Journal of Intelligent Systems with Applications 2025; 8(1): 1-4

Usage and Future of Intelligent Systems in Drilling Technology

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***Abstract*—The drilling operations has had an important place in accessing natural resources and energy production since ancient times. From the past to the present, advances in both the number and methods of drilling activities have been continuously experienced with primitive and modern technologies. Drilling technologies have undergone great changes since their historical development and have reached a new dimension especially with digital transformation and continue to develop with advanced technology. The integration of intelligent systems into drilling operations has made drilling processes more efficient, safe and cost-optimized. Artificial intelligence, machine learning, big data analytics, digital twins and autonomous system technologies provide great convenience compared to traditional methods. In this study, smart drilling systems are investigated in detail; the fundamentals, working principles, components, advantages, current applications and future potential of these systems are examined.**

Keywords*—*Intelligent systems, drilling, energy, petroleum and natural gas

I. Introduction

Drilling technologies are among the main methods used for the exploration and production of energy resources and have a critical place in the global economy due to their importance in energy production. Drilling operations have evolved from simple mechanical methods first used in history to drill wells for access to drinking water to high-tech, automated and artificial intelligence-supported systems today and continue to evolve as an important part of the energy sector [1,2]. The discovery and production of primary energy resources (fossil-based such as oil and natural gas) are increasingly being carried out with more efficient, safe and environmentally friendly methods to meet the increasing global energy demand. While traditional drilling methods are generally based on manpower and manual control, modern drilling technologies are equipped with intelligent systems. Thus, drilling operations can be carried out more reliably, quickly and economically [3]. With the digital transformation that has occurred in the global energy sector in recent years, drilling activities and processes have become more complex and data-driven decision-making mechanisms have come to the fore. In particular, real-time data collection and detailed analysis of this data allow for optimization of drilling activities and enable high-efficiency drilling. Therefore, both environmental and economic drilling activities can be carried out with high efficiency [4]. One of the aims of drilling operations is energy security and sustainable development. Although the production and use of renewable energy sources have become widespread today, fossil fuels, which are primary energy sources, have constituted the majority of the world's energy consumption for many years. In addition, the sustainable development of renewable resources such as geothermal energy also increases the need for advanced drilling technologies. Making drilling processes more intelligent, environmentally and economically is critical to meet the current and future needs of the energy sector day by day [5]. Intelligent systems are defined as autonomous or semi-autonomous systems that integrate advanced technologies such as automation, artificial intelligence, machine learning and the Internet of Things (IoT). By minimizing human influence, these systems optimize decision-making processes and improve the overall performance of operations [6,7]. In drilling operations, intelligent systems are integrated with measurement devices (MWD-Measurement While Drilling and LWD-Logging While Drilling) to provide real-time analysis of underground formations. Therefore, drilling routes to the target depth can be determined, well stability can be improved and the environmental impact of drilling operations can be reduced. Artificial intelligence algorithms can be combined with big data analytics to make predictions about equipment condition, operational performance and potential risks. These systems play a critical role not only in operational processes but also in environmental management and sustainability strategies. Intelligent systems integrated with environmental monitoring systems contribute to reducing carbon emissions and using resources more efficiently [8,9]. In this study, the role of intelligent systems in the drilling industry is examined in detail. Within the scope of the study, the historical development, applications, advantages and disadvantages, future, environmental and economic impacts of intelligent systems are investigated.

II. Historical Development of Intelligent Systems in Drilling Technologies

Traditional methods in drilling technologies started with a period of manual control and mechanical tools. The first boreholes were drilled with simple mechanisms based entirely on manpower. For example, in the early 19th century, pile driving with bamboo sticks was effective at low depths and in less complex ground conditions. However, these methods were insufficient to meet the increasing demands of the energy

sector due to limited depth, low precision and high labour requirements. They have been sufficient only for access to basic water resources [10]. From the beginning of the 20th century to the present, the widespread use of rotary drilling methods has enabled significant advances in the drilling industry. The rotary drilling method has enabled the drill to rotate mechanically and drill rocks with torque, allowing deeper wells to be opened and difficult drilling conditions to be easily overcome. However, despite its significant advantages, it has some disadvantages. These systems are not considered highly efficient today due to their excessive dependence on the human factor and limited automation capacity. With the development of digitalization and the integration of automation into the energy sector, a new era began in drilling technologies in the last quarter of the 20th century. Intelligent systems have played a critical role in optimizing these traditional processes, reducing dependence on the human factor and enabling highly efficient drilling by minimizing the margin of error. In particular, the introduction of autonomous control systems makes a significant contribution to the prevention of malfunctions and interruptions during drilling [11]. The development of artificial intelligence and machine learning techniques in the 2000s has been an important step in the evolution of smart systems in the drilling sector. Artificial intelligence and machine learning-based technologies enable applications such as predicting possible equipment failures, determining optimum drilling parameters and reducing environmental risks by analyzing old drilling data in detail. In these periods, with the widespread use of IoT devices, real data from sensors can be monitored simultaneously and analyzed on cloud-based platforms [11]. In the 2010s, autonomous drilling systems came to the fore in the energy sector. Supported by advanced technologies such as robotic drilling arms, automatic pressure control mechanisms and advanced simulation software, these autonomous systems enabled drilling operations to be carried out with maximum efficiency with minimum human intervention. Today, digital twin technologies allow complex drilling operations to be simulated and optimized in a digital environment [12]. As a result of the technological transformations that took place in the process from the industrial revolution to the digital revolution, significant changes have occurred in the drilling sector. In particular, the integration of artificial intelligence and robotics, seen as part of industry 4.0, has increased the automation of operational processes. This has not only increased efficiency, but also safety and environmental sustainability [12]. Big data analytics support operators in their decision-making processes by performing statistical analysis on millions of data points collected by sensors. As a result, drilling costs can be reduced and environmental risks can be minimized. Furthermore, the interaction between CPS-Cyber-Physical Systems, digital environments and physical drilling equipment has increased transparency and precision in operational processes. These developments are especially critical in complex reservoir conditions and deep-water drilling.

