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Artificial intelligence for satellite communications and geophysics: current and future trends

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Abstract: In 2010, Artificial Intelligence (AI) made a breakthrough, and the technology breakthrough in the industry red line became the common expectation of the society. Driven by both market demand and national policies, the AI boom swept through China. Since the 21st century, the information superhighway has rapidly emerged, and communication technology represented by satellite communication has become increasingly important in the country's economic development. In addition, geophysics under earth sciences has also made numerous breakthroughs in theory and practice, bringing a wide range of application value for social development. There are many crossovers between the fields of communication engineering and machine learning. Geoscience has high requirements for complex and changing heterogeneous and multimodal data, and being able to analyze and process big data in combination with artificial intelligence is a direction that many scholars are exploring. This paper introduces the status of applying two technical fields of artificial intelligence in satellite communications and geophysics to explore the impact of computer technology in the research of the two fields and to look forward to the future development trend of the cooperation between the three.

1. Introduction

Human society is experiencing tremendous technological change, namely the fourth industrial revolution (Klaus Schwab, 2016)[11]. Artificial Intelligence (AI) thrives and has many applications in industry, medicine, and finance. (Chinese Institute of Electronics et al., 2020)[5]. Artificial Intelligence technology broadly consists of machine learning, deep learning, natural language processing, mapping knowledge domain, and perception. Among them, machine learning is one of the core technologies of artificial intelligence, using a large amount of data to train models so that the computer can learn and judge. Secondly, as a branch of machine learning, deep learning simulates the brain's neural network through an artificial neural network, which can assist the machine to learn independently.

Communication Engineering was established along with the development of China's communication business and developed from the mutual complementary development of wired electricity, wireless communication, electronic technology, post and telecommunications communication, and other specialties. *Satellite communication* is a technology that utilizes artificial satellites for communication. It can transmit data and information, including voice, video, image, and broadcasting through satellite networks. Satellite communication can realize wide-area coverage and global communication and has the advantages of long transmission distance, fast transmission speed, and high reliability.

Geoscience, refers to all the sciences that study the Earth and is a specialized branch of planetary science whose various disciplines usually study the Earth from the perspectives of physics, geography, geology, meteorology, mathematics, chemistry, and biology. Among them, geophysics is an essential branch of earth science, mainly responsible for studying the Earth's physical properties and physical processes. Specifically, geophysics explores the Earth's surface based on quantitative differences in physical parameters, as well as searching for the Earth's interior, which is rich in mineral resources needed for the progress of human society. The further development of modern geophysics has extended the perspective from the outer layers of the Earth's atmosphere to other planets in outer space.

On the one hand, advances in acquisition and exploration equipment have led to explosive growth in the total amount of geophysical observation data, covering a wide variety of disciplines, and have also put the problems of comprehensive sources of geologic data, large-scale, long-term time scales, and high complexity in front of us as well (Yan Guangsheng et al., 2015; Chen Jianping et al., 2017)[5]. Broad spatial and temporal scales are one of the characteristics of the Earth, and computers have the qualities to process information quickly and accurately to help scientists better understand scientific phenomena. Therefore, using computer science to process various data generated in geophysics can promote the solution of the current challenges faced by geophysicists and further promote the innovation and development of geoscience research. Satellite communication can make use of artificial intelligence algorithms to optimize and improve the process of communication transmission.

On the other hand, AI can be utilized for signal processing, coding, and decoding in satellite communications to improve communication efficiency significantly. In addition, AI can be applied to the adaptive adjustment and optimization of satellite communication systems to automatically adjust and optimize network configurations and resource allocations according to real-time environmental and demand changes to provide more reliable and efficient communication services. Therefore, satellite communication and artificial intelligence can combine and develop to provide people with better communication experiences and services.

To summarize, one of the questions the author has been thinking about is what discoveries the rapidly developing artificial intelligence can bring to satellite communications and geophysics. We have already seen examples of cooperation between the three in real life, such as the Google Earth software that can provide information such as maps, satellite images, and 3D models of the Earth on a global scale. For future research needs and career directions, the author aims to start from the current status of the latest applications of AI in satellite communications and geophysics, analyze their strengths and weaknesses, and develop predictions of future trends in turn. This study is paving the way for more satellite communication, geophysics researchers, students, and teachers to understand and use AI computer technology.

