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Current Situation and Development of Intelligence Robots

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Abstract

Industrial intelligent robots are treated as a measure of national scientific level and technology innovation, and also the important symbol of high-level manufacturing, while service intelligent robots can directly affect people's daily lives. The development of artificial robots in different areas is attracting much attention around the world. This article reviews the current situation and development of Chinese and international intelligent robot markets including industrial robots and service robots. The intelligent robot technology and the classification of robots are also discussed. Finally, applications of intelligent robots in various fields are concluded and the development trends and outlook of intelligent robots are explored.

Keywords

intelligent robot; artificial intelligence; development trends

1 Introduction

In 1997, IBM's Deep Blue computer defeated the world's chess champion, Garry Kasparov. The match was a momentous occasion for artificial intelligence, showing how far a clever algorithm could go in a game prized for its intellectual difficulty. In 2015, AlphaGo became the first program to beat a professional Go player in an even game after it won 5–0 in a formal match against the reigning 3-times European Champion, FAN Hui. Alpha Go then won 4–1 against the top Go player in the world, LEE Sedol in 2016. After that, an era of artificial intelligence opened.

Since the 21st century, the development of robot technology has been paid more attention at home and abroad. Robotics is considered to be one of the high-level technologies of great significance for the development of emerging industries. UK Royal Academy of Engineering predicted that 2019 would usher in the robot revolution according to the Division Studies Report on Autonomous Systems in 2009 [1]. In 2014, Chinese President XI Jinping emphasized at the Seventeenth Academician Conference at Chinese Academy of Science: "Development, manufacture and application of robots are the measure of a national scientific and technological innovation and an important symbol of high-end manufacturing level; we need not only improve the level of Chinese robots, but also occupy the market as much as possible [2]." Robot revolution is expected to become an entry point and an important growth point of the third industrial revolution, and to affect the pattern of global manufacturing. China is expected to become the world's largest robot market.

Robots broadly include any machines that can simulate behaviors or thoughts of humans and animals, such as robotic dogs, robotic cats, and robotic fish. In a narrow sense, robots have many different definitions and classifications. Some computer programs can also be treated as a robot (such as the crawling robot for search engine). The United Nations Organization for Standardization adopts the definition from the US Robotics Association and defines the Robot as "a programmable and multifunctional manipulator; or a specialized system that performs different tasks can be changed by computer and is programmable. Generally, it's comprised of implementing agencies, driving device, detection device, control system, complex mechanism and other components [3]." A robot is a complex intelligent machine composed by machinery, electron, computers, sensors, control technology, artificial intelligence, bionics and other disciplines. Currently, the intelligent robot has become one of the research hotspots in the world, and an important symbol to measure a country's level of industrialization. Robots are automated robotic devices to perform some specific work, so that it can accept human commands, and also run pre-programmed programs. Moreover, it can perform some human tasks based on the principles and program developed by the artificial intelligence technology. In contemporary industry, the robot means an artificial robotic device that can perform tasks automatically, used to replace or assist human work [4]; usually it is an electromechanical device, controlled by a computer program or electronic circuit. Robots can be autonomous or semi-autonomous and range from humanoid such as Honda's Advanced Step in Innovative Mobility (ASIMO) and TOSY's TOSY Ping Pong Playing Robot (TOPIO) to industrial robots. It also includes collectively programmed swarm robots, and even Nano robots. By mimicking a lifelike appearance or automating movements, the ideal high simulation robot is an advanced product that integrates control theory, machinery, electronics, computer and artificial intelligence, materials science, and bionics. Robots can perform repetitive and dangerous tasks that humans prefer not to do or are unable to do because of size limitations or extreme environments such as outer space or the bottom of the sea. Nowadays, robots resemble humans in more and more fields or aspects, for example, robots can resemble humans in appearance, behavior cognition, and even emotion. Robotics technology was first used in industry. In recent years, driven by the computer technology, network technology, micro-electro-mechanical system (MEMS) technology, development of new technologies, the use of robot technology has been expanding rapidly from the traditional industrial manufacturing to medical service, education and entertainment, exploration and surveying, bio-engineering, disaster relief and many other areas. Robot systems adapted to the needs of different areas are intensively researched and developed. Over the past decades, research and application of robotics technology have greatly promoted the industrialization and modernization of the human society, and gradually formed a robotics industry chain, which is further expanding the scope of robot applications.

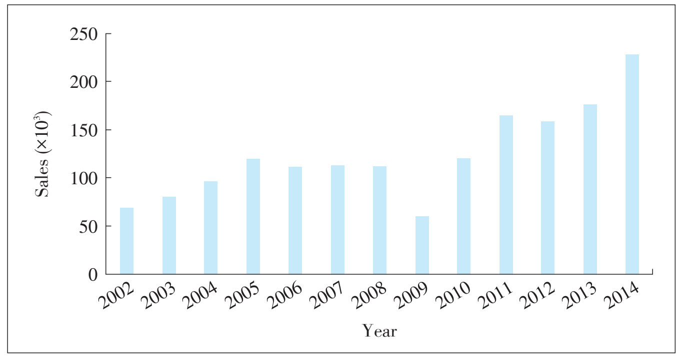
In the following sections, the current development of robots is introduced in section 2. Intelligent robot-related technologies and trends are presented in section 3. The emotional robot is also presented in this section. Section 4 is the conclusions and suggestions for future development of robotics in China.

