Research On the Development of Bionic Robots Through Human-Machine Interaction

Ruoheng Liu

Hefei Thomas School, Hefei, Anhui, China

rhliu001@gmail.com

Abstract. This research article explores the development of bionic robots based on human-machine interaction. Beginning with an overview of bionic robots, the article first introduced the evolution of robots, especially bionic robots, aiming to offer readers a holistic view of this field. It then delves into a historical perspective to elucidate some related developments, including human-machine interaction. Subsequently, it discusses in depth how effective interaction between humans and robots can be achieved. Furthermore, the article explores the applications of human-machine interaction in bionic robots, showcasing their potential in diverse fields, like surgery and industrial manufacturing. Additionally, it discusses the technologies shaping the future of bionic robots, offering insights into the developmental trajectory of this domain. Lastly, it examines the ethics and social impacts, emphasizing the importance of ethical considerations and societal responsibilities alongside technological advancements. Overall, this article provides a thorough analysis of key issues and trends in bionic robot research based on human-machine interaction. As we move forward, it is crucial that we continue to explore and innovate, ensuring that bionic robots remain a force for positive change in our world.

Keywords: Bionic robot, human-machine interaction, medical healthcare.

1. Introduction

Thirteen days after the official announcement of a collaboration with OpenAI, “Figure 01”—a bionic robot which attracted substantial investment from companies in Silicon Valley—has introduced us a noteworthy update.

By integrating with Chat GPT, it has achieved comprehensive dialogue capabilities with humans, marking a groundbreaking achievement in enhancing its interactive abilities. This integration allows Figure 01 to comprehend and react to a wide array of human languages and subtleties in conversation, transforming it into not just a tool, but a companion which can provide meaningful interaction. Its capacity for engaging in real-time conversations, learning from interactions to enhance its responses, and even detecting and adapting to the emotional state of the speaker represents a significant advancement in human-machine communication. The bionic robot industry has evolved from Tesla’s sole standout, Optimus, to a current stage of blooming diversity. In recent years, bolstered by advances in AI technology, bionic robots have rapidly transitioned from a technology verification phase to a commercial trial phase. The bionic robot industry is currently undergoing an unprecedented surge in investment, with Figure 01’s latest advancements demonstrating the potential for these machines to become an integral part of daily life, transforming how we interact with technology on a fundamental level.

Human–computer interaction developed fast in the early 1980s, triggered largely by the PC revolution and the mass use of computers. Core concepts were also formulated in those days including the notion of direct manipulation and user centered design [1]. Driven by AI technology, the focus of HCI work is transitioning from human interaction with non-AI computing systems to interaction with AI systems. As AI technology continues to advance, intelligent agents can be developed to exhibit unique behavior and possess the autonomous characteristics with varying degrees of human-like intelligent abilities. With AI technology, machine can evolve from an assistive tool that primarily supports human operations to a potential collaborative teammate of a team with a human operator, playing the dual roles of “assistive tool + collaborative teammate”. Thus, the human-machine relationship in the AI era has added a new type of human-AI collaboration, often called "Human-Machine Teaming" [2].

Human-machine interaction has become an indispensable part of people's daily lives. As a new type of productivity carrier integrating advanced technologies such as artificial intelligence, high-end manufacturing, and new materials, bionic robots are set to have a revolutionary impact on social industrial transformation and the global competitive landscape. Focusing on the connection between the two provides insights for new breakthroughs in bionic robots, aiding in the actual implementation of bionic robot products.

