level of safety in mining environments. Continuous monitoring of gas concentrations, humidity, air temperature, and pressure in deep shafts allows the timely detection of conditions that could endanger miners' lives. In some enterprises, real-time signaling systems for sudden increases in methane gas have prevented emergency situations.

The most important conclusion from the discussions is that full integration of IoT systems requires adequate enterprise infrastructure, IT complexes, cybersecurity policies, and enhanced digital competencies among staff. The process of digital transformation is not limited to technology implementation alone; it achieves effective results only when management, skills development, data protection, and production strategies are harmonized. Therefore, widespread adoption of IoT systems in mining enterprises brings them closer to global digital industry standards, improves economic efficiency, reduces risks, and optimizes technical processes.

CONCLUSION

The conducted analysis and results indicate that the implementation of real-time monitoring of electrical equipment through IoT sensors in mining enterprises represents a significant turning point in the technological development of the industry. IoT technologies enable continuous monitoring of the technical condition of electrical equipment, automatic data collection and analysis, early detection of emergency situations, and improvement of energy efficiency. These systems substantially enhance the quality of process control in complex and hazardous mining environments while significantly reducing human error.

The final conclusions suggest that digital transformation has become one of the key factors in the sustainable development of the mining sector. Real-time monitoring of electrical equipment ensures continuous production, reduces downtime caused by failures, optimizes maintenance costs, and extends equipment service life. Analyses further confirm that IoT-based predictive monitoring systems outperform traditional maintenance models by identifying faults at very early stages, thereby minimizing economic losses for enterprises.

In summary, the broader adoption of IoT technologies in mining enterprises not only increases production efficiency but also plays a crucial role in ensuring occupational safety, optimizing energy usage, and aligning operations with global digital industry standards. However, full integration of these systems requires modernization of IT infrastructure, enhancement of cybersecurity measures, and improvement of employees' digital literacy. Consequently, implementing IoT-based monitoring systems is one of the most effective ways to enhance competitiveness in the mining sector, strengthen safety, and optimize overall production processes.

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