2 Development Situation of Robots

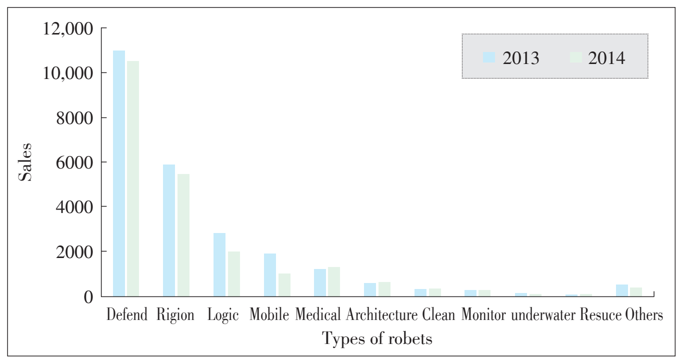
2.1 Global Development

As a measure of a country's scientific and technological innovation and an important indicator of the level of high-end manufacturing, the robot industry gets more and more attention around the world. The major economies have treated the development of this industry as a national strategy and an important means to maintain or regain their competence in manufacturing. The study of robotics started earlier abroad and is comparatively mature there. As the representatives, the United States, Japan and Europe have developed a variety of robots based on their needs. According to the report of the International Federation of Robots (IFR) [5], 229,261 industrial robots [6] were sold in 2014, with an increase of 29% compared to 2013 (**Fig. 1**). All industrial robot companies have achieved growth. In China, the robots sold reached 37,000 units in 2014, with an increase of 60%, ranking the world's top one [7].

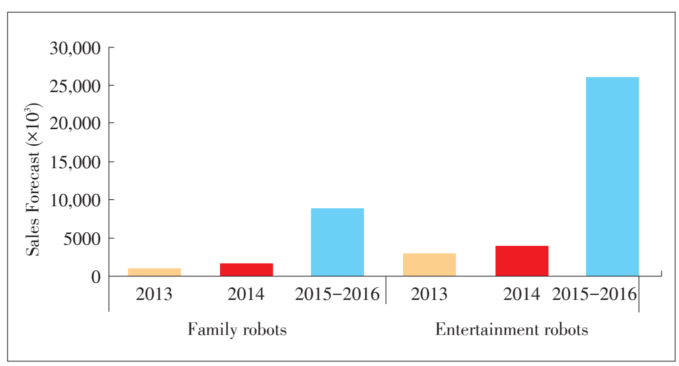
The sales of service robots grew by 11.5% in 2014 [8] (**Figs. 2** and **3**), and the sales amount increased 3% to $377 million [9]. It was predicted that various types of service robots could reach 25.9 million sets during 2015 to 2018, with an estimated value of $1.22 billion [10]. According to a report by Allied Market Research [11], the global industrial robot market would grow at a compound growth rate of 5.4% from 2014 to 2020



▲**Figure 1. Annual supply of industrial robots (IFR) [6].**



▲**Figure 2. Comparison of service robots (IFR) [8].**



▲**Figure 3. Sales prediction of service robots (IFR) [8].**

and its sales would reach $41.17 billion in 2020. McKinsey Global Institute published a report named "12 Disruptive Technologies Leading Global Economic Changes" in 2013 [12], and listed the advanced robotics, cloud computing, the next generation of gene technology, 3D printing, new materials, renewable energy and other 6 technologies. In 2025, robots will bring economies of scale from $1.7 to $4.5 trillion per year worldwide according to McKinsey's prediction [12].

2.1.1 Development in US

In 2010, the US launched its "Advanced Manufacturing Partners' Program", with an explicit goal of revitalizing the manufacturing through the development of industrial robots and developing a new generation of intelligent robots by using information network technology. In 2013, it released a robot development route report with a subtitle of "From Internet to Robotics", in which the intelligent robot was put in the equally important position with the Internet in 21th Century [13]. Robots will influence human life, economic and social development in all respects, and robots technology has been listed as the core technology to achieve manufacturing improvement and economic development in the US.

2.1.2 Development in EU

The EU has launched the world's largest civilian robot research and development program—SPARC, planning to vote 2.8 billion Euros and create 240,000 jobs in 2020. The program includes more than 200 companies and 12,000 R&D persons are involved. Robot applications in various fields such as manufacturing, agriculture, health, transport, security and the family are included in the plan.

2.1.3 Development in Germany

Germany has proposed its Industry 4.0 plan to maintain its leading position in manufacturing. The plan considers intelligent robotics and intelligent manufacturing technology as an entry point to greet the new industrial revolution.

2.1.4 Development in Japan

Japan also has a long-term development strategy of robot technology. The robot industry is one of the priorities in the seven major industries supporting its new industrial development strategy. The Japanese government is planning to use robots as an important pillar of economic growth.

2.1.5 Development in South Korea

South Korea has developed a "Smart Robot Basic Plan", and issued a "Robot Future Strategic Vision 2022" in October 2012. The policy focuses on expanding its robot industry and supporting Chinese robot enterprises to expand overseas markets.

2.2 Development in China

Robot manufacturing in China began in the 1970s, with a focus on researching and manufacturing industrial robots. Although robot technology research and development in China started late, the development speed is very fast. The development can be roughly divided into three stages. In 1980s, the main emphasis was researching and manufacturing industrial robots, with the support of national "863" program and other plans. In the early 1990s, the techniques with independent intellectual property rights emerged, including spot welding, arc welding, assembling, painting, cutting, handling, packaging palletizing and more, and China took an important step in industrial robots in practice. The Chinese government introduced robot development plans covering different aspects of robotics during this period. After the prototype and demonstration phase of the 1990s, China started to enter the industrial stage in 2000. In 2006, China included intelligent service robots in the national long-term technology development program, and in 2012, it published the "Twelfth Five-year Special Plan" for service robot technology development. The "Ministry of Industry Guidance on Promoting the Development of Industrial Robots" was released in 2013. After 2010, the capacity of Chinese installed robots has increased annually, with the development of the robot industry chain.