2. Overview of Bionic Robots and Human-Machine Interaction

2.1. Definition and Scope of Bionic Robots

Bionic robots are a technology developed by emulating the structure, function, working principles, and control mechanisms of biological systems to improve existing mechanical systems or create new ones. It is one of the application areas of bionics, combining biological science and engineering technology, aiming to mimic the characteristics of various organisms in nature to enhance the performance and functionality of robots [3]. Bionic robots primarily include humanoid robots, bio-inspired robots, and bio-robots. Their features include redundant or hyper-redundant degrees of freedom, complex structures, and unconventional driving methods such as cables, artificial muscles, or shape memory alloys. According to the environment of use, they can be divided into underwater, aerial, and terrestrial bionic robots, imitating aquatic life, autonomous flying vehicles, and ground robots with different walking modes respectively. Among bionic robots, humanoid robots are a key focus of research, characterized by bipedal upright walking and basic operational functions, representing the cutting edge of robot technology [4].

2.2. Evolution and Importance of Human-Machine

The evolution and importance of human-machine interaction in the field of bionic robots are reflected in the following aspects:

Miniaturization: The key is to achieve the miniaturization of electromechanical systems. By integrating drives, sensors, controllers, etc., into a single silicon chip forming micro-electromechanical systems (MEMS), some micro bionic robots have moved from laboratory research to practical application phases.

Intelligence: Bionic robots are gradually developing towards intelligence, integrating multidisciplinary knowledge to make their actions more diverse and humanized [5]. Intelligence enables bionic robots to adapt to environmental changes automatically, enter inaccessible disaster scenes to carry out tasks more safely and perfectly.

Cooperation: The cooperative control of multiple robots is a current active topic, requiring multiple robots to collaborate to complete tasks. With deeper research into multi-robot systems, multi-robot simulation systems have also been developed, allowing robots to assist and communicate with each other, achieving mutual cooperation among multiple robots.

Biomimicry: The resemblance of bionic robots to the biological entities they mimic has also garnered attention. In military reconnaissance and spying missions, bionic robots that are completely identical in appearance to the mimicked life forms will complete tasks more covertly and safely.

2.3. Key Concepts and Terminology

Bionics is an independent discipline that officially emerged in 1960, aimed at emulating the structure, function, and working principles of biological entities and transplanting them into engineering technology to create superior performance instruments, devices, and new technologies. Bionic robots are further divided into categories mimicking flying organisms, terrestrial organisms, underwater organisms, amphibious organisms, and humans. Bionic robot mechanisms are characterized by high flexibility and complex functionality, imitating the movement or behavior of organisms, requiring mechanisms to have a high degree of perception and processing ability, with components capable of independent operation. In addition, some bionic robots have high redundancy of degrees of freedom, such as snake robots, enabling them to move and maintain dynamic stability on uneven ground and in unstructured environments. Unlike traditional mechanisms, bionic robots use diverse materials such as shape-memory alloys and expandable smart materials to meet the demands for material performance and shape controllability [6]. Moreover, bionic robot mechanisms feature variable configurations and degrees of freedom, yet still manage to maintain good operational performance [7].

3. Historical Perspective

The development of bionic robots has progressed from simple shape mimicry to the integration of mechatronics, and then to the deep fusion of mechatronics with bionic systems. Over 2000 years ago in China, there were already machines fully utilizing bionics, such as the wooden magpie recorded in "Mozi · Lu Wen" — "Gongshu Pan carved bamboo and wood to make a magpie, which flew for three days without descending, Gongshu Pan considered himself to be extremely clever" [8]. However, the construction of bionic machines at this stage was relatively simple, and the biological principles were mainly limited to the mimicry of simple external structures. After the 20th century, the development of bionic robots entered the stage of mechatronic integration, driven by computers [9]. Starting from the birth of the first robot Unimate in 1959, robot technology has undergone several industrial innovations and technological iterations (see Figure 1).

