SHS Web of Conferences **144**, 03005 (2022) https://doi.org/10.1051/shsconf/202214403005
STEHF 2022

Review of the Application Status and Development Trend of Industrial Robots

Fuzhe Wang*

Beijing Jiaotong University, Maanshan, Anhui Province, China

ABSTRACT: With the progress of industrial civilization and the development of artificial intelligence technology, industrial robots are gradually approaching production workshop, and their status is improving day by day. This article will describe the current development status of emerging industrial robots and share their future development trends, aiming to provide a theoretical basis for industrial robot design departments and factories. Nowadays, industrial robots are developing rapidly in various countries, and have entered many emerging industries, such as aerospace, military and medical fields. The development trend of industrial robots in the future should mainly focus on five development directions: human-robot collaboration, artificial intelligence, new industrial users, digitization, and smaller and lighter robots.

1. INTRODUCTION

Industrial robots are the product of the dual promotion of social economy and science and technology, which involve computer technology, mechanical technology, artificial intelligence and other fields [1]. The use of industrial robots has promoted the development of management in all aspects of industrial production, brought norms and order to production enterprises, and improved the production efficiency of enterprises. According to the International Federation of Robotics (IFR) data report, since 2013, automated production has been accelerating globally, and the market size of industrial robots is growing at an average annual rate of 12% [2]. At the same time, since the COVID-19, the manufacturing industry has been hit hard. Many businesses around the world that produce electronic equipment, machinery, etc. have ceased production. As far as the manufacturing industry is concerned, the impact of the epidemic is mainly reflected in the shortage of labor, the untimely supply of equipment and raw materials, etc. The industry growth rate has dropped from 11.6% in 2017 to 5.2% [3].

In view of the rapid development of industrial robots, it is particularly important to determine the development direction of industrial robots as soon as possible and accurately, which will minimize the cost of research and development and put robots into production as soon as possible. But how are industrial robots classified? What is the current development status of the industrial robot field? What is the future of industrial robots? These questions will be answered in this article. These problems are the selection problems faced by many industrial robot R&D companies, which will provide them with a clear research direction, which can save R&D costs and time to the greatest extent.

2. KEY CONCEPTS AND TERMINOLOGY

2.1. Industrial Robot Structure Block Diagram

The industrial robot consists of three basic parts: the main body, the drive system, and the control system (shown in Figure 1). The main body consists of the base and the actuator, including the arm, the wrist and the hand, and some robots also have a walking mechanism. Most industrial robots have 3 to 6 degrees of freedom of movement, of which the wrist usually has 1 to 3 degrees of freedom of movement. The drive system includes a power device and a transmission mechanism to make the actuator produce corresponding actions; the control system is based on the input The program sends out command signals to the drive system and the actuator, and controls it.

*Corresponding author. Email: 1044739098@qq.com

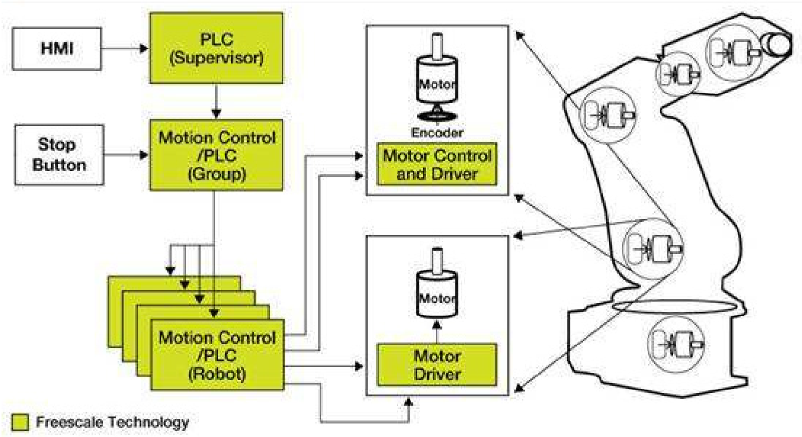

Figure 1. Industrial Robot Structure Block Diagram

2.2. Operation matrix

In order to clearly grasp the motion trajectory, motion coordinates, etc. of the industrial robot, we can simply understand some operation matrices about its motion, and the reader only needs to understand it. Here I simply list the transformation matrix and the Jacobian matrix.

