

Analysis of Key Technologies of Intelligent Robots

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Abstract—With the rapid development of science and technology, intelligent robots have become an important part of the global strategic emerging industries. This paper mainly explores the key technologies of intelligent robots, analyzes the development status of intelligent robots, discusses the key technologies of intelligent robots such as perception, decision-making, control, and human-computer interaction, and puts forward suggestions for the development of intelligent robot technology.

Keywords—Intelligent robots, key technologies, perceive, decision-making, control, interactive.

I. INTRODUCTION

With the rapid development of information technology, artificial intelligence has penetrated into all fields of society, and intelligent robots, as the master of artificial intelligence technology, are gradually becoming an important direction of a new generation of technological innovation. Intelligent robots can autonomously complete tasks in an uncertain environment and have a wide range of application prospects, such as industrial manufacturing, medical services, home services, disaster relief, etc. [1]-[11]. Globally, many countries and regions regard the intelligent robot industry as a national strategy and invest a lot of resources in R&D and promotion.

Scholars at home and abroad have conducted a lot of research on intelligent robot technology, including key technologies such as robot perception, decision-making, control and human-computer interaction, as well as the European Union's robot research and development program, as well as the development of intelligent robots in specific application fields, such as industrial robots, service robots and special robots. In terms of perception technology, researchers have explored a variety of sensor fusion technologies to improve the perception ability of robots in complex environments. In terms of decision-making technology, methods based on deep learning and reinforcement learning are widely used in robot path planning and task execution. In terms of control technology, theories such as adaptive control and robust control are used to improve the accuracy and stability of the robot's motion. In terms of human-computer interaction, researchers have focused on how to make robots better understand and respond to human intentions.

Despite the remarkable progress made in intelligent robotics, there are still many challenges in practical applications. For example, the perception ability of robots in complex environments is insufficient, the intelligence of the decision-making system is not high, the stability and accuracy of the control system need to be improved, and the naturalness and intelligence of human-computer interaction need to be improved. The existence of these problems limits the performance and user experience of intelligent robots in practical applications. Therefore, an in-depth exploration of the key technologies of intelligent robots can not only reveal the shortcomings of existing technologies, but also provide

theoretical basis and practical guidance for future technological breakthroughs.

Through the systematic analysis of the key technologies of intelligent robots, this paper is helpful to improve the theoretical system of intelligent robot technology and provide theoretical support for the research in related fields. In addition, it can provide technical reference for the design, development and optimization of intelligent robots, and promote the application of intelligent robot technology in various fields. Exploring the key technologies of intelligent robots will help enhance the independent innovation ability of the intelligent robot industry, promote industrial transformation and upgrading, and enhance international competitiveness. In summary, the research in this paper has important theoretical and practical value for promoting the development and application of intelligent robot technology.

II. DEVELOPMENT STATUS

As a hot spot in the field of science and technology, the development of intelligent robots has received extensive attention from countries around the world.

The United States started research in the field of intelligent robots earlier and has the world's leading technical level. The U.S. government has invested heavily in research on intelligent robots, especially in the military, space exploration, and other fields. The development of intelligent robot technology in the United States presents the following characteristics: (1) attaches great importance to the combination of artificial intelligence and robots, and promotes the continuous improvement of the intelligent level of robots. (2) It has significant advantages in robot operating systems and open source platforms, such as ROS (Robot Operating System). (3) Actively promote the application of intelligent robots in civilian fields such as medical care, education, and home services.

Japan is an important birthplace of robot technology, and its intelligent robot technology development has the following characteristics: (1) The world leader in the field of industrial robots, and intelligent automated production lines are widely used. (2) There is in-depth research in humanoid robots and service robots, such as Honda's ASIMO and SoftBank's Pepper. (3) Focusing on the combination of robots and an

aging society, we have developed many service robots suitable for the elderly.

Europe is also very active in intelligent robotics research, especially in countries such as Germany, the United Kingdom, and France. The characteristics of the development of intelligent robot technology in Europe include: (1) emphasizing the collaboration between robots and humans, such as KUKA in Germany and ABB in Switzerland have made remarkable achievements in collaborative robots. (2) Prospective research on robot ethics and legal norms has been conducted. (3) Through EU framework programmes, such as Horizon 2020, a number of cross-border robotics research projects have been funded.