2. Analysis of the Application of Artificial Intelligence Technology in the Field of Geophysics

2.1 Application Status of Artificial Intelligence Technology in the Field of Geophysics

The combination of geophysics and artificial intelligence has been applied to some extent, such as in seismic exploration and electromagnetic data interpretation. These applications have improved the accuracy and reliability of geophysical research and helped to solve some new insights and discoveries that traditional methods could not realize.

2.1.1 Applications of Machine Learning in Geophysics

Growing hardware computing power, intelligently optimized algorithms, and expanding database capacity have combined to make machine learning (ML) a new type of competitiveness in our country. Machine Learning, in short, is the process of allowing computers to perform and optimize human learning behaviors. Machine learning integrates multiple disciplines and shows the latest research results of current computer technology in China.

Through extensive reading of literature and visiting surveys, the author learned that machine learning has been widely used in geophysics. Specific cases include:

(1) Geological disaster monitoring and prediction: Beidou GNSS "sensing, transmission, intelligence, and use" entire business chain geological prediction system, utilizing multi-loop double-backup communication mechanism and intelligent disaster monitoring and warning assessment model based on multidisciplinary intersection, realizing the whole process of monitoring and warning of disasters and emergency rescue (Fan Xiaolei et al., 2020)[2]. Machine learning algorithms can use seismic wave data to detect seismic events and classify and localize them automatically. By analyzing the characteristics of seismic signals, machine learning algorithms can learn how to distinguish seismic pieces from other signals and automatically detect and record seismic events, thus improving the accuracy and efficiency of earthquake monitoring.

(2) Geophysical data analysis: Machine learning algorithms can be used for geophysical data analysis, such as those used in geological exploration, to automatically extract and analyze the features of these data and predict the properties of geological layers, such as rock type, ore content, thus helping geologists to understand better and assess the geology and mineral resources of an area.

(3) Climate change prediction: Machine learning algorithms can be used for climate change prediction. By analyzing past climate data, machine learning algorithms can learn various patterns and trends in climate change and predict future climate change. Such predictions can help decision-makers better understand the impacts of climate change and develop appropriate response strategies.

(4) Groundwater model prediction: Machine learning algorithms can be used for groundwater model prediction. By analyzing groundwater level and quality monitoring data, machine learning algorithms can learn the laws and patterns of its changes and predict future groundwater conditions. Such predictions can help water managers to better plan and manage groundwater resources.

In conclusion, machine learning is an efficient data-driven approach different from the traditional model-driven approach. Based on data-driven, deep learning can be widely used in disaster prediction, data exploration, and environmental monitoring. It has a wide range of applications and can help improve research efficiency, reduce labor costs, and improve the accuracy and precision of predictions.

2.1.2 Application of Deep Learning in the Field of Geophysics

Deep learning originated from generations of scientists' research on artificial neural networks. Deep learning helps humans extract and summarize multiple features of the explored objects, thus saving labor costs and reducing errors. In addition, it is worth mentioning that artificial intelligence can recognize deeper features, which are unmatched and consistent with the higher-order functions of the human brain. However, the human brain cannot guarantee a long period of "deep work." In contrast, artificial intelligence can guarantee this "difficult work, but the human brain cannot guarantee "deep work" for long periods, while AI can guarantee the continuity of such "difficult work." At present, put the perspective back to the geophysical field, deep learning, mainly in seismic exploration and source localization, geomagnetic bathymetry data special processing, and other fields play a prominent role.

(1) Seismic exploration: Deep learning technology can be used for processing and analyzing seismic exploration data. By training deep neural networks, the features of seismic signals can be automatically recognized and extracted, and the properties and distribution of geological layers can be predicted. Such predictions can improve the accuracy and efficiency of exploration for mineral resources such as oil and gas. In addition, deep learning can be combined with traditional geophysical methods, such as seismic waveform analysis and source mechanism solution, to improve seismic exploration's accuracy and reliability.