In recent years, China has made a lot of robot technology achievements and the market prospect of robot industry is bright. Many Chinese research institutes, such as Harbin Institute of Technology, Beijing University of Aeronautics and Astronautics, Tsinghua University and Hefei University of Technology, are carrying out related research of intelligent robots. Hefei University of Technology has built an emotion robot platform which will be presented in the following sections.

The world's four giant robot manufacturers including Sweden ABB, German KU-KA, Japanese FANUC) and Japanese YASKAWA have set up branches in China and are positive to the prospect of Chinese robot market. On the other hand, the Chinese robot brands have also grown and begun to take shape, such as Shenyang XINSONG Robot Automation, Anhui Efort Intelligent Equipment, and Guangzhou Dongguan STS robotics. Until October 2014, there were more than 430 robot-related companies in China, with an average of two new companies appearing per week. There are more than 4000 companies involved in industrial robots and the number is still growing with an annual increase of more than 300 enterprises. According to Great Wall Securities' latest research, Chinese industrial robot industry will have a explosive growth and the market is expected to reach 100 billion in 2020. In the next six years, the total installed capacity is expected to reach the range of 638,000–1,760,000, with a conservative estimate of 850,000 units. Chinese service robotic industry is also expected to an unparalleled growth in 5 to 10 years. With a conservative forecast, in the next six years, the total Chinese market size of industrial robots will be ￥127.5 billion, that of service robots is ￥144.3 billion, and that of the system integration market is ￥382.5 billion. Specifically, the market size of military ground robots will be ￥34 billion; that of unmanned aerial vehicles will be about ￥46 billion; that of service robots for aged people will be about ￥39 billion; that of assistive robots will be ￥24.3 billion; and that of public service robots will be around ￥10 billion.

The Chinese Robot Industry Alliance led by China Machinery Industry Federation was established in Beijing on April 21, 2013. The alliance aims to vigorously promote the production, science and research of Chinese robots, and to accelerate the universal application of robotics technology and products in various sectors. The alliance has more than one hundred members and try to achieve the healthy and orderly development of the robot service platform based on the optimization of the industrial chain, innovative integration of resources, complementary advantages, cooperative development, and win-win cooperation models. China has exported mobile robots in batches, and Chinese service robots and special robots began to form a strong competitive power. The total sales of Chinese industrial robots are over 9500 units in 2013. Based on this, China supports the construction of robot industry bases, such as Shenyang XINSONG Robot Automation and Harbin Boshi Automation, which are leading the development of Chinese robotics industry.

However, Chinese robot brands still have a low market share in China. International robot brands account for more than 90% of the Chinese market share. Six large Japanese robot companies occupy 50% of the Chinese industrial robot market, while Chinese four robotic equipment manufacturers only account for 5% of the Chinese market. Chinese industrial chain of robots, including production, manufacture, sale, integration and ordered service has not yet formed. Compared with the major developed countries, Chinese robot industry develops slowly, the core technology is weak, and the market share and additional values are low. However, with the wide application and expanding of robotics technology and products, robots will maintain rapid development in China.

3 Intelligent Robot-Related Technologies and Trends

3.1 Intelligent Robot-Related Technologies

There are certain technical indicators and criteria to measure intelligent robot technology level, and the robotics capability evaluation includes:

- Degree of intelligence. It mainly refers to a robot's feel and perception of the outside world, including memory, calculation, comparison, identification, judgment, decision making, learning ability, logical reasoning ability, etc.
- Performance characteristics, including task flexibility, common areas or space possessory, etc.
- Physical energy index. It generally refers to a robot's power, speed, reliability, combinability and service life. For some special robots, it also includes actuators, drives, sensors and control systems, and complex mechanical and other components.

3.1.1 The Robot Actuator

The robot actuator is the body of a robot and the robot arm (if any) and generally uses the space open chain bar linkage, where the motion pairs (rotation pair or revolute pair) are often called joints. The number of joints is typically the robot degrees of freedom. According to the different joint configuration types and movement coordinate forms, robot actuators can be divided into rectangular coordinate type, cylindrical coordinate type, polar coordinate type, and joint type. In some certain application scenarios, the relevant parts of the robot body are often called base, waist, arms, wrists, hands (gripper or end effecter), walking part (for mobile robots), etc. for anthropomorphic considerations.

3.1.2 The Drive Device

The drive device drives the movement of the actuator, in accordance with instructions signals issued by the control system, and by means of the dynamic element to make robot perform the related action. The input of a drive device is an electric signal and the output is a linear and angular displacement. Driving devices used for a robot are mainly electric drives, such as stepper motors and servomotors. In addition, for the specific needs of a particular scene, the hydraulic and pneumatic drives are also used.

3.1.3 The Sensing Device

Robots generally get external information through a variety of sensors. The sensors are used for real-time detection of the robot's internal movement and work and of the external operating environment information as well. A sensor also feeds back to the control system as needed, after comparison with the set of information, adjusting the actuator to ensure that the operation of the robot meets predetermined requirements. Sensor devices used for detection can be divided into two categories. One is the internal information sensor for detecting the internal status of the various parts of the robot, such as the position of each joint, velocity and acceleration, and the measured information as a feedback signal will be sent to the controller, forming a closed loop control. The other is the external information sensor for acquiring the work object, external environment and other relevant information of the robot, to make movement of the robot adapt to changes in the external conditions. In this way, the robot can achieve a higher level of automation and even lead the robot to have some human-like feels. The robot also gets the development of intelligence, such as using the visual, sound and other external sensors to get the work objects, work environment and relevant information, and then use the information to form a large feedback loop, which will greatly improve the working precision of the robot.

