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A Review of Intelligent Research Dynamics in Oil and Gas Exploration and Development

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Abstract: The intelligentization of oil and gas exploration and development has attracted much attention in recent years. This involves artificial intelligence, big data analysis, and other cutting-edge technologies and methods. The paper explores the trend of intelligent development within the oil and gas industry, focusing on the utilization of large-scale data collection, integration, and analysis techniques. It delves into the in-depth exploration of geological, geophysical, production, and other pertinent information to deliver more comprehensive and precise data support for the exploration and development processes. Continuous advancements in big data and artificial intelligence technologies further refine solutions, ensuring greater accuracy and efficiency in oil and gas exploration and development. Data-driven intelligent technologies play a pivotal role in the exploration and development of oil and gas resources, providing a robust foundation for the industry's intelligent advancement. While intelligent technology presents significant opportunities, it also presents a myriad of challenges. Thus, collaboration and knowledge-sharing will serve as the primary catalysts for field development, facilitating the exchange of technology and expertise to collectively tackle challenges in the future.

Keywords: Artificial intelligence, Exploration and development, Data-driven.

1. Introduction

China has a complex and diverse distribution of oil and gas resources, which makes exploration and development challenging due to varying geological conditions and environmental issues. As a result, different exploration technologies and engineering approaches are required [1]. Additionally, oil and gas resources serve as the lifeblood of the industrial economy, playing a crucial role in the economic operation and social development of the nation. Increasing hydrocarbon exploration and development helps minimize reliance on imported energy, strengthen energy autonomy and resilience, and protect energy security while also improving the country's energy supply, assuring stability and satisfying rising demand [2]. The rapid advancement of the latest technological revolution has led to the widespread adoption of modern information technologies like the Internet of Things (IoT), big data analysis, artificial intelligence (AI), and cloud computing across various scenarios. These technologies have exhibited significant potential, and a wave of technological innovations and industrial transformations centered around intelligence is poised to provide unprecedented opportunities for traditional industries [3]. This trend is also sweeping through the oil and gas sector, where the industry is increasingly dependent on big data and artificial intelligence technologies to enhance exploration and development efficiency and streamline production processes. The integration and implementation of these technologies are gradually reshaping production methods, industrial structures, and operational mechanisms, emerging as a significant driving force for the advancement of oil and gas exploration and development [4].

The intelligent advancement of oil and gas exploration and development represents not merely a technological shift but also exerts a profound influence on the entire oil and gas industry, ushering in both new opportunities and challenges [5-6]. This paper aims to comprehensively survey current research dynamics to offer insights into the application of intelligent technology in oil and gas exploration and development, as well as to shed light on future research directions and industry development trends. Considering how the oil and gas industry may embrace more sustainable and efficient development by implementing intelligent technology will be the center of attention for everyone in this age of technological revolution. Despite the numerous opportunities afforded by intelligent technology, there remain a series of problems and challenges in its application process. Additionally, this paper will address the current challenges confronting the intelligent development of oil and gas exploration and production (E&P), and explore how cross-disciplinary collaboration can foster innovation and application of intelligent technologies in the oil and gas E&P sector.

2. Current Status of Intelligence Technology Development

Big Data and Artificial Intelligence (AI) share a symbiotic relationship: Big Data furnishes data for AI to train and learn from, while AI conducts processing and analysis of Big Data to unearth vital information and unveil the underlying laws and logic embedded within the data, thereby complementing each other. The advancement of Big Data and Artificial Intelligence technologies has emerged as a crucial catalyst for modern technological progress, exerting significant influence across various domains including business, industry, healthcare, education, and numerous other fields [7-8]. Big data-driven AI technologies continue to evolve to offer increasingly intelligent and effective solutions for society and industry.

The evolution of Artificial Intelligence (AI) unfolds in distinct phases, tracing its development from conception to its current state of increasing maturity and widespread application. In the early 1940s, Minsky and Edmonds constructed the initial neural network simulator, known as

SNARC. The term "Artificial Intelligence" was first coined by scientists, including McCarthy, during a conference held at Dartmouth in 1956. The 1960s focused on the development of symbolic systems, aimed at problem-solving through the application of rules and knowledge representations, with expert systems emerging as a prominent outcome of this phase. In the late 1970s, following an initial period of optimism, AI research encountered its first downturn, known as the first AI winter, due to technological constraints and inflated expectations. In the 1980s, expert systems achieved some commercial success, but progress was relatively slow due to limited computational resources and theoretical challenges. By the mid-1980s, machine learning, including decision trees, neural networks, and knowledge-based reasoning methods, started to emerge. However, the pace of AI technology development once again decelerated, leading to a second winter period. The advent of big data and the emergence of cloud computing since the 21st century have created new opportunities for AI development. The availability of large-scale datasets and enhanced computational resources has driven significant advancements in algorithms, particularly in machine learning and deep learning [9]. The progression of artificial intelligence is depicted in Table 1.