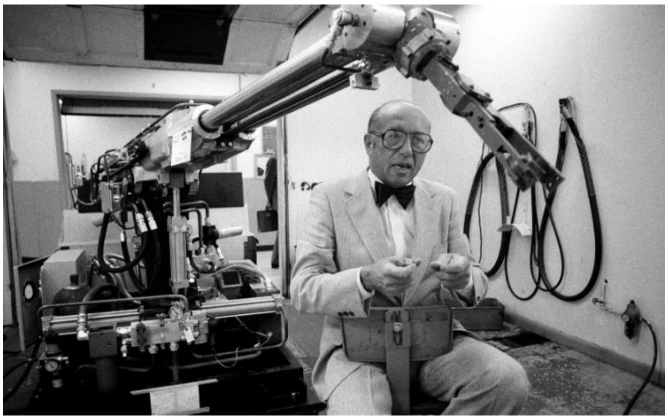

Fig. 1 The robot with mechatronic integration [9]

During this stage, robots could receive information transmitted by mechatronic systems and partially developed abilities such as movement, expression, mimicry, and intellectual thinking, initially achieving shape bionics, information, and control bionics. From the start of the twenty-first century, with the increasing investment in the robotics industry and the development of biotechnology and intelligent technology, bionic robots have entered the third stage, the fusion stage of mechatronic systems and bionic systems, like the ASIMO humanoid robot by Honda in 2000, which could achieve walking modes similar to humans [10].

Initially, there was little connection between human-robot interaction and bionic robots, which primarily operated based on simple mechanical principles with very limited interaction with humans. With the rise of mechatronic integration and computer technology in the 20th century, bionic robots began to exhibit initial interactive capabilities, being capable of receiving commands through sensors and providing responses. However, the mode of interaction remained constrained and limited in scope. After entering the 21st century, the rapid development of intelligent technology has led to significant advancements in human-robot interaction technology [11] (see Figure 2). Bionic robots have started to integrate with technologies such as voice recognition and facial recognition, making their communication with humans smoother and more intelligent [12].

Fig. 2 Structure of bionic robot with integrated technologies [11]

4. Principles of Human-Machine Interaction

Many scholars have proposed different views on the design principles of human-machine collaboration. Some have summarized the principles of human-machine interaction design in the field of visualized news, viewing from three levels: visual, behavioral, and cognitive. The design of visualized news should be beautiful and follow unified standards, possess strong interactivity and grant users ample control over interaction, and should also provide timely feedback and guide user operations [13]. In terms of user-centered design practices in human-machine interaction, scholars believe that unlike the simple and single-channel human-machine interaction technologies in the early stages, such as verbal interaction, touch interaction, tactile technology, posture interaction, multi-modal interaction, and other new human-machine interaction technologies are rapidly developing. These technologies, on one hand, provide new avenues for designing richer consumer user experiences, and on the other hand, also pose new challenges for effective interaction design.ess.

5. Applications of Human-Machine Interaction in Bionic Robots

5.1. Medical Healthcare and Medical Robots

The application of medical healthcare and medical robots in bionic robots is mainly reflected in the fields of medical rehabilitation and surgical operations. Precise interaction and collaboration between robots and doctors play an important role in the safety of surgeries and the effectiveness of rehabilitation. For example, robots mimic the tactile sensations of doctors during surgery, sensing the status of the operation in real-time and interacting with doctors to ensure safety. A significant advancement in surgical applications has been the development of the da Vinci Surgical System, a robotic system that enables surgeons to execute intricate procedures with enhanced precision, flexibility, and control compared to traditional techniques. This system translates the surgeon's hand movements into smaller, precise movements of tiny instruments inside the patient's body, viewed through a high-definition, 3D vision system. The da Vinci System has been widely adopted for a variety of surgical procedures, improving patient outcomes by reducing recovery time, minimizing scarring, and decreasing the risk of infection.

In rehabilitation, robots directly interact with patients to help restore, compensate, or assist with motor functions. Integrating humans and medical rehabilitation robots through human-machine fusion systems for information interaction and control is the goal of medical rehabilitation robot development. Applications of medical rehabilitation robots require advanced sensing, perception, and motion technology to accurately process various human-machine interaction information, including tactile, visual, and auditory sensory information. In rehabilitation training, bidirectional feedback between robots and patients is crucial, especially in hand rehabilitation training. To enhance rehabilitation effects, robot systems need to possess human-machine intelligent interaction functions, allowing patients to interact naturally with the robots [14].