III. Applications of Intelligent Systems in Drilling Operations

A. Real-Time Data Collection and Analysis Systems

One of the most common uses of intelligent systems in drilling operations is real-time data acquisition and analysis. MWD and LWD technologies enable the optimization of drilling processes by regularly monitoring the physical and chemical properties of formations during drilling. These systems enable continuous recording and analysis of data such as pressure, temperature, vibration, torque and flow collected instantaneously by sensors [13]. Real-time data analytics facilitates the prediction of major problems that can arise during drilling, such as well collapse, bit wear or failure and kick fluids, and enables action to be taken before the problem progresses or occurs. For example, well collapse risk can be predicted by analyzing formation pressure and stress, drill wear and failure can be detected from anomalies in torque and vibration data from sensors, and problems with spike fluids can be identified with density and permeability data from LWD systems. Therefore, these systems not only increase productivity but also contribute to reducing operational costs by predicting or predicting potential problems and failures.

B. Autonomous Drilling Systems

Autonomous drilling systems include advanced robotics and artificial intelligence technologies that enable drilling without the need for manual operation. These systems are used to improve drilling safety and operational efficiency, especially in high-risk and difficult-to-access locations such as deep-water reservoirs or high-temperature geothermal resources [14]. Autonomous drilling systems have many advantages. Artificial intelligence algorithms enable real-time decision making by analyzing data from sensors during drilling to determine the optimal drilling speed and pressure. The condition of the system and equipment is continuously monitored and potential failures are detected in advance, minimizing operational interruptions, thus enabling fault prediction and preventive maintenance. Autonomous control ensures that problems such as environmental leakage or fluid loss are detected as soon as possible, so that environmental impacts can be easily controlled.

C. Artificial Intelligence and Machine Learning Based Forecasting Models

Advanced technologies such as artificial intelligence (AI) and machine learning (ML) are widely used in drilling operations today to create data-driven predictive models. These technologies enable high-accuracy predictions for future drilling operations by learning and analyzing data obtained from past drilling activities. For example, by collecting and analyzing data such as bit design, formation characteristics and drilling parameters, optimum drilling speed can be estimated with the outputs based on this data, and thus, drilling progress rate (ROP) optimization can be made. In addition, thanks to the algorithms used in AI and ML technologies, drilling risks such as well collapse or filtration can be estimated and possible

problems can be prevented. A large number of data points collected during drilling are analyzed by artificial intelligence algorithms to continuously update and improve the optimal parameters [15].

D. Digital Twin Technology

Digital twin technology refers to the creation of a virtual copy of a physical system in a digital environment. In the drilling industry, digital twins are used to simulate and optimize every stage of well operations. This technology is constantly updated with real-time data, allowing operators to make more accurate and faster decisions. Digital twin technology has significant advantages for drilling operations [16]. For example, various drilling scenarios are tested digitally before the actual operation begins. This allows potential risks to be identified in advance and operations to be optimized. By simulating the interaction between equipment and formation during drilling, operational efficiency can be achieved with the most appropriate operational parameters. For these reasons, digital twin technology plays a critical role in controlling costs, especially in high-cost and complex drilling projects.

E. IoT and Intelligent Drilling Platforms

IoT is defined as an infrastructure system that enables drilling equipment and sensors to connect to each other and continuously exchange data. With the IoT, intelligent drilling platforms allow data collected from the field to be transferred to cloud-based systems and analyzed. With IoT, operational parameters such as torque, pressure, temperature and fluid flow can be monitored and analyzed instantaneously during drilling [17]. With IoT sensors and the data received from these sensors, the status of the equipment can be continuously monitored and malfunctions and possible disruptions can be prevented. In addition, emissions and liquid leaks can be controlled by monitoring with IoT-based systems, thus controlling environmental risks and minimizing environmental damage. In general, IoT technology enables field operations to be monitored and managed from a centralized control unit, reducing labour costs and increasing operational safety.