The transformation matrix (shown in Figure 2) represents the coordinate change of the industrial manipulator between different coordinate systems.

$$A_i^{i-1}=\begin{bmatrix} \cos\theta_i & -\cos\alpha_i\sin\theta_i & \sin\alpha_i\cos\theta_i & a_i\cos\theta_i \\ \sin\theta_i & \cos\alpha_i\cos\theta_i & -\sin\alpha_i\cos\theta_i & a_i\sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Figure 2 Transformation Matrix

The Jacobian matrix (shown in Figure 3) represents the differentiation of the linear velocity and the angular velocity during the movement of the manipulator, which can show the movement process more clearly.

$$\begin{bmatrix} \upsilon_x^6 \\ \upsilon_y^6 \\ \upsilon_z^6 \\ \omega_x^6 \\ \omega_y^6 \\ \omega_z^6 \end{bmatrix} = \begin{bmatrix} n_x & n_y & n_z & (p\times n)_x & (p\times n)_y & (p\times n)_z \\ o_x & o_y & o_z & (p\times o)_x & (p\times o)_y & (p\times o)_z \\ a_x & a_y & a_z & (p\times a)_x & (p\times a)_y & (p\times a)_z \\ 0 & 0 & 0 & n_x & n_y & n_z \\ 0 & 0 & 0 & o_x & o_y & o_z \\ 0 & 0 & 0 & a_x & a_y & a_z \end{bmatrix} \begin{bmatrix} \upsilon_x^i \\ \upsilon_y^i \\ \upsilon_z^i \\ \omega_x^i \\ \omega_y^i \\ \omega_z^i \end{bmatrix}$$

$$\upsilon_x^6 = \boldsymbol{n}\cdot((\omega\times p)+\upsilon^i) \qquad \omega_x^6 = \mathbf{n}\cdot\omega^i$$
$$\upsilon_y^6 = \mathbf{o}\cdot((\omega\times p)+\upsilon^i) \qquad \omega_y^6 = \mathbf{o}\cdot\omega^i$$
$$\upsilon_z^6 = \mathbf{a}\cdot((\omega\times p)+\upsilon^i) \qquad \omega_z^6 = \mathbf{a}\cdot\omega^i$$

Figure 3 Jacobian Matrix

3. TYPES OF INDUSTRIAL ROBOTS

There are many types of industrial robots, which can be classified according to their function, mechanical structure, movement mode of the robot arm, control function of executing the movement structure, input method, etc.

3.1. Sort by function

With the continuous development of artificial intelligence and robotics, industrial robots can be roughly divided into electric arc welding robots, assembly robots, spraying robots, handling robots, grinding robots, and palletizing robots (shown in Figure 4) according to their different functions [4].

Figure 4 QH-165 Spot Welding Robot

3.2. Sort by mechanical structure

According to the classification of mechanical structures, industrial robots are mainly divided into two categories: series robots and parallel robots [5].

The tandem robot is an open kinematic chain robot, which is formed by a series of connecting rods connected in series through rotating joints or moving joints. The drive is used to drive the movement of each joint and the relative movement of the connecting rod, so that the end of the robot can reach a suitable posture. The research of tandem robots is relatively mature, and has the advantages of simple structure, low cost, simple control, and large movement space. It has been successfully used in many fields, such as various machine tools, assembly workshops, etc.

A parallel robot refers to a closed-loop robot with a moving platform and a fixed platform connected by at least two independent kinematic chains, the mechanism has two or more degrees of freedom, and is driven in parallel. The parallel robot has the advantages of high stiffness, strong bearing capacity, high precision, and small inertia of the end piece, and has obvious advantages in the occasion of high speed and large bearing capacity. Common parallel robots have spider hands, as shown in Figure 5.

Figure 5 Spider Hands

3.3. Equations

According to the motion form of the arm, it is mainly divided into 4 types, namely Cartesian coordinate robot, cylindrical coordinate robot, spherical coordinate robot, and articulated robot.

A cartesian coordinate robot refers to a multi-purpose manipulator that can realize automatic control, can be programmed repeatedly, has multiple degrees of freedom, and the freedom of movement can be built into a right-angle relationship in space.