5.2. Industrial Automation and Manufacturing

The application of bionic robots in industrial automation and manufacturing is continuously expanding, from traditional automobile manufacturing, electronic manufacturing to food processing, medical devices, aerospace, etc. Robots can complete manufacturing tasks such as assembly, handling and logistics, and inspection. For example, robots can assemble products by accurately positioning, grasping, and placing parts, improving work efficiency and product quality; the application in logistics systems is becoming a trend, enhancing logistics efficiency through artificial intelligence, digitalization, and autonomous systems; meanwhile, robots can perform visual, vibration, functionality, and temperature inspections of items through sensors or cameras, analyzing the results and performing automatic repairs [15].

5.3. Robots Assisting with Special Needs

Robots assisting with special needs, such as Leka, are designed for children with autism, down syndrome, or multiple disabilities. It provides sensory stimulation to help children who require special needs become more independent and improve their athletic and social skills. Leka was developed together by parents, therapists, and caregivers, aiming to make these children more accessible to the outside world. Users can manually control its movements and behaviors or access autonomous applications via Bluetooth. Equipped with sensors, Leka is able to respond to children's reactions, such as turning red to indicate sadness when mistreated and helping improve their social skills.

5.4. Environmental Exploration and Disaster Response

To meet the needs of environmental exploration and disaster response, Japan has been developing disaster relief robots dedicated to rescue and prevention in nuclear power plants and all kinds of natural and man-made disasters. Construction robots are designed to undertake more complex tasks in disaster area reconstruction while monitoring the surrounding environment. These robots can fly for extended periods, providing aerial views of entire regions, and use multi-camera systems in strong wind conditions. They are equipped with seismic sensors to sense or determine the size of touched objects. Moreover, the light source equipped on the robots' cameras allow them to clearly identify targets in darkness and fog locate disaster victims amidst rubble. With image recognition technology, robots can identify human belongings and provide accurate location information, significantly improving rescue efficiency.

6. Technologies Shaping the Future of Bionic Robots

6.1. Application of Artificial Intelligence and Machine

Learning in Bionic Robots AI can endow bionic robots with intelligent perception and cognitive abilities. Using sensors and cameras, bionic robots can perceive and acquire information about their surrounding environment. AI technologies can then efficiently process and analyze this acquired information, enabling robots to accurately understand and perceive the objects, sounds, and context around them. AI endows bionic robots with autonomous learning and decision-making capabilities. Through machine learning and deep learning technologies, AI enables bionic robots to have the capability of self-learning, thereby continuously optimizing their operations and decision-making processes. Through natural language processing and voice recognition technologies, people can interact more directly and intelligently with bionic robots. Bionic robots are capable of understanding human voice commands, answering questions, and even performing corresponding actions and reactions based on the dialogue. Mimicking the internal perception, control, and decision-making mechanisms of biological beings is an important aspect of robotics control and intelligence research. The neural network models, Central Pattern Generator (CPG) models, and various learning mechanisms used in the research of humanoid robots, bionic fish robots, quadruped robots, etc., are derived from the emulation of biological systems. Using robots to validate hypotheses and research findings in neuroscience and cognitive science not only promotes the development of related disciplines but also advances the foundational theories of robotics [16]. Intelligent bionic robots are systems that mimic the structure, functions, and behaviors of living organisms. They combine technologies from fields such as artificial intelligence, mechanical engineering, materials science, and biology, aiming to achieve perception, movement, and decision-making capabilities similar to living organisms [17].