The development status of intelligent robots in China is as follows: (1) Policy support: In recent years, the Chinese government attaches great importance to the development of the intelligent robot industry and has issued a series of policy support documents to provide a good policy environment for the development of the intelligent robot industry. (2) Technological research and breakthroughs: China has made a series of important progress in intelligent robot technology. For example, in terms of perception technology, the visual and auditory sensors developed by the company are close to the international advanced level in terms of performance. In terms of control technology, the accuracy and stability of industrial robots are constantly improving, and the market share is increasing year by year. In terms of human-computer interaction, companies such as iFLYTEK have made remarkable achievements in speech recognition and natural language processing technology. (3) Industrial application: China's intelligent robots have been widely used in industry, medical care, home services and other fields, especially in the industrial field, and have become the world's largest industrial robot market.

To sum up, intelligent robot technology has developed rapidly around the world, but it is still necessary to continue to increase research and development efforts to promote industrial technological innovation.

III. KEY TECHNOLOGIES

The key technologies of intelligent robots are the basis for their autonomous perception, decision-making, action and interaction. The following is a detailed exploration of the key technologies of intelligent robots.

A. Perception Technology

Perception technology is the ability of intelligent robots to obtain information about the external environment, and is the basis of intelligent behavior of robots. It mainly includes the following aspects:

(1) Visual perception: Visual perception technology simulates the human visual system through cameras and other devices to realize the recognition of the environment and the tracking of objects. Key technologies include image recognition, object detection, scene understanding, and more. For example, the application of deep learning technology in visual perception enables intelligent robots to identify and classify objects more accurately.

(2) Auditory perception: Auditory perception technology

captures sound signals through microphones and other devices for sound recognition and speech understanding. Key technologies include noise suppression, echo cancellation, speech recognition, and more. Intelligent robots use auditory perception technology to receive and execute voice commands.

(3) Tactile perception: Tactile sensing technology simulates human touch through tactile sensors to perceive the shape, hardness and other properties of objects. Key technologies include force perception, slip perception, temperature perception, etc. Haptic perception technology enables intelligent robots to get more nuanced feedback when manipulating objects.

B. Decision-Making Technology

Decision-making technology is the ability of intelligent robots to make logical reasoning and decision-making based on perceived information. It mainly includes the following aspects:

(1) Task Planning: Task planning techniques involve how to develop action strategies based on a given task. Key technologies include rule-based inference, model-based programming, heuristic search, and more. Intelligent robots determine the sequence and manner of performing tasks through task planning.

(2) Path planning: Path planning technology is the optimal path for intelligent robots to plan from the starting point to the target point during the movement process. Key technologies include A* algorithm, Dijkstra algorithm, RRT (Rapidly-exploring Random Trees), etc. Path planning ensures that the robot reaches its destination efficiently and safely.

(3) Task allocation: In a multi-robot system, task assignment technology is the key. It involves how to rationally distribute tasks to different robots for efficient collaboration. Key technologies include market mechanisms, auction algorithms, distributed planning, etc.

C. Control Technology

Control technology is the core of intelligent robots to achieve precise movement and operation. It mainly includes the following aspects:

(1) Position control: Position control technology ensures that the intelligent robot can accurately reach the predetermined position in space. Key technologies include PID control, fuzzy control, adaptive control, etc.

(2) Speed control: Speed control technology regulates the movement speed of the intelligent robot to maintain a stable motion state in different environments. Key technologies include speed feedback, acceleration control, and more.

(3) Force control: Force control technology enables intelligent robots to control the magnitude and direction of force when interacting with objects. Key technologies include torque control, impedance control, force/position hybrid control, and more.

D. Human-Computer Interaction Technology

Human-computer interaction technology is the ability to effectively communicate between intelligent robots and users. It mainly includes the following aspects:

(1) Voice interaction: Voice interaction technology realizes natural language communication between humans and robots through speech recognition and speech synthesis. Key technologies include speech recognition, natural language understanding, speech synthesis, and more.

(2) Visual interaction: Visual interaction technology achieves a richer interactive experience by analyzing non-verbal information such as facial expressions and body movements of users. Key technologies include expression recognition, gesture recognition, etc.