Table 1. History of Artificial Intelligence Technology

Period	Characteristics	Events
Mid-1940s 1956	The first peak	The first network computer Dartmouth Conference
1974-1980	The first valley bottom	Defects in data analysis
1980s	The second peak	Expert system and artificial neural network
1987	The second valley bottom	AI has been denied
Early 21 century	The third peak	Deep learning algorithms and big data

The modern era of deep learning was marked by a series of studies in 2006 conducted by Hinton et al., which showcased that employing unsupervised pre-training in multilayer neural networks could greatly enhance network performance. This work introduced Deep Belief Networks (DBNs) as the designation for these network structures [10-11]. Deep learning has advanced significantly in image identification, audio recognition, and natural language processing in recent years, exhibiting tremendous growth. Its success is mostly due to the abundance of large-scale data, powerful computing power, and improved algorithms. Currently, the most prevalent deep learning frameworks include TensorFlow, Keras, PyTorch, and MXNet. These frameworks, which are compatible with the Python programming language and GPU parallel computing, empower developers to effortlessly deploy a diverse range of complex neural networks. Examples include Fully Connected Neural Networks, Convolutional Neural Networks, and Generative Adversarial Neural Networks, which play pivotal roles in addressing a multitude of problem types, including classification, dimensionality reduction, clustering, and regression [4].

3. Intelligent Technology in Oil and Gas

3.1. Logging curve processing analysis

Due to various reasons, logging curve data may be missing or incomplete. The advent of artificial intelligence for reconstructing and correcting logging curves through data analysis and pattern recognition enables more precise geological interpretation. This approach has yielded superior results in identifying and delineating petrographic types and calculating physical parameters of oil and gas reservoirs, among other applications [12]. Akinnikawe et al. [13] addressed the issue of missing logging data by employing a range of machine learning algorithms for predictive training. They identified the optimal algorithm by verifying the minimum mean square error of the dataset. Yang et al. [14] utilized existing logging and core data to predict porosity. They employed a convolutional neural network model constructed using deep learning methods for this purpose.

Korjani et al. [15] developed a deep learning model using extensive logging data and rock fluid data. The prediction results, which closely matched the actual logging data, validated the accuracy and reliability of the method. Tian et al. [16] created a log phase delineation model comprising five clusters, derived from petrographic identification results and log phase calibration of core data. They also developed a graphical plate for quantitative petrographic interpretation. Subsequently, they conducted continuous clustered log phase delineation and petrographic prediction based on this model. Zhou et al. [17] enhanced the traditional neural network model and established a nonlinear model correlating reservoir parameters, logging response, and lithology. They attained remarkable results with this approach.

3.2. Seismic information interpretation

Artificial intelligence techniques, particularly deep learning algorithms, demonstrate the ability to process vast quantities of seismic data, automatically extract and learn intricate seismic patterns, and enhance the accuracy of seismic data interpretation. However, the expansion in the size of 3D seismic data volumes and the complexity of seismic attributes present significant challenges for seismic interpreters. Zhao et al. [18] introduced six AI algorithms for analyzing 3D seismic data collected in the Canterbury Basin offshore New Zealand, aiming to distinguish the conformational elements of the turbidite system. Lewis et al. [19] employed deep learning algorithms to extract knowledge from seismic imagery, utilizing earth model-related features to construct a priori models for implementing full waveform inversion (FWI).

Wu et al. [20] developed a coded convolutional neural network model for fault detection, structure-oriented smoothing with edge retention, and slope estimation. Multiple field examples demonstrate the model's ability to accurately perform all three image processing tasks in typical seismic images. Lin et al. [21] employed a convolutional neural model in deep learning to intelligently extract, classify, and identify oil and gas features in seismic data. The study demonstrated that this method can achieve the anticipated results and has the potential to reduce the duration of seismic data interpretation.