(2) Deep learning can help geomagnetic data processing, mainly in the following aspects: a. Data pre-processing: geomagnetic data contains a large amount of noise and interference, and deep learning can be used to reduce noise and de-interference processing of the data through automatic learning, to improve the quality and credibility of the data; b. Feature extraction: Geomagnetic data features are relatively complex, making it difficult for traditional methods to feature extraction effectively. Deep learning can use its automatic learning ability to automatically learn and extract the features of the data through the multi-level neural network structure, improving the accuracy and efficiency of feature extraction. c. Model construction: Geomagnetic data processing requires establishing complex models for data analysis and interpretation. Deep learning can use its powerful computing and automatic learning ability to quickly build efficient models and improve data processing and analysis efficiency and accuracy. d. Data classification: Geodetic electromagnetic data contains many types of data, and deep learning can use its classification ability to automatically classify the data and identify the characteristics and distribution of different types of data. e. Data prediction: Geodetic electromagnetic data has a specific predictive value. Deep learning can utilize its ability to automatically predict the trend and distribution of future data by learning historical data, providing a scientific basis for geological exploration and development of mineral resources.

Deep learning (DL), a new data-driven technology, has attracted increasingly more attention in geophysics, with diversified application scenarios. We can use this deep learning-based geophysics practice to explore its future application trend in geophysics.

2.2 Analysis of Advantages and Disadvantages of the Combination of Artificial Intelligence Technology and Geophysics

In addition to the application practices in specific fields discussed above, the author believes that, on the one hand, combining geophysics and artificial intelligence can improve the accuracy and reliability of geophysical research and help solve some new insights and discoveries that traditional methods cannot realize. At the same time, using AI technology can improve efficiency and accuracy, reduce labor costs and risks, and bring convenience and breakthroughs to scientific research and practice in related fields.

On the other hand, although combining geophysics and AI has many benefits, there are also some problems. The domestic scientific and technological innovation capacity in geology must be increased. There needs to be more independent innovation and application of new technologies, methods, and equipment, and the degree of informatization is low (Zhang Runli, 2014) [7]. Furthermore, the application of artificial intelligence requires a large amount of data and computational resources, and the selection and application of algorithms are subject to certain limitations. In addition, the application of artificial intelligence requires professional technicians to develop and maintain, and there is also a certain degree of uncertainty and the rate of misjudgment of manual judgment has been high, which cannot better guide the application of equipment.

In general, combining geophysics and artificial intelligence can improve research efficiency, reduce labor costs, and promote the innovation and development of geoscience research. Nevertheless, some existing problems need to be solved, and their advantages and disadvantages must be clarified to apply better and develop this new research method.

2.3 Prospect Prediction of the Combination of Artificial Intelligence Technology and Geophysics

Artificial intelligence technology has attracted much attention in geoscience, and the high degree of integration with geophysics is also an inevitable choice in line with the trends of the times. Therefore, what aspects of artificial intelligence and geophysics should be further developed to take advantage of the benefits and avoid harm?

First, the author believes we need to expand the application fields under the combination of the two and explore new possibilities. The application of artificial intelligence in geophysics is still relatively limited, but it may be expanded to more fields in the future. Combined with the actual needs of the business in the field of geology, Li Canfeng et al. (2022)[3] believe that the future focus of the development of AI applications can also be in the direction of intelligent mapping, intelligent geophysics, intelligent geochemistry, intelligent deep-searching, intelligent hydrology, intelligent cities, intelligent geologic equipment, and intelligent mine rehabilitation. In addition, many nonlinear optimization techniques developed in artificial intelligence, such as genetic algorithms, simulated degradation algorithms, particle swarm algorithms, and Markov Chain Monte Carlo, should also be incorporated into the research field of geophysical inversion technology more widely.

Second, the theoretical and technological research required for AI techniques in panning to geophysics must break through the bottleneck. With the U.S. Industrial Internet (Evans & Annunziata, 2012), German Industry 4. 0 (Ding et al., 2014)[1], Made in China 2025 and other strategic planning implementation, coupled with the increasing maturity of artificial intelligence, Internet of Things and other technologies, intelligent equipment gradually mature. In addition, it is a pleasant surprise that China Geological Survey (China Geological Survey) in the field of geoscience and technology to carry out the top ten disaster early warning projects has delivered new results - intelligent landslide online monitoring and early warning system, the use of entirely independent technology, can be operated 24 hours a day, for high-precision, high-reliability, ultra-low-power monitoring, and the accuracy has reached 95%. Monitoring and accuracy have reached more than 95%. Zhang Maosheng et al. (2019) [6]proposed a program for constructing a geologic disaster prevention and control system based on artificial intelligence, which provides a theoretical basis for "geologic disaster prevention + artificial intelligence" and more clues and ideas for future scientific research. Therefore, this paper hopes to see faster, more accurate, and more innovative data processing and analysis methods in the future, realizing more real-time and more accurate monitoring, exploration, and early warning, which is of decisive significance for the deeper integration of the two and the broader field of cooperation.