(3) Haptic interaction: Haptic interaction technology provides tactile perception through haptic feedback devices, enhancing the naturalness and intuitiveness of interaction. Key technologies include haptic displays, force feedback, and more.

Through the exploration of the above key technologies, we can see that the development of intelligent robots is the result of multidisciplinary integration, and each key technology field has its own unique challenges and opportunities. Future research needs to be deepened in these fields to promote the progress and application of intelligent robotics.

IV. UNRESOLVED ISSUES

Although intelligent robot technology has made remarkable progress, there are still some unsolved problems and challenges in the process of practical application and development, which limit the performance and application scope of intelligent robots.

A. Environmental Adaptability

The adaptability of intelligent robots in complex and changeable environments is still insufficient. Especially in unstructured environments, robots' perception and decision-making capabilities are limited, making it difficult to deal with unknown situations or unexpected events. For example, robots' ability to understand complex scenarios, handle multi-target tracking, and perceive extreme weather conditions still needs to be improved.

B. Perceptual Accuracy and Reliability

At present, the perception system of intelligent robots still needs to be improved in terms of accuracy and reliability. The visual perception system performs poorly in light changes, occlusions, and dynamic scenes, and the recognition rate of auditory perception in noisy environments is not high, and the resolution and sensitivity of tactile perception are insufficient. The existence of these problems affects the robot's accurate understanding and response to the environment.

C. Decision-Making Complexity and Real-Time

When intelligent robots face complex tasks, the complexity and computation of their decision-making systems increase exponentially, resulting in a decrease in decision-making speed and difficulty in meeting real-time requirements. In addition, robots lack effective decision-making strategies when dealing with uncertainty information and multi-objective optimization problems.

D. Stability and Flexibility of the Control System

The control system of intelligent robots lacks stability and flexibility in the face of model uncertainty and external interference. Especially in high-speed motion and precise operation tasks, how to achieve smooth and stable control is still a difficult point in research.

E. The Naturalness and Intelligence of Human-Computer Interaction

Despite significant advances in human-computer interaction technology, the interaction of intelligent robots still appears stiff and unintelligent compared to the level of natural human interaction. For example, bots have limitations in understanding complex language structures, non-verbal behaviors, and emotional expressions.

F. Security and Privacy Protection

When intelligent robots collect and use personal information, how to ensure the security and privacy protection of user data is an urgent problem to be solved. In addition, robots can cause harm to humans during operation, and how to design a safe and reliable interaction mechanism is another challenge.

G. Cost and Energy Efficiency

The manufacturing cost and operating energy consumption of intelligent robots are high, which limits their wide application in some fields. How to reduce costs and improve energy efficiency, so as to make intelligent robots more economical and practical, is an important direction of future research.

In conclusion, the development of intelligent robotics still faces many challenges, and these unsolved problems require interdisciplinary cooperation, technological innovation and long-term research investment to gradually overcome

V. CHALLENGES

In the development of intelligent robotics, in addition to the above-mentioned unsolved problems, there are also a series of challenges, which involve multiple levels such as technology, market, ethics and law.

A. Technology Integration and Innovation

The development of intelligent robot technology requires the deep integration and innovation of multidisciplinary technology. Here are some specific challenges:

- (1) Interdisciplinary integration: how to effectively integrate technologies in the fields of mechanical engineering, electronic engineering, computer science, materials science, etc., to achieve the overall performance improvement of intelligent robots.
- (2) Technological innovation: how to achieve technological breakthroughs in perception, decision-making, control and human-computer interaction to promote the development of intelligent robots to a higher level.

B. Limitations of Artificial Intelligence

Although artificial intelligence technology plays a central role in intelligent robots, it still has its own limitations:

- (1) Algorithm generalization ability: how to improve the generalization ability of algorithms, so that intelligent robots can better cope with unknown environments and tasks.
- (2) Learning efficiency: How to improve the learning efficiency of machine learning algorithms and reduce the dependence on a large amount of annotated data.