6.2. Advances in Sensor Technology

Sensors are devices that can convert physical signals into electrical signals, serving to perceive the surrounding environment and convert the perceived signals into digital signals for computer processing. Common types of sensors include: Light sensors, which judge the status of objects through reflected light; temperature sensors, which detect changes in air or object temperature, commonly used in home appliances and cold chain transportation; humidity sensors, widely applied in agriculture and industry, detect the humidity level of the surrounding environment; carbon dioxide sensors, which can sense the concentration of CO2 in the environment to ensure safety; pressure sensors, used in weather forecasting or altitude measurement by measuring gas pressure. Traditional robots often rely on pre-programming to perform tasks, but they struggle to complete tasks accurately in complex environments. Smart sensor technology makes more precise and quicker task completion. The application of smart sensor technology enables robots to not just perform tasks but also to interact with and adapt to their environment. For example, in the medical field, smart sensor technology allows robots to better sense patients' conditions, provide timely feedback to doctors, and process information. In environmental protection, it helps robots accurately gather various environmental and emission data, thereby better supervising and protecting the natural environment. To better adapt sensors to the needs of soft robots, researchers have explored new materials and manufacturing processes, such as injecting the conductive liquid eGaIn into micro-channels within silicone bodies, changing the resistance of the conductive fluid as the body deforms [18]. Using Hall effects by embedding tiny magnets and Hall elements into different parts of a soft robot's body allows the detection of the robot's bending curvature based on changes in magnetic field strength. Whisker sensors, as part of bionic perception research, enhance robots' autonomous navigation abilities and intelligence level when mounted on robots as a complement to other sensors.

6.3. Integration of Virtual Reality and Augmented Reality

Human-machine interaction plays a crucial role in enhancing robotic capabilities and meeting the needs of complex tasks. 3D modeling of real-time work environments, implementing various human-machine interaction methods such as auditory, visual, haptic, and tactile, and safety controls in human-machine interactions are all important research areas. Virtual Reality (VR) is an advanced computer simulation technology that offers users real-time interactivity, three-dimensional visual spaces, and multi-channel (visual, auditory, tactile, etc.) human-machine interfaces [19]. It can dynamically simulate the real world, responding in real time to user gestures, voice commands, etc. Virtual prototyping technology, emerging in the mid-90s, is a computer simulation technology that represents a higher level than CAD, CAM, and VR [20]. Virtual Prototyping (VP) is a new design concept that involves creating 3D models using virtual reality technology before physical prototypes are built, conducting various dynamic simulation experiments to provide a visualized operation process of the system.

7. Ethics and Social Impacts

As the development of human-machine interaction technology deepens, privacy and security issues are becoming increasingly prominent. In the use of bionic robots, users' personal information, behavioral habits, and even emotional states may be perceived and recorded by robots. If this information is misused or leaked, it would constitute a severe violation of users' privacy rights. When bionic robots can recognize and understand human language, facial expressions, gestures, and other personal information, the collection, storage, and use of these data must adhere to strict privacy protection principles [21].

The widespread application of bionic robots will have profound effects on employment and the labor market. The extensive application of human-machine interaction technology allows some traditional positions to be gradually replaced by bionic robots. For instance, in manufacturing, bionic robots on automated production lines can complete repetitive labor efficiently and accurately, thereby reducing the demand for a large workforce. This substitution effect may lead to the disappearance of some low-skilled jobs, causing a shock to the job market [22]. On the other hand, the introduction of robots will also create new job opportunities, especially in the fields of robot research and development, maintenance, operation, and management. Therefore, society needs to consider the changes in the labor market and provide necessary training and support for workers who are affected.

The impact of bionic robots on society also includes cultural influences. From a cultural perspective, human-machine interaction technology involves communication and understanding across different cultural backgrounds. As bionic robots serve as a “second self” created by humans, their behavior and performance must conform to the norms and values of specific cultural environments. Otherwise, cultural differences could lead to misunderstandings, conflicts, or even rejection reactions [23]. For example, consider the story depicted in the movie “Ex Machina”: the artificial intelligence “Ava” was created not only with high intelligence but also with self-awareness and emotions. This has ignited a fundamental cultural dilemma: should artificial intelligence be regarded as a living being? How should humans treat such existences? Do humans have the right to control an intelligence that approaches human? Only through comprehensive contemplation on these factors can we ensure the proper development, widespread application, and societal embrace of the new technology.