3.1.4 Control System

One is the centralized control, that is to say, the entire control of the robot is completed by a micro computer. The other is the dispersed (level) control, which uses more than one computer (at upper and lower levels) to complete control of the robot. The host computer is often responsible for system management, communications, kinematics and dynamics calculations, and for sending command information to the lower level computer. As a subordinate slave, each joint corresponds to a CPU which could do interpolation operation and servo control process with real specific movement, and then passes the feedback to the host. Depending on the different mission requirements of tasks, the control modes of the robot can be divided into the position control, continuous path control and force (torque) control.

3.1.5 Intelligent System

Intelligent system refers to the computer system that produces human-like intelligence or behavior. This system can own the self-organization and adaptability to run on a conventional Von Neumann machine, and also run on a new generation computer of non-Neumann architecture. The concept of "intelligence" covers a wide range and is also constantly in an evolving process. Its essential needs further exploration, thus, it is difficult to give a complete and precise definition for the word "intelligence". It is generally stated like: intelligence is reflection of higher activity of the human brain, and it should at least have the ability to automatically acquire and apply knowledge, think and reason, solve problem and learn automatically [14]. Smart robots have the function of completing similar intelligence capabilities with humans. For an intelligent system, its processed objects are not only data, but also knowledge. The ability to represent, acquire, access and process is one of the main differences between the intelligent system and the mechanical system. Therefore, an intelligent system is a knowledge-based processing system. It requires the following facilities: knowledge representation language; knowledge organization tools; the method and environment to establish, maintain and query knowledge base; and supporting the reuse of existing knowledge. Intelligent systems often use the artificial intelligence problem solving mode to get the results. Compare with the traditional system's problem solving mode, it has three distinct features: 1) its problem solving algorithms are often non-deterministic or heuristic; 2) problem solving relies heavily on knowledge; and 3) intelligent system problems tend to have exponential computational complexity. The typical problem solving methods an intelligent system uses are roughly divided into three categories of search, reasoning, and planning. Another important difference between the intelligence robot system and traditional system is that the intelligent system has field perception (acclimatization) capabilities. Scene perception helps robots to interact with the abstract of real world and adapt to their scene. Such exchanges include perception, learning, reasoning, judgment and appropriate action making. This is well known as automatic organizing and automatic adapting. Nowadays, the chatbot is another hot spot in robot technology. Many chatbot systems and methods have been developed and studied such as Siri and Xiaobing.

3.1.6 Intelligent Human-Machine Interface System

Intelligent robots cannot be in full autonomy yet, and it still needs to interact with people. Even a fully autonomous robot also needs to feedback real-time implementation of the mandate to people. The intelligent human-machine interface system enables a robot to provide users with a friendly, natural and good adaptive human-computer interaction system. With the support of intelligent interface hardware, the intelligent human-machine interface system generally has the following features:

- Using natural language directly to lead a human-machine dialogue
- Allowing multimedia such as sounds, text, graphics and images to lead the human-machine interaction
- Interacting with human by brain waves and other physiological signals
- Self-adapting to different user types
- Self-adapting to the needs of different users
- Self-adapting to different computer systems support.

3.2 Development and Trends of Intelligent Robot Technology

Intelligent robots are the third generation robots with a variety of sensors. It can fuse information obtained by multiple sensors and effectively adapt to the changing environments, with strong adaptive ability, learning ability and autonomic functions. Multiple key technologies decide the intelligence level of an intelligent robot, which are introduced as follows.

3.2.1 Multi-Sensor Information Fusion Technology

The multi-sensor information fusion technology integrates sensory data from multiple sensors to produce more reliable, accurate and comprehensive information. The multi-sensor fusion system can more accurately reflect the characteristics of the detection target, eliminate uncertainty information, and improve the reliability of information. For example, the emotional robot can adopt multimodal information from human to get accurate emotion of human, by combing text, sounds, facial expressions and information from other channels or models.

3.2.2 Navigation and Location Technology

For autonomous mobile robot navigation, whether it is local real-time obstacle avoidance or global planning, the technology is used to precisely tell the current state and position of the robot and obstacles for completing tasks like navigation, obstacle avoidance and path planning.

3.2.3 Path Planning Technology

Based on one or multiple optimization criterions, the optimal path planning technology finds an optimal path from the initial state to target state and avoids obstacles in the robot workspace. Nowadays, almost all the moving robots use this technology to increase the covering rate.

3.2.4 Robot Vision Technology

The robot vision system implements image acquisition, image processing and analysis, output and display. Its core task is feature extraction, image segmentation and image recognition. Nowadays, deep learning and related technologies have been widely adopted in this field and great progress has been made.

3.2.5 Intelligent Control Technology

Intelligent control methods improve the speed and precision of the robot. The human-machine interface technology makes it possible for people to naturally and conveniently communicate with the robot.

3.3 Wide Use of Intelligence Robots

Modern intelligent robots can basically complete various complex tasks according to people's instructions, such as deep sea exploration, combat, reconnaissance, intelligence gathering, and rescue. Robots can complete the tasks humans are unable or unwilling to complete independently, and also collaborate with people to complete tasks under the guidance of people. Therefore, they have been widely used in different fields.