C. Ethical and Moral Issues

The widespread application of intelligent robots raises a series of ethical and moral issues:

- (1) Autonomy: As robots become more autonomous, how to ensure that they make ethical decisions without human intervention.
- (2) Attribution of responsibility: When an intelligent robot causes an accident, how to define the attribution of responsibility, whether it is the manufacturer, developer or user.

D. Laws and Regulations

The development and application of intelligent robots need corresponding laws, regulations and industry standards to regulate:

- (1) Legislation: How to formulate and improve laws and regulations related to intelligent robots to ensure technological development and protect the public interest.
- (2) Industry standards: how to establish unified technical standards and safety specifications to promote the healthy development of the intelligent robot industry.

E. Market Acceptance and Talent Training

The marketing and talent training of intelligent robots are also challenges:

- (1) Market acceptance: how to improve the public's acceptance and trust in intelligent robots, and promote their wide application in various fields.
- (2) Talent training: how to cultivate interdisciplinary high-end talents to meet the needs of the rapid development of the intelligent robot industry.

These challenges require not only technological breakthroughs, but also policy support, social awareness, and talent training. Only by overcoming these challenges can intelligent robotics better serve human society.

VI. COUNTERMEASURES AND SUGGESTIONS

In view of the challenges and unsolved problems in the development of intelligent robot technology, this paper puts forward the following countermeasures and suggestions, aiming to provide reference for the continuous progress and industrial application of intelligent robot technology.

A. Strengthen Interdisciplinary Research and Cooperation

In order to promote the development of intelligent robotics, the cross-integration of mechanical engineering, electronic engineering, computer science, materials science and other disciplines should be strengthened to promote interdisciplinary research and cooperation.

- (1) Establish an interdisciplinary research platform to encourage experts from different fields to participate in intelligent robotics projects.
- (2) Establish a dedicated fund to support interdisciplinary research projects.

B. Promote Technological Innovation and Transformation

For the key technologies of intelligent robots, research and development efforts should be increased, technological innovation should be promoted, and research results should be transformed into practical applications.

- (3) Encourage enterprises and research institutions to invest resources in core technology research and development, especially in the fields of perception, decision-making, control and human-computer interaction.
- (4) Establish a technology transfer mechanism to shorten the distance between laboratory research results and market applications.

C. Formulate and Improve Laws and Regulations

In order to standardize the development of the intelligent robot industry, relevant laws and regulations should be formulated and improved.

- (1) Accelerate the legislative process to clarify the responsibilities, ethical standards and usage norms of intelligent robots.
- (2) Establish a certification and testing system for intelligent robots to ensure product quality and safety.

D. Establish Industry Standards and Safety Specifications

In order to promote the healthy development of the intelligent robot industry, unified technical standards and safety specifications should be established.

- (1) Led by industry associations, jointly developed by enterprises and research institutions.
- (2) Regularly update standards to meet the needs of technological developments.

E. Strengthen Personnel Training and Exchanges

The development of intelligent robot technology requires a large number of professionals, and personnel training and exchanges should be strengthened.

- (1) Set up courses related to intelligent robots in higher education to train professionals.
- (2) Carry out international exchanges and cooperation, attract outstanding overseas talents, and improve the level of domestic research.

F. Improve Market Acceptance and Public Awareness

In order to promote the application of intelligent robots, market acceptance and public awareness should be improved.

- (1) Strengthen science popularization and increase public understanding and trust in intelligent robot technology.
- (2) Demonstrate the application value of intelligent robots in various fields through practical cases to enhance public acceptance.

G. Promote the Coordinated Development of the Industrial Chain

The development of the intelligent robot industry requires the coordination of the entire industrial chain.

- (1) Encourage upstream and downstream enterprises to strengthen cooperation and form a benign interaction in the industrial chain.
- (2) Support small and medium-sized enterprises to give full play to their expertise in the intelligent robot industry chain and promote the diversification of the industrial ecology.

Through the implementation of the above countermeasures and suggestions, we can effectively promote the development of intelligent robot technology, promote its wide application in all walks of life, and contribute to the prosperity of China's intelligent robot industry.

VII. TRENDS

As an important direction of future science and technology, the development trend of intelligent robot technology will have a profound impact on all walks of life. The following is an outlook and analysis of the future development of intelligent robotics.