Cylindrical coordinate robots can realize intelligent detection, automatic yarn clearing, automatic yarn joining, etc [6].

The spherical coordinate robot can make up and down pitching movements and can grab the coordinated workpiece on the ground or in a low position, and its position accuracy is high.

In a jointed robot (shown in Figure 6), the motion of each joint is rotational, similar to a human arm. Articulated robots are one of the most common forms of industrial robots in today's industry.

Figure 6 Six-axis articulated robot

4. DEVELOPMENT STATUS OF INDUSTRIAL ROBOTS

As early as the 1960s, American automakers begun to use industrial robots in production. This is also a sign that industrial robots officially provide services for human production activities, and has a milestone significance in the development history of robots. Through the continuous improvement and improvement of scientific researchers, the United States has become the country with the most mature robot technology today, which has established the United States' leading position in the field of industrial robots and also consolidates the status of the United States as an industrial power in the long term. Since the 1980s, the research and development of industrial robots in Japan, Russia and many western developed countries have also made great progress, and many industrial robots have the same strength as the United States in some fields [7].

4.1. The market for industrial robots

According to the data released by IFR in 2021[8], the global operating stock of industrial robots has reached a new record of about 3 million units, with an average annual growth of 13% (2015-2020).

Asia (including Australia and New Zealand) is still the region with the highest sales volume of robots, with 261,826 units sold in 2017, an increase of 37% over 2016 and a record high [9]. From 2012 to 2017, the average annual growth rate of robot installations was about 25%. In 2017, China was still the world's largest robot market and the fastest growing market for robots in the world, with 137,920 robot sales, an increase of about 59% over 2016, and surpassing the total sales of robots in Europe and the Americas (112,400 units), accounting for 36% of the total global sales of industrial robots.

4.2. Status of Industrial Robot Technology in Different Countries

At present, the United States, Japan, Germany, etc. are at the forefront of global industrial robots in terms of technology.

4.2.1. America

Although the world's first robot was born in the United States, the United States did not attach great importance to the development of robots at first. Later, in order to maintain the continuous growth of manufacturing in the United States, the US government formulated policies to encourage the development of industrial robots on the one hand, and increased funding for robot research on the other hand. At present, the main characteristics of American robots are:

Reliable performance, comprehensive functions and high accuracy;

Robot language research has developed rapidly, with many language types and wide applications, ranking first in the world;

The rapid development of intelligent technology, its vision, touch and other artificial intelligence technologies have been widely used in the aerospace (shown in Figure 7) and automotive industries;

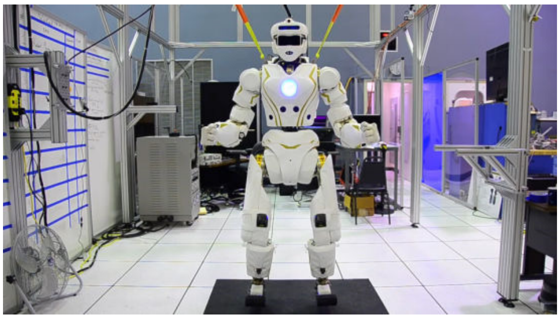

Figure 7 American Mars robot model Valkyrie

Military robots (shown in Figure 8) with high intelligence and high difficulty are used for minelaying, mine clearance, reconnaissance and space exploration.

Figure 8 US military humanoid robot Atlas

4.2.2. Japan

The development of Japan's robot industry is later than that of the United States, but it has long ranked first in the production and sales of industrial robots in the world. Especially in the automobile and electronics industries, Japan took the lead in using industrial robots, which improved the quality of automobiles and electronic products, soared the output, and greatly reduced the manufacturing cost, thus making it enter the developed country market with an absolute advantage of low price and high quality.

4.2.3. Germany

KUKA, Germany's most famous industrial robot manufacturer, is one of the world's top industrial robot manufacturers. Products are used in instruments, automobiles, aerospace, consumer products, logistics, food, pharmaceuticals, medicine, casting, plastics, etc. Mainly used in material handling, machine tool loading and unloading, assembly, packaging, stacking, welding, surface finishing and other fields. Figure 9 shows us the different models of KUKA robots.