According to different workplaces, intelligent robots can be divided into pipes, water, air and ground robots. Pipe robots can be used to detect the rupture, corrosion and weld quality in the course of using pipeline, doing pipe cleaning, painting, welding, internal polishing and other maintenance work in the harsh environments, and repairing underground pipeline. Underwater robots can be used for scientific marine research, offshore oil development, seabed mineral exploration, undersea salvage lifesaving, etc., while air robots can be used in terms of communications, meteorology, disaster monitoring, agriculture, geology, transport, radio and television and other aspects. Service robots work semi-autonomously or autonomously to provide services for human, for example, the robots used in the traditional Chinese medicine field have a good application prospect. With a human-like shape, humanoid robots have a mobile function, operation function, perceptive function, memorizing and self-government ability, to achieve friendly man-machine interaction. Micro-robot based on nanotechnology has broad application prospects in bio-engineering, medical engineering, micro-electromechanical systems, optical, ultra-precision machining and measurement (such as scanning tunneling microscope) and more.

3.3.1 Robots for National Defense

In the field of national defense, military intelligent robots have got unprecedented attention and development. In recent years, the US and UK have developed the second generation of military intelligent robots, such as the United States' Navlab autonomous navigation vehicles, SSV autonomous ground combat vehicles, and Big Dog robots. The robots use independent control to complete the reconnaissance, combat and logistical support and other tasks. They are able to see and smell on the battlefield, to automatically track the terrain and choose the path, and to automatically search, identify and eliminate enemy targets. In the future, military intelligent robots will include intelligent fighting robots, intelligent reconnaissance robots, intelligent alert robots, intelligent engineering robot, intelligent transportation robot, and more, and they will become a new bright spot in defense equipment. The unmanned combat air vehicle (UCAV) is an upgraded form of the unmanned aerial vehicle (UAV) and can do a variety of tasks, including combat. Unmanned aircrafts, such as BAE Systems Mantis, have the ability to fly autonomously, choose routes and goals independently, and make decisions independently. BAE Raytheon is an unmanned combat aircraft researched and developed by the UK, and it cannot fly across the continent without pilots and new methods to avoid detection.

3.3.2 Service Robots

The whole world, especially western countries, is committed to the research and development of the wide application of intelligent service robots, although the definition of "service robots" is not clear. The International Federation of Robotics gives a preliminary definition: "service robot refers to a class of robots, by its semi-autonomous or fully autonomous operation, providing helpful service for the guardian of human health or monitoring equipment operation status, but does not include industrial operations [15]." Take the cleaning robots as an example. With the scientific and technological progress and social development, people want to be free more from the tedious daily affairs, which make cleaning robots enter into families possible. The floor cleaning robot developed by Japanese companies can start from any one location along the wall automatically using constantly rotating brush to sweep the waste into its own container. The station floor cleaning robot sprays the cleaning fluid onto the ground, and simultaneously uses constantly rotating brush scrubbing the floor and sucked dirty water to its container. The factory automatic cleaning robot can be used for a variety of clean-up work. A cleaning robot named "Roomba" of America, with high autonomy, can walk in the gaps of furniture in each room, deftly completing clean-up work. A Sweden robot "trilobite", with smooth surface, round shape and built-in search radar, can quickly detect and avoid the leg, glassware, pets or any other obstacles. Once its microprocessor recognizes these obstacles, it will re-select the route, and make judgment and re-calculated for the entire room to ensure that every corner of the room is to be cleaned.

Service robots can recognize people or objects, talk, provide companionship, monitor environment quality, respond to alarms, pick up supplies and perform other useful tasks. They perform multiple functions at the same time, or play different roles at different times of the day. Some robots try to imitate humans; this type of robot is called a humanoid robot. The humanoid robot is still at a very limited stage, and until now no humanoid robot can navigate in the room it had never been to. Thus, the functions and applications of humanoid robots are quite limited, despite their considerable intelligence behavior in familiar environment. Semi-autonomous robots, such as Friend (**Fig. 4**) and other various wheelchair robots can help the elderly and the disabled people to complete some common

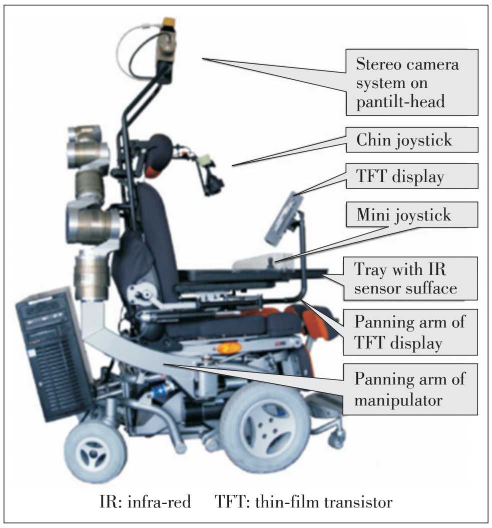


Figure 4. Wheelchair robot "Friend".

tasks. The increase of aging population in many countries, especially in Japan, means that there are more and more elderly people in need of care, but relatively fewer young people could care for them. Human beings are the best caregivers, but they are very busy. That is why robots are gradually being introduced. Friend (Fig. 4) is a semi-autonomous robot (wheelchair robot), helping the disabled and the elderly in daily life, such as preparing and serving meals. Friend makes it possible for paraplegic patients with muscle diseases or serious paralysis (due to stroke and other reasons) to complete some tasks without the help of a therapist or a nurse.