3.3. Geological modeling of oil-gas reservoirs

The advancement of big data and artificial intelligence technology enables the acquisition and analysis of increasingly complex data. Leveraging big data technology, researchers can construct more comprehensive geological models by integrating and analyzing diverse data sources, including seismic, logging, geology, and geomagnetism. Simultaneously, this approach facilitates the identification of blocks with high productivity. Deep learning methods, utilizing intelligent technologies, enhance the complexity and representational capacity of geological models for oil and gas reservoirs, thereby enabling better capture of geological information. Strebelle et al. [22] introduced the SNESIM multipoint geostatistical simulation algorithm, leveraging training images of intricate geological structural information for constructing reservoir models. The construction process illustrated its capability to characterize reservoir inhomogeneity of any type, shape, and scale, provided suitable training images are accessible. Al-Anazi et al. [23] utilized the support vector machine (SVM) technique from statistical learning theory to predict the spatial distribution of permeability in strongly inhomogeneous sandstone reservoirs. They showcased the technique's potential for predicting permeability in such reservoirs. Mosser et al. [24] utilized Generative Adversarial Network (GAN) to achieve the conditionalized construction of 3D reservoir models. They employed content loss to confine the conditional data and assessed perceptual loss through the discriminator network, yielding successful outcomes with this method.

3.4. Intelligent drilling and completion

Advanced technologies and automated systems form the foundation for achieving efficient, precise, and automated drilling and completion operations for oil and gas wells. This entails utilizing a variety of sensors, real-time data analysis, artificial intelligence, and other technologies to enhance drilling efficiency, reduce costs, and ensure the quality and safety of wells. AlArfaj et al. [25] applied a radial basis function as an activation function in an artificial neural network. They utilized a dataset comprising parameters such as depth, drilling pressure, rotational speed, tooth wear, Reynolds number function, equivalent circulating density, and porosity for training to predict drilling speed. Elkatatny et al. [26] devised a visual mathematical model leveraging the weights, bias, and transfer function of an artificial neural network. This model utilizes data such as martensitic funnel viscosity, solids content, and density to forecast real-time drilling fluid rheological parameters and drilling fluid performance. Nieto et al. [27] employed multi-attribute linear regression and artificial neural network models alongside reservoir characterization, including fault and fracture identification, and real-time pressure monitoring to optimize the process of completing oil and gas wells.

3.5. Production dynamic analysis and prediction

With the advancement of modern technology, big data and artificial intelligence technologies are assuming increasingly significant roles in dynamic analysis and production prediction. Zhou et al. [28] conducted research on horizontal well water-driven oil recovery, focusing on intelligent well feedback control algorithms and a numerical model capable of downhole monitoring and control. They validated Proactive control, Reactive control, and a hybrid control method combining the two, assessing their advantages and applicability in oilfield production. Jia et al. [29] proposed a set of big data-driven optimization methods for fine water injection schemes, integrating traditional numerical simulation and optimization algorithms with field data collected through real-time monitoring and automatic control processes for stratified injection and extraction.

Costa et al. [30] addressed the complexity and time-consuming nature of history fitting calculations in reservoir numerical simulations by employing an artificial neural network (ANN) agent model instead of numerical simulation. The ANN effectively handles the nonlinear features in the simulation, enabling the prediction of oilfield production data. Mohammadmoradi et al. [31] integrated an artificial intelligence algorithm into reservoir uncertainty modeling, presenting a mechanism-supported data-driven model. Utilizing collected data and incremental learning methods, the constructed virtual flow metering technique yields data that aligns with actual production data and predicts well fluid flow rates.

3.6. Oil-gas field surface engineering

The integration of big data and artificial intelligence technology has led to further advancements and reforms in oil and gas field ground engineering, with the construction of digital twins emerging as a crucial step towards achieving intelligence [32]. Intelligent oil and gas field ground engineering involves establishing a digital system through three-dimensional design and digitization technology. This system integrates dynamic production data and intelligent applications, enabling real-time monitoring through sensors and data acquisition technology. It facilitates real-time perception, analysis, prediction, optimization, and decision-making within a virtual production environment. Oil and gas field ground engineering serves as a vital component for managing investment, reducing costs, enhancing development efficiency, ensuring safety, and promoting energy conservation and environmental protection. Additionally, it plays a crucial role in optimizing management practices and improving overall quality and efficiency. The advancement of oil and gas field ground engineering technology directly impacts development outcomes [33]. To enhance the quality and efficiency of oil and gas field ground operations, various artificial intelligence technologies, including cloud platforms, big data analytics, Internet of Things, image recognition, machine learning, supercomputing, and knowledge mapping, offer essential technical support [34].

