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Research on Innovation Path of Artificial Intelligence Technology Based on Comparative Analysis

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Abstract: Artificial intelligence (AI) technology has been applied extensively in socio-economic development and national defense construction; however, it still requires improvement in terms of flexibility, interpretability, robustness, and security. This study defines AI technology and AI industry, and subsequently compares AI technology with nuclear and photovoltaic technologies according to the aspects of the basic theory, technology development, and market application, with the aim of exploring an effective path for AI development and innovation. The study reveals that the development of AI technology is bound to shift from an involution to an evolution mode, and integrated development provides an optimized path for AI technology innovation in China. In particular, a three-step development route should be adopted, which includes the direct transfer of civilian achievements to military use, military–civilian coordinated innovation, and the promotion of civilian use based on military development. Moreover, new research institutions should be established, financial support should be increased, talent training should be promoted, and ethical research should be conducted to promote the deep integration of AI technology.

Keywords: artificial intelligence; technological innovation path; involution mode; evolution mode; integrated development; comparative analysis

1 Introduction

Artificial intelligence (AI) technology emerged in the 1950s and has developed into one of the most cutting-edge high-tech fields. It is one of the main pillars of the fourth technological revolution and has become an important aspect of the future comprehensive national power contest. The United States, Russia, the European Union, Japan, and other countries and regions globally attach great importance to the development of AI technology, actively formulate relevant strategies and plans, and strengthen technological research and development in this field [1–4].

In recent years, China has launched numerous strategies and policies to strengthen the top-level layout so as to direct AI development, and to support the rapid and healthy development of AI technology. During this process, it is necessary to follow the objective laws of technological development and to seek an AI technology innovation path that is suitable for national conditions. The major current challenges that urgently need to be resolved are the development and innovation model as well as the optimal path of AI technology under the national system in the new era. Furthermore, the exploration of compatible investment policies, talent mechanisms, project management systems, and performance evaluation systems is required.

As AI is a disruptive emerging technology, systematic studies thereon have not been carried out regarding its development rules. To this end, this study uses comparative analysis methods to compare relatively mature nuclear

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energy, photovoltaic technology, and AI technology. These technologies are discussed according to the three aspects of basic theory, technology development, and the technology market application mode. The unique development laws and innovation path of AI technology are established. Furthermore, measures and suggestions are presented to promote the development of AI technology innovation in China.

2 Definition of AI technology and industry

2.1 Definition of AI technology

The Standardization Administration of China defines AI as follows [5]: Theories, methods, technologies, and applications that use digital computers or machines controlled by digital computers to simulate, extend, and expand human intelligence, perceive the environment, acquire knowledge, and use knowledge to obtain the best results.

According to this definition, AI can be understood as allowing machines to imitate human intelligence through specific technical means. Based on the maturity of the imitation ability, AI technology can be divided into different stages, including weak AI, strong AI, and super AI [6]. Weak AI refers to AI that is good at a single aspect and basically operates at the level of intelligence in computing and perception. Strong AI refers to AI that can design plans, solve problems, conduct abstract thinking, understand complex ideas, and perform deep learning; it is similar to human processing in all aspects. Super AI refers to AI that has more processing power than humans in almost every field, such as scientific innovation, general education, and social skills. At present, AI technology is in the weak AI stage [7,8]. To develop AI technology from the weak AI stage to the strong AI stage, major breakthroughs need to be achieved in basic frontiers and core technologies.

The core technologies of AI include the following: machine learning, computer vision, knowledge engineering, natural language processing, speech recognition, computer graphics, multimedia technology, human–computer interaction technology, robotics, database technology, visualization technology, data mining, and information retrieval and recommendation. Benefiting from the progress made by universities, scientific research institutions, and enterprises in the area of AI core technology, AI technology has gradually assimilated the characteristics of intelligence, versatility, efficiency, and globalization; thus, its role in economic and social development will become increasingly important. It should also be noted that certain problems remain in AI core technology, such as insufficient flexibility, weak interpreting ability, and poor robustness, all of which pose a severe challenge to the future development of AI technology.