Figure 9 KUKA robots

4.3. Common features of global industrial robots

Although all countries in the world have their own characteristics in the field of industrial robots, and there are differences in technology and policies, they all have some common characteristics.

4.3.1. The general direction of industrial robots is driven by the market

It can be seen from historical data that the development of industrial robots in various countries is closely related to the rapid development of domestic automobiles, electronics and other industries that require high-efficiency manufacturing equipment [10]. At present, the five countries with the largest installed amount of industrial robots are also the world's major auto producers. According to the data released by the World Automobile Organization (OICA), auto production in the five countries accounted for 62% of the global total in 2015 [11], as shown in Figure 10.

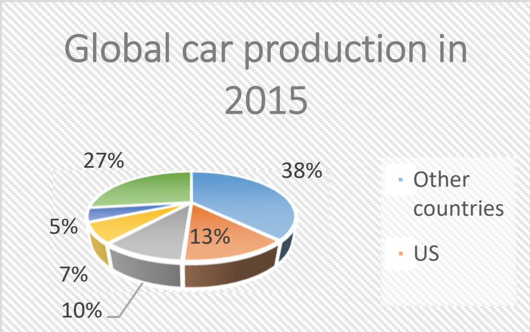

Figure 10 Global car production in 2015

In recent years, with the slowdown in the development of the automobile industry and the vigorous development of the electronics industry, the demand for industrial robots in the electronics industry has increased day by day. In Asia, where industrial robots are growing the fastest, the electronics industry's demand for industrial robots surpassed the automotive industry for the first time in 2015, becoming the industry with the largest amount of industrial robots.

4.3.2. The government's policy support will have a decisive impact on the robot industry

Throughout the history of robot development in countries around the world, the impact of government policies of various countries on the development of the robot industry cannot be ignored.

Take the United States, which is currently relatively advanced in robotics, as an example. In the mid-20th century, unemployment in the United States was high, and the government at the time worried that the production and use of robots would bring about an even more serious wave of unemployment. Therefore, the US government did not actively develop the robot industry at that time.

And the latecomer in the robot industry, Japan, although the robot industry started later than the United States, the Japanese government has been actively promoting and encouraging the development and application of robots for many years. The government has adopted many economic preferential policies for small and medium-sized enterprises, such as providing preferential low-interest funds by government banks, and encouraging fundraising to establish long-term robot leasing companies. At the same time, the government has also reduced or exempted the rent of such enterprises, which greatly reduces the financial burden required for enterprises to purchase robots. In addition, the government also provides funding for small enterprises to provide professional knowledge and technical training guidance on the application of robots for free [12].

5. THE FUTURE DEVELOPMENT TREND OF INDUSTRIAL ROBOTS

In traditional industrial manufacturing, industrial robots have been widely used in industries such as automobiles, metal products, electronics and rubber [13]. With the innovation of industrial robot technology and the reduction of cost, the development trend of industrial robots in the future should mainly focus on the five development directions of human-robot collaboration, artificial intelligence, new industrial users, digitization and smaller and lighter robots [14].

5.1 Human-robot collaboration

A collaborative robot (cobot or co-robot for short) is a robot that interacts closely with humans in a common workspace, and is designed to work with humans and perform corresponding production tasks. Figure 11 shows us the ABB Yumi collaborative robot.

Figure 11 ABB Yumi

Collaborative robots add tireless endurance to repetitive tasks, reduce labor costs, and can adapt to changes by adding sensors, with high flexibility. But its cost is high and it has not been applied on a large scale.

5.2. Artificial intelligence

In addition to sensing its own state and the state of the external environment through internal and external sensors, the intelligence of industrial robots can also perform logical reasoning, judgment and decision-making based on the obtained information. The intelligence of industrial robots is a system-level problem, and its intelligence involves many key technologies, such as sensor technology, navigation and positioning, robot vision, intelligent control and human-machine interface technology [15].

At present, the development of various technologies and the integration between various technologies still have a large space for development.

5.3. New industrial users

The automotive industry and the electronics industry are currently the largest customers in the field of industrial robots. The absorption of more potential users is one of the current breakthroughs for industrial robots. At present, small and medium-sized manufacturing enterprises such as new energy batteries, environmental protection equipment (shown in Figure 12), high-end equipment and line inspection have become new industrial users of industrial robots.