8. Current Research Trends and Future Directions

In today’s era, there is a growing demand for adaptive and intelligent bionic robots to contribute to societal needs. Artificial Intelligence is changing the world, especially changing the way of interaction between machines and humans. The integration of machine learning, deep learning, and natural language processing helps improve the conversational AI. Dialogue agents are a good example of conversational AI, yet they only converse in text, while humans communicate in various ways or senses [24]. With the development of artificial intelligence and machine learning technologies, future bionic robots may combine multimodal sensing methods such as voice, vision, touch, etc., to understand users’ feelings, context, and emotions. They will generate comprehensible and engaging responses and personalize responses through sentiment and emotional analysis [25]. This will make communication between humans and robots more natural and efficient.

As bionic robots interact with users, they will encounter users’ private data. With the continuous improvement of bionic robots’ interactive abilities, a growing emphasis on addressing ethical and privacy concerns. The consideration of how to effectively balance fairness, transparency, and privacy protection in bionic robot interaction warrants careful contemplation. Robots can be widely applied in dangerous environments such as outer space exploration, military reconnaissance, warfare conflicts, and disaster relief. Bionic robot technology can be integrated with various industries, such as service, home, entertainment, industry, and aerospace, where human and bionic robot interactions become more common. Human-machine interaction systems that exhibit empathy can enhance people’s trust in machines, engagement, reduce frustrations in interactions, and increase interaction duration [26]. Therefore, the development of empathetic capabilities in bionic robots is a focus for the future.

9. Conclusion

This work provides a thorough analysis of key issues and trends in bionic robot research based on human-machine interaction. As we move forward, it is crucial that we continue to explore and innovate, ensuring that bionic robots remain a force for positive change in our world. Bionic robots, which are founded on human-machine interaction, constitute a novel form of robotics technology, distinguished by their remarkable biomimicry and profound interactivity tendencies. Bionic robots will be widely applied in various fields, such as medical healthcare, rescue and detection, environmental monitoring, and industrial manufacturing, etc. Therefore, the development of bionic robots also needs to conduct technological research and application promotion according to the application needs of different fields. As technology continues to develop and innovate, future bionic robots will gradually become more intelligent, flexible, and energy autonomous. However, challenges related to perception, control, power supply, and safety must be effectively addressed through ongoing innovation and exploration.It is incontrovertible that bionic robots will occupy a crucial position in the forthcoming era, providing remarkable convenience and advancement for the betterment of humanity.

References

[1] Dix A. Human–computer interaction, foundations and new paradigms[J/OL]. Journal of Visual Languages & Computing, 2017, 42: 122-134.

[2] Xu W, Dainoff M J, Ge L, ect. Transitioning to Human Interaction with AI Systems: New Challenges and Opportunities for HCI Professionals to Enable Human-Centered AI[J/OL]. International Journal of Human–Computer Interaction, 2023, 39(3): 494-518.

[3] Cui Xinzhong, Chang Cheng, Miao Xinying. Development and Application Studies of Bionic Robots [J]. Robot Technology and Application, 2017(04):33-36.

[4] Soul Dancer. A Brief Discussion on the Concept and Classification of Bionic Robots [EB/OL]. 2018 [Accessed March 17, 2024]. http://news.eeworld.com.cn/robot/ic596299.html.

[5] Bengi C. Self-Growing Bionic Robot Using Nanotechnology[J]. Journal of Research in Science and Engineering, 2022, 4(6).

[6] H.M.K.K.M.B. H, W.R. M D, Mamta M. Brain-computer interfacing for flexion and extension of bio-inspired robot fingers[J]. International Journal of Cognitive Computing in Engineering, 2023, 489-99.