2.2 Definition of AI industry

Industry is a complex economic system that includes management, technology, personnel, production, market, resources, and information, among other factors [9]. At present, the concept of the AI industry is usually defined in both broad and narrow senses, in which the meanings and manifestations of the related elements differ. From a broad perspective, the AI industry refers to the in-depth and extensive application of AI technology to promote technological integration and business model innovation, promote intelligent product innovation in key areas, and promote intelligent upgrades in key industries, thereby forming an intelligent drive, human–machine collaboration, and the cross-border integration of new industrial development forms. From a narrow perspective, the AI industry refers to the collection of a series of economic activities, such as the research and development, production, and sales of groups, teams, and individuals aimed at AI basic theories, technologies, systems, platforms, and products and services based on AI technology [10]. The research presented in this article is based on the narrow concept of the AI industry.

The AI industry is a structural system. From the perspective of the supply and dependency at each stage of the industry chain, it is divided into the basic, technology, and application layers from top to bottom (Fig. 1). The basic layer mainly provides data or computing power support, such as chips, sensors, and biometrics. The technology layer mainly conducts key technology research and implements related applications, relying on computing platforms and data resources for massive recognition training and machine learning modeling, and developing application technologies for different fields, such as speech and natural language processing, computer vision, machine learning. The application layer is mainly applied in sub-industry scenarios. The core lies in the commercialization of AI technology and the use of AI technology to provide products, services, and solutions [11].

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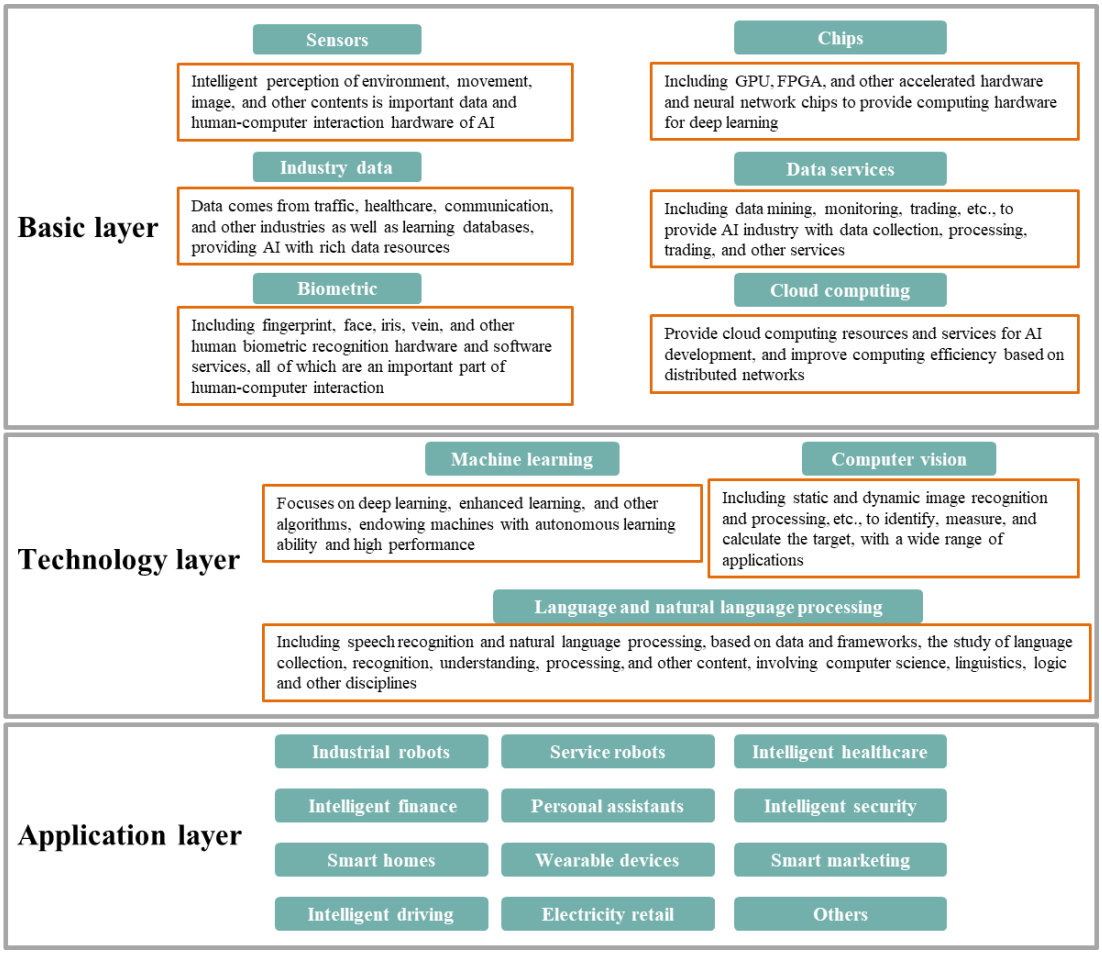

Fig. 1. Industrial structure chart of AI [10].