3.3.3 Education Robots

In the field of education, the robot has had a long involvement since the 1980s; the Turtle robot has been put into use in schools with Logo programming language [9], [16]. Moreover, the robot kits, such as Lego, robot teaching kit "BIOLOID", OLLO robot and BotBrain educational robot, can help children learn math, physics, program, electronics and other knowledge. FIRST company also introduced robots into primary and secondary students' life through robot competitions. FIRST company organized the first robot competition, the first LEGO League, the basic of Junior Lego Match and the first Technique Challenge. There were also some devices whose shapes like robots, such as teaching computer Leachim (1974) and 2-XL (1976) that is an 8-track tape player.

3.3.4 Sports Robots

In the field of sports, the intelligent robot has also been greatly developed. In recent years, high-tech combat activities of soccer robots have been carried out among nations, and the international community has set up relevant federations, such as Federation of International Robot-soccer Association (FIRA). Many regional associations have also been set up, reaching a more formal level and a considerable scale. In order to win a robot soccer match, the camera hanging in the air transfers the match status to the computer and the pre-installed software makes appropriate decision and measures and passes the command to the robot players by way of wireless communications. The robot in a soccer match fuses the computer vision, pattern recognition, decision countermeasure, wireless digital communications, automatic and optimal control, intelligent body design and electric drive technology into its system to realize intelligence.

3.3.5 Humanoid Robots

Robots with emotions have also been developed rapidly in recent years. The REN Research Lab in Tokushima University, Japan has developed a conversation robot with emotions [17] (**Fig. 5**). During a conversation with the human, the robot can detect the human emotions and make corresponding responses considering both content context and human emotions.

Anhui Key Lab of Affective Computing and Advanced Intelligence Machine, Hefei University of Technology (China), has achieved some progress in emotional assist robots. The researchers in the Lab study affective computing systems on the humanoid robot platform for mental health problems, funded by the National "863" Program of China. The humanoid robot is built in the Lab according to a real person's outlook and body structure (**Fig. 6**). In order to make a perfect approximation, the reverse method is used for the robot head design according to the real person's size; the robot's hair is also planted and cut according to the real person's style (**Fig. 7**). The researchers in the Lab think that a realistic appearance can improve the acceptability of the robot.

The robot was first made to perform six basic emotions, including surprise (**Fig. 8**) and sad (**Fig. 9**). Then the researchers built a personalized fusion heart state transition network for the robot, and developed a multi-model emotion conversation model based on the transition network. In this way, the robot could make reactions to emotions (**Fig. 10**).

The researchers of the Lab have also built a female emotional robot (**Fig. 11**). This female emotional robot is designed as a platform to enhance mental health for the human. According to the user's micro-blog, blog, conversational language, voice, facial expressions and emotional interaction, the robot could perceive human's mental health status and calculate the heart en-

Figure 5. The conversation robot with emotions from REN Lab.

◀Figure 6. Body structure size collection for robot.

◀Figure 7. Planting and cutting robot's hair.

Figure 8. ▶ The robot simulates surprise.

Figure 9. ▶ The robot simulates sadness.

▲Figure 10. Robot-human emotional conversation.

▲Figure 11. Female emotional robot from HFUT.

richment degree. The system is able to appease and chat with persons. The researchers have also developed an emotional robot conversation cloud platform. Key functions of the platform include person identification and emotion cognition, gestures and voice interaction, intelligent emotional chat, and other emotional interaction. Emotional robots can be adopted at home and medical facilities for people of all ages (especially the elderly), providing recovery assistant service in specific conditions (autism and depression).

Modern intelligent robots have not been widely used, but will permeate all aspects of life. For example, the coal and mining industry has demands for intelligent robots because of the harsh environment in coal mining; for building construction, there are high-rise buildings plastering robots, mounting robots, indoor decoration robots, robots for wiping glass, floor polishing robots and so on. The nuclear industry requires smart, accurate, reliable, quick and lightweight robots. For emotional accompanying, service robots use cameras and microphone sensors to collect people's real-time information, obtain their real-time emotional states by machine learning and data mining algorithms, and then synthesize the corresponding human facial expressions and gestures to do the real-time emotional interaction. The application fields of intelligent robots are expanding day by day and people are using intelligent robots to replace human beings to complete more complex and more advanced work.

3.4 Robot Technology Trends

Various robotic technologies constantly emerge. One approach is to use evolutionary robotics. A parent robot constructs some different sub-robots and after testing, the sub-robots with best performance will be used as a standard model to create a new generation of the robot. Another approach is developing robots (developmental robotics) by tracking the inner changes of the robot in solving problems in specific functional areas, thereby improving the intelligence of the robot. A new one has just launched and is named new RoboHon robot, which can be seen as a smart phone and a robot as well [18]. Japan expects to achieve full commercialization of service robots by 2025 and many leading technology research institutions there are led by the Japanese government, particularly by its Ministry of Economy and Trade [19]. With the development of robots, it is expected to establish a standard computer operating system for robot design. The robot operating system is a set of open source codes and is being developed by Stanford University, Massachusetts Institute of Technology, Technical University of Munich, and more. Robot Operating System (ROS) provides methods for robot navigation and program of its limbs. These methods do not need to consider the specific hardware involved. It also provides high-level commands, such as image recognition and even opening the door. When ROS starts on computer of a robot, it will get the robot's attribute data, such as the length of the limbs and robot motion data. Then it passes the data to a higher-level algorithm. Microsoft started its research and development of robots in 2007 [20], and is developing a "robot window" system. Caterpillar is making an automatic driving truck [21], without any manual operation.