Finally, in the much-anticipated process of AI + geoscience development, the country needs to train more next-generation physical data scientists with scientific strengths in both fields. Rapidly adapting training and education to capitalize on emerging technologies has not traditionally been a strength of academia. Any intelligent software and groundbreaking theories are the result and outcome of expert wisdom, and talent has always been a core competency of the geology industry. As artificial intelligence expands its application in various fields of the geological industry to serve geological work, intelligent software that is supposed to work closely with people cannot keep up with the needs of the times. To realize the synergistic development of man and machine, brainstorm from think tanks and address the obstacles to cooperation between the two fields at the source of technology and to build a nationally unified incubation base for the training of geodata scientists to break down problems such as information barriers and silos so that data can flow more efficiently in all fields, inclusion and sharing will better prepare talents for future cross-field cooperation.

Apparently, these are only possible future trends, and the specific realization still needs to rely on the progress of technology and the actual needs of applications. Combining geophysics and AI has a broad development prospect and can bring more innovation and progress to geoscience research and application. So far, "artificial intelligence + geophysics" seems to be promising.

3. Analysis of the Application of Artificial Intelligence Technology in the Field of Satellite Communication

3.1 The Current Situation of the Application of Artificial Intelligence Technology in the Field of Satellite Communications

In the extensive data communication technology network, the application of artificial intelligence technology is of great practical significance for improving communication management and realizing the efficient circulation and transmission of information (Zhao Weili et al., 2022)[9]. Artificial intelligence technology's application in satellite communication is relatively limited, but there are some related applications. On the one hand, by applying neural networks and deep learning algorithms, AI can improve the signal decoding ability of satellite communication systems. On the other hand, machine learning and intelligent algorithms can also assist satellite communication systems in automatically adjusting and optimizing network configuration and resource allocation according to real-time environmental and demand changes. Meanwhile, AI can be applied to fault diagnosis and intelligent maintenance of satellite communication systems to improve system reliability and maintenance efficiency.

For example, Crosslink Network is an essential issue in satellite communications, which involves establishing reliable communication links between multiple satellites. Traditionally, the configuration of Crosslink Networks has relied on manual intervention and static planning, but this approach is challenged by complexity and inefficiency. By utilizing AI's autonomous learning and adaptive capabilities, satellites can instead adjust their cross-communication network configurations at different moments to suit different communication needs and environmental conditions.

3.2 Analysis of Advantages and Disadvantages of the Combination of Artificial Intelligence Technology and Satellite Communications

The author believes that, on the one hand, AI can continuously optimize the satellite communication system through autonomous learning and adaptive ability to dynamically adjust the configuration of the cross-communication network according to different communication needs and environmental conditions to improve communication reliability and reduce energy consumption. In addition, AI's signal processing capability can improve the data transmission rate and reliability of satellite communication. Further, AI can make quick decisions in a real-time environment to adapt to different satellite communication needs and unexpected events.

Although AI has the characteristic of "intelligence" in nature, it is not an individual because it is only a system or software (Ping Liu, 2021)[4]. Therefore, there are some disadvantages of combining AI technology with satellite communication. The most prominent one is its complexity. Although AI technology is developing rapidly, it is itself one of the most complex sciences currently facing humanity, and the development of AI technology requires a large amount of computational resources and processing power, which may lead to an increase in the hardware and software requirements of the satellite communication system, increasing the cost and complexity of the system. Not only that, in the field of satellite communications, accessing and processing large-scale data may be challenging, especially for distant satellite systems. The application of AI techniques may also face data privacy and security risks, which is unacceptable for satellite communication systems.

In summary, the combination of AI technology and satellite communications brings many advantages and some challenges. Therefore, these factors must be considered comprehensively, fully practiced, and verified when applying AI technology in satellite communication.

3.3 Prospect Prediction of the Combination of Artificial Intelligence Technology and Satellite Communications

With the continuous development of artificial intelligence technology and the continuous improvement of satellite communication technology, the two collaborations will bring significant changes to society.