Note: GPU represents graphics processing unit; FPGA represents field programmable gate array.

2.3 Relationship between AI technology and industry

Emerging industries are formed as a result of the continual developments in cutting-edge technology that undergoes engineering and industrialization, and technological innovation is an important driving force for the development of emerging industries [12,13]. As AI is an important emerging industry, the relationship between the AI industry and AI technology is explained as follows: AI technology plays an important role in promoting the development of the AI industry; the development trend of the AI industry revolves around key AI technologies, thereby propelling the upward and downward directions of the progress, and driving the development of the structural basic and application layers of the AI industry; the overall development of the AI industry is limited by the development and innovation capabilities of AI core technologies, and it is inevitable that the innovation and development of AI key technologies should be promoted.

At present, the overall trend of AI industry development in China still lags behind that of developed countries in Europe and America. The exploration of the development path of AI technology innovation in line with national conditions and the promotion of the rapid development of AI industry through the “technology-promoting industry” model will offer great practical significance and far-reaching strategic value.

3 Preliminary study on development laws of AI technology based on comparative analysis

Technological development generally follows a path that is guided by basic theories and driven by market demand. The strong market demand subsequently promotes the continuous upgrading and optimization of the technology. The analysis of the impact of basic theoretical breakthroughs and market demand generation on technological development is helpful to broaden our knowledge and understanding of the laws of technological development. Owing to the late start of AI technology, this study explores the general laws of AI technology development by comparing it with the more mature and widely used nuclear and photovoltaic technologies, and by

studying their respective development characteristics.

3.1 Nuclear energy technology

3.1.1 Progress in basic research

The basic theories of nuclear energy technology have mainly been obtained by analyzing experimental phenomena and summarizing inferred conclusions based on of the experimental research of scientists. In 1919, the British physicist Rutherford used alpha particles to strike a nitrogen nucleus to obtain protons, thereby achieving the first artificial transformation of the nucleus. In 1939, Nobel Laureate in Physics, Fermi, proposed the chain reaction principle, which laid the theoretical foundation for the peaceful use of atomic energy. Following a long period of research, nuclear energy technology has a solid theoretical foundation at present.

3.1.2 Technology development

Firmly founded on basic theories, the development of nuclear energy technology is strongly driven by the needs of national defense and military. It has gradually acquired complete technical capabilities and is regarded as a mature technology field. The “Manhattan Project,” initiated by the United States in 1940, is a classic model of nuclear energy technology research. Since then, the United States, the Soviet Union, the United Kingdom, and France have successfully exploded atomic bombs. China successfully exploded its first atomic bomb and hydrogen bomb in 1964 and 1967, respectively.

3.1.3 Technology market applications

Nuclear energy technology was initially designated for use in the field of defense and military applications. For example, in 1933, the Hungarian physicist Zillard published a related treatise, which proposed that nuclear energy development can be used in the field of defense and military. After the end of World War II, scientists quickly focused nuclear energy on peaceful applications based on the solid research foundation of nuclear energy technology. For example, the world’s first 5 MW experimental graphite boiling water reactor (Obninsk Nuclear Power Plant), which was constructed by the Soviet Union in 1954, is an important symbol of the application of nuclear energy technology in the civilian market.

In summary, the basic theoretical research of nuclear energy technology is sufficient, the technical research is solid, and the demand for national defense and military applications is the starting point for driving the vigorous development of civilian demands in the field, which is a typical example of high-tech development in the 20th century.