A. Intelligent Perception Technology

With the continuous progress of artificial intelligence technology, the perception technology of intelligent robots will be more intelligent. Future trends include:

- (1) Multimodal perception fusion: Intelligent robots will be able to use multiple perception methods such as vision, hearing, and touch at the same time to achieve a comprehensive understanding of the external environment.
- (2) Deep learning and reinforcement learning: Through deep learning and reinforcement learning technologies, intelligent robots will be able to process complex environmental information more effectively and improve the accuracy of identification and decision-making.

B. Adaptation of Decision-Making and Control

The decision-making and control technology of intelligent robots will develop in the direction of adaptation, including:

- (1) Adaptive decision-making: Robots will be able to make adaptive decisions quickly in uncertain and dynamic environments.
- (2) Autonomous navigation and obstacle avoidance: Intelligent robots will have more advanced navigation and obstacle avoidance capabilities, and will be able to autonomously plan paths in complex environments.

C. Naturalization of Human-Computer Interaction

The development of human-computer interaction technology will pay more attention to naturalness and intuitiveness, and the following are some key trends:

- (1) Natural language processing: Intelligent bots will be able to understand and generate language more naturally, enabling fluent conversational interactions.
- (2) Expression and emotion recognition: Robots will be able to recognize and understand human facial expressions and emotional states, providing a more personalized interactive experience.

D. Diversification of Application Fields

The application fields of intelligent robots will continue to expand, covering more industries and scenarios:

- (1) Service industry: Intelligent robots will play a more important role in catering, retail, healthcare and other fields.
- (2) Industrial manufacturing: With the development of intelligent manufacturing, intelligent robots will play a greater role in the automation of production lines.
- (3) Home services: Home service robots will become more ubiquitous and help people with daily household chores and caregiving tasks.

E. Integration of Technology and Ethics

With the development of intelligent robot technology, ethical issues will receive more and more attention:

- (1) Ethics: The design and application of intelligent robots will pay more attention to ethical norms to ensure the sustainable development of technology.
- (2) Transparency and explainability: Improve the transparency and explainability of the decision-making process of intelligent robots and enhance public trust.

F. Networking and Cloudification

Intelligent robots will be more dependent on network and cloud computing technology:

- (1) Cloud robots: Through cloud computing, intelligent robots will be able to share data and computing resources and increase processing power.
- (2) IoT integration: Intelligent robots will be seamlessly integrated with IoT devices for more efficient data exchange and collaborative work.

Overall, the trend of intelligent robotics shows that the robots of the future will be more intelligent, adaptive, interact naturally, and play an important role in more fields. At the same time, the development of technology will also be accompanied by the resolution of ethical, legal and social issues.

VIII. CONCLUSION

Through an in-depth exploration of the key technologies of intelligent robots, this paper analyzes the development status of intelligent robots in perception, decision-making, control and human-computer interaction, reveals the challenges and unsolved problems in their practical application, and puts forward corresponding development countermeasures and suggestions. On this basis, the following conclusions are drawn:

- (1) Intelligent robot technology is an important direction for the development of science and technology in the future, and it has great potential to improve production efficiency, improve quality of life, and promote social progress.
- (2) Perception technology, decision-making technology, control technology and human-computer interaction technology are the four key technologies of intelligent robots, and the development level of these technologies directly determines the degree of intelligence and application scope of intelligent robots.
- (3) Despite the remarkable progress made in intelligent robotics, there are still many challenges and limitations in

terms of environmental adaptability, autonomous learning, safety, cost, and energy efficiency.

(4) In order to promote the sustainable development of intelligent robot technology, it is necessary to strengthen interdisciplinary research and cooperation, promote technological innovation and transformation, improve market acceptance and talent training, and promote the coordinated development of the industrial chain.

(5) The development trend of intelligent robot technology shows that future robots will be more intelligent, adaptive, and naturally interactive, and will be widely used in more fields. At the same time, the development of technology will also be accompanied by the resolution of ethical, legal and social issues.

To sum up, the development of intelligent robot technology is not only a breakthrough at the technical level, but also a profound change to the way of life of human beings. Researchers should seize this historical opportunity, increase R&D investment, cultivate high-end talents, promote the intelligent robot industry to the high end of the value chain, and contribute to social development.

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