Figure 12 "Smart" sanitation robot

5.4. Digitization

The so-called digitization refers to the use of digital information processing technology in all aspects of a certain field or in all aspects of a certain product. The application of efficient and intelligent digitalization in industrial robots can further help enterprises improve production efficiency and energy efficiency, and realize flexible and intelligent production. Digitization will become one of the important considerations for whether an industrial robot can fully open the market.

5.5. Miniaturization and Lightweight

As the application fields of industrial robots become more and more extensive, various manufacturers have put forward higher requirements for the weight and volume of industrial robots, and lightweight and miniaturization have become a new development trend. This will mean that new industrial robots will be easier for factory workers to operate and will greatly improve the working conditions of workers [16]. Japan's Epson folding arm six-axis robot N2 (shown in Figure 13) can complete flexible operations within 60% of the station space of the existing robotic arms of the same level; the folding arm six-axis robot N6 adopts an internal wiring design, and its folding arm can naturally enter high-level equipment and machines. And narrow spaces such as shelves [17].

Figure 13 Epson's new folding arm six-axis robot N2

6. CONCLUSION

The industrial robot industry is currently developing rapidly. This article discusses the classification of industrial robots, the development status of industrial robots, and the future trend of industrial robots. It can be concluded that the field of industrial robot technology is relatively mature, and will enter more industries and fields in the future, and industrial robots will develop in five directions: human-robot collaboration, artificial intelligence, new industrial users, digitalization, and smaller and lighter robots. continue to develop. However, some of the documents referenced in this article are relatively old (some documents are from 2010-2015), which may become one of the factors for inaccurate prediction of the current situation and future trends of industrial robots.It is expected that future research can be conducted based on the latest literature.

REFERENCES

1. Jing Bai, Research on the development path of industrial robots, Equipment Management and Maintenance. 2021, (01)
2. Ren Zhigang, The development status and development trend of industrial robots [J], Equipment Manufacturing Technology, 2015 (3): 166-168
3. Zou Fang, Research on human-machine collaboration standards and application dynamics [J], Aviation Manufacturing Technology, 2016, 59(23/24): 58-63
4. Liyuan Wu, Talking about the classification and development trend of industrial robots, Tech wind, March 2017
5. Shiwei Wang, Application analysis of industrial robots in steel industry, Process and equipment, 2020.0770
6. Yongming Chen, Debin Liu, Application of Cylindrical Coordinate Robot in Knitting Circular Weft Machine, Knitting Technology, Issue 9, 2018
7. Wenqiang Chen, Research status and development trend of industrial robots, 10.16621/j.cnki.issn1001-0599.2020.12D.68
8. IFR, http://nb.sanhaostreet.com/newsdata/202204/1622823.html
9. Wenli Liang, Global Robotics Market Statistical Data Analysis, Industrial economy, F416.46
10. Qiyu Chen, Zhiheng Wu, Brief Commentary on the Development History of Global Industrial Robots, 1000 − 4998 (2017) 07 − 0001 − 05
11. OICA.2015 PRODUCTION STATISTICS [EB/OL]. http://www. oica.net/category/production-statistics/2015-statistics.
12. Aizhen Chen, The development history and current situation of industrial robots in Japan [J], Mechanical Engineer, 2008 (7): 8-10
13. Jing Bai, Yi Xu, Analysis on the development of manufacturing industry from the perspective of

industrial robots, Mechanical Engineering and Automation, Issue 6.

14. Enrique GN, Hugo IM, Yan XT, et al. Haptic-enabledvirtualplanningandassessmentofproductassembly[J]. Assembly Automation, 2020, 40(4): 641-654.
15. Jayasekera R D M D, Xu X. Assembly validation in virtual reality-a demonstrative case [J]. International Journal of Advanced Manufacturing Technology, 2019, 105(3): 3579-3592.
16. IFR, https://www.sensorexpert.com.cn/article/23157.html
17. Yong Yu, Jian Tao, Yuqing Fan, Boeing 787 aircraft assembly technology and its assembly process [J]. Aviation Manufacturing Technology, 2009 (14): 44-47