3.2 Photovoltaic technology

3.2.1 Progress in basic research

The photovoltaic effect, which was discovered during an experiment by the French scientist Becquerel in 1839, is the operating principle of the solar cell. The discovery of this principle has promoted research on photovoltaic technology and the development of the industry. With the expansion of theoretical research, scientists have discovered that numerous materials experience photovoltaic effects. For example, Adam and Day studied the photovoltaic effect of selenium in 1877. In 1904, Hallwachs discovered that the combination of copper and cuprous oxide had photosensitivity. In 1932, Audobert and Stora discovered that cadmium sulfide exhibited a photovoltaic phenomenon. Subsequently, in 1941, Orr discovered the photovoltaic effect of silicon.

3.2.2 Technology development

Following the development of photovoltaic technology, common solar cells include the silicon solar cell, III-V solar cell, copper indium gallium selenium solar cell, cadmium telluride solar cell, organic solar cell, and dye-sensitized solar cell. In recent years, with the continuous research and development of new materials, photovoltaic technology research has exhibited a diversified trend and an increasing number of new battery materials have been discovered (such as perovskite and graphene). However, the technical research on new solar cells has also faced several challenges. For example, compared to many new types of solar cells, although perovskite solar cells offer the advantages of low cost and high efficiency, they exhibit disadvantages in the substitution of toxic metals, long-term battery stability, and large-area solar cell preparation technology, which may eventually pose a challenge to product commercialization [14,15]. Therefore, although photovoltaic technology has a strong theoretical foundation, deficiencies remain in the development and preparation of advanced materials, the technical research is lacking, and the research levels of different technical directions are unbalanced.

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3.2.3 Technology market applications

The market application model of photovoltaic technology is similar to that of nuclear energy technology. It began with military demand and subsequently drove the development of civilian demand. In 1958, the first United States satellite powered by solar cells, Pioneer One, was launched into orbit, thereby marking the early application of photovoltaic technology in the military market. In 1962, Telstar, which was a commercial communications satellite equipped with 14 W solar cells, was also launched into orbit, thereby marking the beginning of the application of solar cells in the civilian market.

In summary, similar to nuclear energy technology, the basic theoretical research of photovoltaic technology is sufficient. Furthermore, its application in the technology market also started in the field of national defense and military, following which it began to drive the development of civilian demand. Limited by the research level of new materials, the research level of each sub-direction of photovoltaic technology is unbalanced.

3.3 AI technology

3.3.1 Progress in basic research

Unlike nuclear energy and photovoltaic technology, AI technology did not have a complete basic theoretical foundation in the early stage of its development. In 1936, the British scientist Alan Turing created the theory of automata, which can be regarded as the origin of the AI concept. In 1956, John McKinsey, Minsky, Rochester, and Shannon first proposed a definition of AI technology. Throughout the development of AI technology, far more methodological research than basic theoretical research has been conducted in the application of AI in certain fields. The basic theories of AI were considered as “ideas” and “concepts,” and did not provide sufficient explanations of basic principles [8,16], but rather paid more attention to methodological research in certain specific fields. The basic theoretical research is weak, leaving many fields in need of further exploration. The general consensus is that the basic theory of AI technology exhibits certain deficiencies and inadequacies, and has not yet reached the research level of nuclear energy or photovoltaic technology.

3.3.2 Technology development

The development of AI technology is also very different from nuclear energy and photovoltaic technology. AI technology remains in the weak AI stage. Although it has been applied in many fields, it is limited by the lack of existing technology, thereby reducing the reliability of the technology. It has not been used extensively in “high-precision” fields such as national defense. AI technology has been widely applied in conventional civilian fields and the update iteration speed is very fast. At present, the situation of AI technology is one in which the conventional technology is quite advanced, but the high-end technology remains underdeveloped.

3.3.3 Technology market applications

The development of AI technology application has experienced three waves [6], and representative nodes and applications have been produced in the civilian market. For example, the Webot 1 robot developed by Japan in 1973 was the first humanoid robot to run on intelligent software that could play music; the Webot 2 robot developed by Japan in 1980 could communicate with people, read sheet music, and play an electronic keyboard. The Deep Blue developed by IBM in 1997 defeated the chess champion, and in 2006, the French Aldebaran Robotics Company developed the intelligent robot Nao. From the perspective of demand, given the particularity of demand scenarios in the defense field, such as less data, uncertain boundaries, complex environments, and high real-time response, several problems remain in the application of AI technology in that field. Overall, the market application of AI technology differs from those of nuclear energy and photovoltaic technology and is still dominated by civilian needs. Limited by the level of technology, the application of AI technology in the civilian field will be more extensive than that in the military field for a long time in the future.