IV. Advantages and Challenges of Intelligent Systems in Drilling Operations

Intelligent systems utilize advanced technology in drilling operations, creating a safer, more efficient and eco-friendly working. These advantages are critical to meeting modern energy needs. In general, intelligent systems provide efficiency at every stage of drilling operations. Advanced data analytics and AI-powered systems determine optimal drilling parameters, reducing equipment wear and shortening drilling time. It can also reduce operational costs by up to 30Despite all advantages, the implementation of intelligent systems in the drilling sector can face some challenges, such as technological, economic and organizational factors. The development and implementation of intelligent systems requires a significant financial investment, and advanced sensors, robotic equipment and AI-based software are costly. Therefore, small and medium-sized energy companies in particular may find it difficult to cover these costs. Moreover, integrating legacy drilling equipment with intelligent systems is a complex and time-consuming process. Challenges include harmonizing traditional drilling systems with modern intelligence technologies, installation of advanced integration systems to process data from different sources, cyber security risks due to the large amount of data collected with IoT devices and cloud-based systems, manipulation of critical drilling data by unauthorized persons and data collection processes, compliance with legal regulations and privacy standards. In addition, the effective use of intelligent systems requires operators to adapt to these systems. Therefore, a comprehensive training program is required for the existing workforce to adapt to new technologies, and some traditional professions are being replaced by automation systems, which may result in job losses.

V. Future of Intelligent Systems in Drilling Technologies

The positive effect of intelligent systems on drilling operations is increasing every day. Innovative technologies such as artificial intelligence, machine learning, robotic systems and digital twin are both improving current operations and reshaping the future of the drilling industry. With the environmental impact of fossil fuels under scrutiny, sustainable energy production and efficiency are crucial for the future of drilling technologies. For this reason, intelligent systems support sustainability and efficiency by providing solutions to reduce environmental impacts. By optimizing energy consumption, intelligent systems reduce carbon emissions and thus enable low-emission drilling operations. With the use of intelligent systems in geothermal drilling, efficient use of renewable energy resources can be achieved and low-cost drilling operations can be carried out [18]. Fully automated drilling rigs and platforms are expected to be realized in the future. Such rigs and platforms will increase drilling efficiency and safety by minimizing human influence. AI-powered algorithms will be able to manage real-time data in drilling operations, enabling the development of intelligent systems that can make decisions on their own. Robotic control of drills and other drill string elements will speed up drilling operations and minimize safety risks. In addition, with the ability to remotely control field equipment, successful drilling operations can be realized in locations with deep sea or difficult terrain conditions [18]. In the future of drilling technologies, big data analytics will continue to play a critical role in the coming years. Detailed analysis of historical data will enable more precise planning of future operations. With big data analytics, the production performance, yield and economic life of boreholes can be predicted with high efficiency. Failures and potential problems related to the borehole can be predicted in advance with high accuracy, thus enabling accurate risk management. In addition, all operational parameters can be optimized simultaneously depending on different conditions during the drilling process [18]. Digital twin technology will have a much wider use in future drilling operations. These systems will enable virtual simulations of drilling rigs and platforms, enabling drilling

to be carried out with high efficiency. Real-time dynamic simulation of changing conditions in the well can be performed, maintenance processes can be optimized by predicting failure of drill string equipment, and a low-cost and risk-free environment for training new personnel can be provided. The integration of intelligent systems into drilling operations is driving fundamental changes in drilling and drilling equipment. Future drilling equipment is moving towards being smarter, more durable and more environmentally friendly. With sensor-integrated drills, intelligent drill systems that can analyse their own condition and report fault conditions will become widespread. Adaptive drills will be able to adjust themselves according to formation characteristics and increase operational success rates. In addition, the use of lightweight and highly durable new generation composite materials will extend the lifetime of drill string equipment and reduce costs. AI decision support systems are being used today and will become more prevalent in the future to overcome uncertainties in drilling operations. Strategic decisions such as identifying drilling locations, selecting drilling fluids and determining production methods will be optimized by AI algorithms. The ability to simulate potential risks will improve drilling safety and enable highly accurate risk scenario analysis. In addition, equipment and workforce planning will be optimized to provide more production with fewer resources, thus enabling efficient operational planning. In the future, drilling operations are expected to comply more strictly with environmental regulations and legal standards. Intelligent systems will play an important role in meeting these requirements. Emission monitoring and reporting activities will be possible with the automation of carbon footprint monitoring and reporting. In addition, with the possibility of automatic monitoring and reporting of legal requirements, compliance processes will be carried out quickly.

VI. Conclusion

Intelligent drilling technologies offer great opportunities not only for the oil and gas sector, but also in different engineering fields such as geothermal drilling, mining and water drilling. In recent years, many academic studies and industrial projects worldwide have focused on the further development of intelligent systems. The energy sector is expected to undergo a major transformation and development by 2050 with advances in digitalization and automation. In light of these developments, intelligent drilling systems will not only offer economic and operational advantages, but will also become a more sustainable and highly efficient power generation technology.

As a result, intelligent drilling systems are a critical technology to meet not only today's energy needs but also those of the future. Therefore, it is necessary for both the energy sector and the drilling industry to accelerate the development of these technologies in both academic and industrial fields.

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