[7] Shen Huiping, Ma Xiaomeng, Meng Qingmei, et al. Research Progress in Bionic Robots and Bionic Mechanisms [J]. Journal of Changzhou University (Natural Science Edition), 2015, 27(01):1-10.

[8] Sun Yirang: "Annotations to Mozi", Beijing: Zhonghua Book Company, 2017, 480-481.

[9] Liu Xinjun, Yu Jingjun, Wang Guobiao, et al. Research Progress and Scientific Challenges in Robotics [J]. China Science Foundation, 2016, 30(05):425-431.

[10] Neil S. Bioinspired robots walk, swim, slither and fly. [J]. Nature, 2022.

[11] Zhu Yan. The Current Status and Implications of Humanoid Robot Industry Development [J]. Science Technology and Industry, 2023, 23(22):136-141.

[12] Hirose, Masato, and Kenichi Ogawa. "Honda humanoid robots' development." Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences. 2007, 365(1850): 11-19.

[13] Chen Shiyi, Lü Yanru. Application of Human-Machine Interaction Design Principles in Visualized Data Journalism [J]. New Media Research, 2022, 8(14):12-16.

[14] Li Guanglin, Zheng Yue, Wu Xinyu, Hu Ying, Fang Peng, Xiong Jing, Xia Zeyang, Wang Can. Research Progress and Trends in Medical Rehabilitation Robots. Bulletin of Chinese Academy of Sciences, 2015, 30(6): 793-802.

[15] Xu Lan, Shang Li, Xu Zixin, et al. Application and Development Trend of Robots in Manufacturing [J]. Science & Technology Information, 2023, 21(24):44-48.

[16] Tan Min, Wang Shuo. Research Progress on Robot Technology [J]. Acta Automatica Sinica, 2013, 39(7): 963-972.

[17] Dong Geyu. The Impact of Intelligent Biomimetic Robot Development on the Labor Market and Economic Transformation [J]. Robot Industry, 2023, 05:68-74.

[18] Kramer R K, Majidi C, Wood R J. Wearable tactile keypad with stretchable artificial skin[C]// Robotics and Automation (ICRA)，2011 IEEE International Conference on，May 9-13，2011，Shanghai，China：IEEE, 2011, 1103-1107.

[19] Hong Bingrong, Cai Zesu, Tang Haoxuan. Virtual Reality and Its Applications. Beijing: National Defense Industry Press, 2005, 3-9.

[20] Liu Xingtang, Wu Xiaoyan. Modern System Modeling and Simulation Technology. Xi'an: Northwestern Polytechnical University Press, 2001, 9.

[21] Ye Mingyi. On the Basic Categories of Personal Information Rights [J]. Tsinghua Law Review, 2018, 12(05):143-158.

[22] He Xiaogang, Liu Kouming. Robots, Work Tasks, and the Polarization Effect of Employment - Evidence from Chinese Industrial Enterprises [J]. The Journal of Quantitative & Technical Economics, 2023, 40(04):52-71.

[23] Coeckelbergh, Mark. "The Ubuntu robot: towards a relational conceptual framework for intercultural robotics." Science and Engineering Ethics 2022, 28(2): 16.

[24] Sundar A, Heck L. Multimodal Conversational AI: A Survey of Datasets and Approaches[J/OL]. 2022.

[25] Kusal S, Patil S, Choudrie J, ect. AI-Based Conversational Agents: A Scoping Review from Technologies to Future Directions[J/OL]. IEEE Access, 2022, 10: 92337-92356.

[26] Pelau C, Dabija D C, Ene I. What makes an AI device human-like? The role of interaction quality, empathy and perceived psychological anthropomorphic characteristics on the acceptance of artificial intelligence in the service industry[J/OL]. Computers in Human Behavior, 2021, 122: 106855.