3.4 Conclusions of comparative analysis

According to the comparison with nuclear energy and photovoltaic technology in terms of the basic theoretical research, technology development, and technology application market (Table 1), it is evident that AI technology exhibits the following laws of development:

(1) AI technology is relatively lacking in terms of basic theoretical research [16]; therefore, it is very important to lay a solid foundation for theoretical research as soon as possible to promote the mature development of AI technology in the future. Innovation is at the core of information technology development, and the rapid and continuous innovation of AI technology is the only solution for its development.

(2) As with nuclear energy and photovoltaic technology, AI technology also offers the potential for applications in both the military and civilian markets. The coordinated development of the military and civilian markets is an inevitable method for future development. Owing to the limitations of the insufficient development of high-end AI technology, and significantly different demands for AI technology between the military and civilian markets, the unique and innovative development path of AI technology in the application of the military and civilian markets is the key development direction for AI technology.

Table 1. Comparison of nuclear energy, photovoltaic, and AI technology research.

Category	Nuclear technology	Photovoltaic technology	AI technology
Basic theoretical research	Adequate	Adequate	Inadequate
Technological development	Solid	Irregularities between different technologies	The conventional technology is good, but the development of high-end technology remains inadequate
Technology application market	The large scale of the military market is the starting point of technology application. The application of technology in the civil market has been mobilized and developed on a large scale	The large scale of the military market is the starting point of technology application. The application of technology in the civil market has been mobilized and developed on a large scale	The large scale of the civil market is the starting point of technology application. The military market has great demands, but the application of technology has not yet been mobilized

4 Path of AI technology innovation

4.1 "Evolutionary" development is inevitable for the development of AI technology

Owing to the insufficient development of basic theories, the current AI development remains at the weak AI stage; although there exists a huge civilian market and a large military market demand, practical application of AI technology in the military fields is rare; therefore, a unique innovation path must be adopted for the development of AI technology in China. To this end, the concepts of "involution" and "evolutionary" development are adopted for discussion in this article. Involution development refers to a method for increasing the total output by investing a large amount of existing technology in a limited field [17]. Involution development is generally represented by the duplication, extension, and refined development of technology, but there exists the dilemma of limited efficiency improvement in the development process. Evolutionary development places emphasis on the technology development and the achievement of developmental breakthroughs, and results in new social benefits through expanding the application fields.

AI technology is currently following the involution development model, in which conventional technology is quite advanced, high-end technology remains underdeveloped, and the technological value and influence have not been adequately demonstrated. Certain AI technologies (such as language recognition and image recognition) have been used extensively in the fields of social media, translation, security, and medical treatment, but the low robustness and interpretability have not been improved, and the application scenarios are constrained. This phenomenon relates to the difficulty of making breakthroughs in the technology itself. Moreover, owing to the huge scale of the domestic civilian market, the use of only weak AI in certain specific markets and market segments can benefit technology owners significantly, thereby resulting in a lack of motivation for in-depth research on AI technology. The high returns of involution development are short lived and the subsequent market competition will weaken the returns [18]. AI technology can only maintain its strong technical vitality by strengthening innovation and creativity, and adopting an evolutionary technology development model that focuses on non-specific markets and "non-comfort zone" market applications.

4.2 Integrated development promotes the evolutionary development of AI technology

New external environmental drivers are required to promote the development of AI technology to move beyond its "comfort zone" for transformation from an involution to an evolutionary development model. Compared to the civilian demands, the military demands for AI technology are more high precision and sophisticated, and the market characteristics differ significantly. To achieve a breakthrough in the field of strong AI and super AI, it is impossible to rely solely on civilian market demands; thus, the industry must be developed according to military demands. Military scenario applications require AI technology to exhibit features that work in environments with

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battlefield characteristics, such as boundary uncertainty, strong antagonism in games, effective real-time response, high environmental complexity, and information incompleteness. The corresponding equipment should meet the demands of reliability, maintainability, testability, security, and environmental adaptability, which forms the development pathway for advancing AI from weak AI to strong AI, and subsequently super AI. It can be considered that the realization of the integrated development of AI technology based on military needs has become the preferred means for overcoming the difficulties of AI technology innovation and ensuring innovation vitality.