First, the combination of artificial intelligence technology and satellite communications will accelerate the realization of intelligent global interconnection. Satellite communication systems can provide wide-area coverage and high-capacity transmission capabilities. In contrast, AI technology can provide powerful capabilities for data processing and analysis, thus enabling data to be transmitted and shared faster and more accurately on a global scale, which will help promote the development of scientific research, business activities, medical services, and other fields on a global scale.

Second, the combination of AI technology and satellite communications will accelerate the development of intelligent transportation. With the assistance of satellite communication technology, intelligent transportation systems can connect vehicles, transportation facilities, and traffic management centers in real time to achieve timely transmission of traffic information and mutual coordination. Moreover, artificial intelligence technology can analyze and predict traffic data, optimize traffic flow and vehicle routes, and improve road safety and efficiency.

Further, the combination of AI technology and satellite communications will also promote the development of environmental protection and resource management. Through the monitoring and transmitting satellite sensors and communication systems, environmental data from all corners of the Earth can be obtained in real-time, including information on climate, soil, and water quality, to provide a more accurate and effective decision-making basis for environmental protection and resource management.

In summary, the combination of artificial intelligence technology and satellite communications has excellent potential and prospects and will bring many innovations and developments in the future. Artificial intelligence technology will be more widely used in the 5G era, a long-term development stage requiring gradual advancement (Zhu Yunjun, 2019)[8].

4. Summary and Outlook

Thanks to the technical services and rapid publicity provided by Internet giants such as Google, Microsoft, Baidu, and Alibaba, the fashionable terms of artificial intelligence, machine learning, deep learning, and big data have become closely related to the lives of modern human beings. Driverless cars, machine translation, accurate face recognition, and other artificial intelligence technologies are no longer scenes unique to science fiction movies but have become a tangible part of our real lives. The new technological paradigm and economic activities formed by the deep integration and application of Internet technologies and industrial sectors will significantly improve the modern economy's intelligent decision-making ability, agility, and precision (Peter et al., 2012)[10].

Geophysical exploration, a critical technological area in the traditional energy industry, has also been affected by this new wave of technological revolution, and there has been a shift in the mindset and technological approach of exploration developers. In addition, satellite communications are in a new era of development, moving toward greater efficiency, reliability, and breadth. The new generation of communication satellites has high demands for more extensive, faster data transmission capacity, communication quality, and anti-interference capability, and therefore, there is an urgent need for integration with other emerging technologies. In the era of mobile networks, AI technologies are poised for a full-fledged boom with explosive data growth and geometric increases in computing power. These AI technologies are also penetrating all aspects of satellite communications and geophysical fields at an unprecedented speed, quietly changing people's traditional ideas and concepts of satellite communications and geophysical work.

The author believes the current application of "AI + geophysics" and "AI + satellite communications" is comprehensive and in-depth. In recent years, with the continuous maturation of artificial intelligence technology (represented by machine learning and deep learning), satellite communications and geophysics are no longer alone with the traditional positioning, transmission, and measurement instruments, but rather the use of artificial intelligence technology to reduce human intervention, improve the interpretation of data precision and accuracy, reduce errors, and significantly increase the effectiveness of communication work and exploration tasks. It is certain that "AI + geophysics" and "AI + satellite communications" applied research has been rapidly developing, the field of application is expanding, and some of the results have already had a certain degree of practical ability. At the same time, the author is also well aware of the existence of advantages and disadvantages of everything; artificial intelligence technology is not omnipotent, and the combination of traditional fields and modern technology will not be smooth sailing; there must be times of non-adaptation and conflict, and it takes time to integrate, and the two application research is still faced with a series of challenges, for example, how to flexibly adapt to the complexity and variability of the application scenarios, and how to build a platform for information interoperability, mutual understanding of technology, and close cooperation between scientists.

In conclusion, satellite communication and geophysics will experience a brand new renaissance under the advent of the artificial intelligence era. In the absence of theoretical innovation in satellite communication and geophysics and the obstruction of application practice, artificial intelligence may become a new source of innovation and power. In addition, to meet the development needs and talent cultivation of communication engineering and geoscience, relevant scholars and experts need to take the initiative to adapt to the change, seize the crucial historical opportunity of "AI + geophysics" and "AI + satellite communication," and lead the development of AI technology in the communication and geological fields, providing a rare opportunity for these two areas. China will soon catch up with this trend and promote the rise of the "star chain," injecting new vitality into the sustainable development of resources and the environment for human society.

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