Intelligent robots in various industries have bright application prospects and the intelligent robot research at home and abroad has made many achievements. However, there is still much room for growth of intelligence level [22], [23]. Future intelligent robots will be task-oriented [24], [25]. Because the current artificial intelligence cannot provide intelligent machines with a complete theory and methods for open tasks, most of the existing artificial intelligence technologies rely on domain knowledge and special robots are developed for special tasks.

Some artificial intelligence technologies in specific areas are used for promoting the development of intelligent robots:

- Sensor technology and integration technology: The sensor technology is used to develop better and more advanced processing methods based on the existing sensors, and find new sensors as well. The integration technology improves the integration information.
- Robot cloud interconnection technique: Using the cloud Internet network technology, robots are connected to a computer network and their knowledge base comes from cloud [26], [27]; on the other hand, the cloud can effectively control the robots through the computer network.
- Calculation methods of intelligent control system: Compared with traditional methods, the fuzzy logic, reasoning based on probability theory, neural networks, genetic algorithms and chaos calculation [28]–[30] have higher robustness, ease of use, low cost calculation and more advantages. When applied to robotics, these methods can help robots to improve the speed of problem solving and to handle multivariable and nonlinear system problems better.
- Machine learning in smart robots: The emergence of various machine learning algorithms promote the development of artificial intelligence, depth of learning, reinforcement learning, ant colony algorithm, immune algorithm and others for robotic systems, making robots possess the human-like learning ability, adapt to increasingly complex, uncertain and unstructured environments.
- Human interface of intelligent optimization: The demand of human-computer interaction is developed toward simplicity, diversity, intelligence and humanization. Therefore we need study and design a variety of intelligent human-machine interfaces [30]–[32] such as multi-lingual voice, natural language understanding, images, handwriting recognition, and even physiological information, in order to better adapt to different users and different application tasks, and eventually to improve human-robot interaction harmony.
- Multi-robot coordination schemes: They organize and control multiple robots to collaborate on complex tasks that cannot be completed by a single robot, realizing real-time reasoning reaction, group decision making and operation of interaction in a complex and unknown environment.

4 Conclusions

About 50% of the world's robots are in Asia, 32% in Europe, 16% in the northern United States, 1% in Australia, and 1% in Africa [33]. Japan has 40% of the robots in the world [34]. Currently, Japan has the largest number of robots. As robots become more advanced and complex, more and more experts and scholars have even begun to explore the need to establish what kind of ethics to manage the robots' behavior [35], and study whether the robot can have any type of social, cultural, moral or legal rights [36]. A scientific team has said that the robot's brain will probably exist by 2019 [37]. Others predict that 2050 will be a breakthrough of intelligent robots [38]. The recent developments have made the robots' behavior more complex [39]. The social impacts of intelligent robots are discussed in a documentary film called Plug & Pray in 2010.

For the development of intelligent robots in the future, it is very important to improve technology and comprehensive application in all directions, including improving the intelligence level of robots, and improving the autonomy and adaptability of intelligent robots.

Simultaneously, intelligent robots for multiple disciplines' cooperative work involve the technology base, and even the psychology, ethics and other social sciences. It is essential to lead the intelligent robots to complete the work beneficial to mankind, and liberate human from the heavy, repeated and dangerous work, as described in the science fiction writer Isaac Asimov's *Three Laws of Robotics*, and to make the intelligent robots truly serve the interests of humanity, not a tool against humanity. It is believed that in the near future, all walks of life will be filled with all kinds of intelligent robots, and scenarios in science fictions will become a reality under the scientists' efforts, which is expected to improve the quality of human life and the ability to explore the unknown.

Intelligent robots' development in China still lags behind the world's advanced level, while the intelligent robot technology is a concentrated reflection of high-tech and has an important development value. Therefore, in the field of intelligent robots, China should find a clear development target, take feasible development strategy in line with China's national conditions, strive to narrow the gap with the world advanced level, and make the intelligent robot serve roundly for the social development. We believe that the development level of China's intelligent robots can reach a new height through the government's attention and investment, as well as by persistent efforts of scientists and engineers.

The research emphasis of robots is moving from industrial robots to the intelligent service robots. The software and hardware of intelligent robots will be equally important in the next 20 years, and the software will be much more important than hardware 20 years later. The future robots should be a complete intelligent robot with both IQ and EQ.