Furthermore, it should be noted that the development model of AI technology for the military and civilian markets differs from that of nuclear energy and photovoltaic technology. The marketing model of nuclear energy and photovoltaic technology serves the national defense and military field first, and then drives the application in the civilian market. The technical barriers to transfer from the military market to the civilian market are relatively low, and it is easier to cross the military–civilian industry boundary and to realize the evolutionary development of technology in the military–civilian field. Owing to the notable differences in the military and civilian market demands, AI technology faces a greater obstacle in transforming back and forth between military and civilian needs. The evolutionary development of AI technology can be achieved by strengthening the traction of military demands and crossing the military–civilian industry boundary.

Based on national conditions, a three-step route can be adopted to achieve the integration and development of AI technology. First, the civilian technological achievements are matched with the demand application scenarios of the special needs of the military market to realize the direct conversion of civilian achievements into military applications. For example, the civilian market of smart security technology is relatively mature, but military scenarios have not yet been thoroughly developed. Through this transformation, not only can the application scope of the technology be expanded, but the maturity and reliability of conventional weak AI technology can also be initially tested, and the deficiencies of the technology can be determined rapidly. In the second step, emerging AI technologies, such as intelligent security technologies, can achieve breakthroughs in military–civilian collaborative innovation and joint research, thereby promoting the emergence of general-purpose AI technologies with strong AI characteristics and dual-use attributes. The third step is to address the high demand for military use. The military will also guarantee necessary investments for special needs, conduct high-end technology research that is difficult to carry out or faces resistance in the civilian field, and promote the development and commercialization of super AI technology. It will also transfer research results to the civilian field in stages and explore the formation of “military traction for civilian use”; for example, bio-intelligence and intelligent micro-systems are possible directions for technological application.

5 Countermeasures and suggestions

5.1 Top-level layout and construction of new-type R&D institutions

It is recommended that the State Council and Central Military Commission jointly guide and support the construction of a new type of R&D institution with leadership and resource deployment capabilities in the civilian and military fields. In view of the diversification of AI technology and the characteristics of “group intelligence,” and based on the principles of high efficiency and pragmatism, the project operation mode of “top-level coordination, military–civilian coordination, individual focus, and teamwork” should be adopted, so that the basic theoretical research of AI can be explored freely and a highly qualified team can conduct centralized research on the high-end technology. The military and civilian market needs should also be effectively coordinated, so that the operation of new R&D institutions will conform to the basic characteristics and development laws of AI technology innovation.

5.2 Broadening channels and increasing resource protection

The integration and development of AI technology requires stable funding support channels. It is recommended that the “research funding + market benefit” driving model be adopted. When civilian achievements are transformed into military use, a major national science and technology project should be established to guarantee resources through scientific research funding. In the stage of military–civilian collaborative innovation and military traction for civilian use, when relevant research results are transformed into the civilian field, state-owned or private enterprises may be introduced into the industry, with a special cultivation fund for civil products providing directional support.

5.3 Attaching importance to talents and promoting the construction of an integrated talent team

At present, the leading figures and teams in the AI field are concentrated in well-known research institutes and key enterprises locally and globally, but the integrated development of AI technology requires the construction of a multi-source integrated talent team to focus on scientific research more thoroughly. The construction of this talent team needs to rely on relevant scientific research institutions. During the early stage, the "dual-employment system" model can be used to introduce advanced talents and teams to clarify the rights and obligations of personnel. Once the team building gradually matures, a targeted training mechanism can be introduced to cultivate core teams and leading figures. Thus, the deadlock in the introduction of existing talents can be broken. Moreover, to achieve "equal pay for equal work," military and local talents can be attracted to tackle key problems jointly, and full play can be given to their respective advantages to achieve strong military–civilian collaborative innovation. During the process of building a talented team, an evaluation mechanism that reflects differentiation should be established simultaneously.

5.4 Collaborative development and conducting ethical research

The research on the ethics of AI technology in civilian scenarios has been developed. However, as the application of military scenarios started later than civilian use, several deficiencies remain in the current research on the ethics of military scenarios. Thus, attention should be focused on the coordinated development of ethical norms in the application of AI technology in the military and civilian markets. Furthermore, research should be conducted on military-specific ethical norms, such as responsibility ownership, deterrence, and destructive trade-offs, based on the existing research results of ethical norms.

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