4. Challenges and Trends of Intelligentization

4.1. Future issues and challenges

4.1.1. Complex geological conditions

Oil and gas fields frequently reside in geologically intricate regions, heightening the challenges of exploration and development. Moreover, complex tectonic features and heterogeneous strata amplify uncertainty throughout the exploration and development phases. Under challenging geological conditions, intelligent technologies need to be able to analyse and interpret data accurately, and must be optimised and adapted to various geological conditions to ensure efficient, safe and environmentally friendly exploration and development of hydrocarbon resources in complex environments.

4.1.2. Data quality and safety problem

Intelligent oil and gas exploration and development heavily relies on extensive data analysis, where the quality and reliability of data serve as the cornerstone of intelligence. Inaccurate or flawed datasets can significantly misguide prediction models, consequently impacting the accuracy of the model's outcomes. Oil and gas exploration and development entail vast datasets from geological exploration, production monitoring, among others. Ensuring data security and privacy emerges as a crucial concern, particularly when leveraging cloud computing platforms and big data technologies. Special attention must be directed towards addressing the heightened cybersecurity risks associated with analyses.

4.1.3. Investment and cost

The integration of intelligent systems necessitates investments in advanced sensing technologies, big data analytics platforms, artificial intelligence algorithms, and other components to establish resilient and efficient exploration and development systems. These investments encompass not only the procurement of hardware and software but also the training and recruitment of skilled professionals to manage and sustain these systems. Furthermore, factors such as oil price volatility and geological risks must be meticulously evaluated in investment planning processes.

4.2. Trends in the development of oil and gas intelligence

4.2.1. Data-driven decision making

Leveraging big data and artificial intelligence technologies, oil and gas exploration and development are increasingly dependent on data-driven decision-making. Data analysis and mining constitute pivotal components of intelligent decision-making processes. Employing techniques such as machine learning, model building, and predictive analytics, data from exploration, production, and operational phases will be thoroughly mined to uncover potential patterns, trends, and correlations. These insights will furnish robust support for crafting more precise exploration plans, optimizing production processes, and mitigating costs.

4.2.2. Intelligent tools and digital twins

The extensive adoption of smart sensors, automated systems, and robotics across oil and gas exploration, production, and transportation promises substantial enhancements in efficiency and a reduction in the risk of human error. The convergence of these advanced technologies has catalyzed improvements and innovations within the oil and gas industry. Notably, the utilization of digital twin technology enables the testing and validation of diverse production and maintenance strategies through simulation. This is achieved by accurately mapping the physical attributes, operational procedures, and performance metrics of real oil and gas systems into virtual environments.

4.2.3. Cooperation sharing and sustainability

As technological innovation requires huge investments and resources, the oil and gas industry may increasingly incline towards collaboration and data sharing to tackle the challenges presented by intelligence. This collaborative and sharing ethos is poised to expedite technological advancement and enhance the industry's overall competitiveness. Moreover, it aligns with a broader trend steering the industry towards sustainable development, prioritizing environmental friendliness. This collective effort underscores a pivotal step towards achieving a more sustainable and environmentally conscious future for the oil and gas industry.

5. Conclusions

(1) Intelligent technologies are rapidly gaining traction in the global oil and gas sector, emerging as a pivotal driver of industry advancement. Confronted with challenges in exploration and development, these technologies offer novel solutions to enhance efficiency, mitigate costs, and ensure safety and sustainability.

(2) The ongoing innovation of cutting-edge technologies, such as big data and artificial intelligence, furnishes more precise and efficient tools and methodologies for oil and gas exploration and production (E&P). These advancements extend to areas including logging curve analysis, seismic data interpretation, geological modeling, intelligent drilling and completions, production dynamics analysis, and surface engineering within oil and gas fields.

(3) Achieving intelligent oil and gas exploration and development necessitates interdisciplinary collaboration and knowledge sharing across fields. It entails integrating expertise and resources from diverse stakeholders to address challenges posed by intelligent technologies, thereby fostering an efficient, intelligent, and sustainable future for the oil and gas industry.

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