References

[1] TSK. (2017, Jan. 03). *Depth report in the robotics industry* [Online]. Available: http://sanwen8.cn/p/6299jtY.html
[2] T. Wu. (2015, Aug. 31). *Can China create new century of "made in China"* [Online]. Available: http://www.chinanews.com/it/2015/08-31/7497842.shtml
[3] Machine Design. (2017, Jan. 03). *Robot overview* [Online]. Available: http://www.iw168.cn/jixiesheji/jiqirengaishu
[4] A. Crystal. (2015, October 15). *5 jobs being replaced by robots* [Online]. Available: http://excelle.monster.com/benefits/articles/4983-5-jobs-being-replaced-by-robots
[5] IFR. (2015, Oct. 15). *IFR international federation of robotics* [Online]. Available: http://www.ifr.org/home
[6] IFR. (2015, Oct. 15). *World robotics 2015 industrial robots* [Online]. Available: http://www.ifr.org/industrial-robots/statistics
[7] UNPROFOR. (2016, Nov. 14). *Teach you how to be a lazy in the future* [Online]. Available: http://zjphoto.yinsha.com/bhyszx/10463352.html
[8] IFR. (2015, Oct. 15) *World robotics 2015 service robots* [Online]. Available: http://www.ifr.org/service-robots/statistics
[9] J. Barnard. "Robots in school: games or learning?" Washington, Rep. TR-01-29, 1985.
[10] MCL. (2016, Jan. 03). *Service robot market is in explosive growth, with inestimable developing prospect* [Online]. Available: http://www.robot-china.com/news/201601/26/30920.html
[11] Aiden Burgess. (2015, Sept. 09). *Global industrial robotics market set to rise to $41.17bn by 2020* [Online]. Available: http://www.themanufacturer.com/articles/global-industrial-robotics-market-set-to-rise-to-41-17bn-by-2020
[12] J. Manyika, M. Chui, and J. Bughin, "Disruptive technologies: Advances that will transform life, business, and the global economy," San Francisco, USA, McKinsey Global Institute, Rep., 2013.
[13] T. Collaborative, "From internet to robotics," 2009.
[14] TSK. (2017, Jan. 03). *Automatic intelligence* [Online]. Available: http://baike.baidu.com/item
[15] IFR. (2012, Dec. 27). *Definition of service robots* [Online]. Available: http://www.ifr.org/service-robots
[16] L. Mitgang, "Nova's talking turtle profiles high priest of school computer movement," Gainesville Sun, Rep. TR-10-25, 1983.
[17] F. Ren. (2011). *The REN research lab* [Online]. Available: http://a1-www.is.tokushima-u.ac.jp/member/ren/A1/A1.html
[18] K. N. RoboHon. (2015, Oct. 15). *Cute little robot cum smart phone* [Online]. Available: http://blog.codexify.com/2015/10/robohon-cute-little-robot-cum-smart-phone.html
[19] Y. Myoken, "Research and development for next generation service robots in Japan," Science and Innovation Section British Embassy, 2009.
[20] M. G. Campbell, "*Robots to get their own operating system*," *New Scientist*, vol. 203, no. 2720, pp. 18–19, 2009.
[21] T. McKeough, "The caterpillar self-driving dump truck," *Fast Company Magazine*, no. 131, pp. 80. Dec./Jan. 2009.
[22] X. Sun, F. Ren, and J. Ye, "Trends detection of flu based on essemble models with emotional factors from social networks", *IEEJ Transactions on Electrical and Electronic Engineering*, to appear in 2017. doi:10.1002/tee.22389.
[23] X. Sun, J. Yi, and F. Ren, "Detecting influenza states based on hybrid model with personal emotional factors from social networks," *Neurocomputing*, vol. 210, pp. 257–268, 2016.
[24] F. Ren and H. Yu, "Role-explicit query extraction and utilization for quantifying user intents," *Information Sciences*, vol. 329, no. 1, pp. 568–580, 2015.
[25] F. Ren and K. Matsumoto, "Semi-automatic creation of youth slang corpus and its application to affective computing", *IEEE Transactions on Affective Computing*, vol. 7, no. 2, pp. 176–189, 2016. doi: 10.1109/TAFFC.2015.2457915.
[26] F. Ren, X. Kang, and C. Quan, "Examining accumulated emotional traits in suicide blogs with an emotion topic model", *IEEE Journal of Biomedical and Health Informatics*, vol. 20, no. 5, pp. 1384–1396, Sept. 2016. doi:10.1109/JBHI.2015.2459683.
[27] F. Ren, Y. Wang, and C. Quan, "TFSM-based dialogue management model framework for affective dialogue systems," *IEEJ Transactions on Electrical and Electronic Engineering*, vol. 10, no. 4, pp. 404–410, Jul. 2015. doi: 10.1002/tee.22100.
[28] F. Ren and Y. Wu, "Predicting user-topic opinions in twitter with social and topical context," *IEEE Transactions on Affective Computing,* vol. 4, no. 4, pp. 412–424, 2013. doi: 10.1109/T-AFFC.2013.22.
[29] F. Ren and M. G. Sohrab, "Class-indexing-based term weighting for automatic text classification," *Information Sciences*, vol. 236, pp. 109–125, Jul. 2013. doi: 10.1016/j.ins.2013.02.029.
[30] F. Ren and X. Kan, "Employing hierarchical bayesian networks in simple and complex emotion topic analysis," *Computer Speech and Language*, vol. 27, no. 4, pp. 943–968, Jun. 2013. doi: 10.1016/j.csl.2012.07.012.
[31] F. Ren, "From cloud computing to language engineering, affective computing and advanced intelligence," *International Journal of Advanced Intelligence*, vol.2, no.1, pp.1–14, Jul. 2010.
[32] F. Ren, "Affective information processing and recognizing human emotion," *Electronic Notes in Theoretical Computer Science*, vol. 225, pp.39–50, Jan. 2009. doi:10.1016/j.entcs.2008.12.065.
[33] IFR, "Robots today and tomorrow: IFR presents the 2007world robotics statistics survey," World robotics, Oct. 2007.
[34] Reuters. (2007, Dec. 01). *Japan's robots slug it out to be world champ* [Online]. Available: http://www.reuters.com/article/us - robot - fight - idUST32811820071202
[35] AAAI, "Robot ethics," Archive Rep. TR-10-15, 2015
[36] AAAI compilation of articles on robot rights, sources compiled up to2006.
[37] P. Lester. (2009, Jul. 29). *Scientist predicts functional artificial brain in 10 years* [Online]. Available: http://www.gizmag.com/ted-2009-artificial-brain/12362
[38] H. Moravec, *Robot: Mere Machine to Transcendent Mind*. Oxford, UK: Oxford University Press, 2000.
[39] W. Matthew. (2009, Aug. 17). *Robots almost conquering, walking, reading, dancing* [Online]. Available: http://www.koreaittimes.com/story/4668/robots-almost-conquering-walking-reading-dancing

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