Powering your potential

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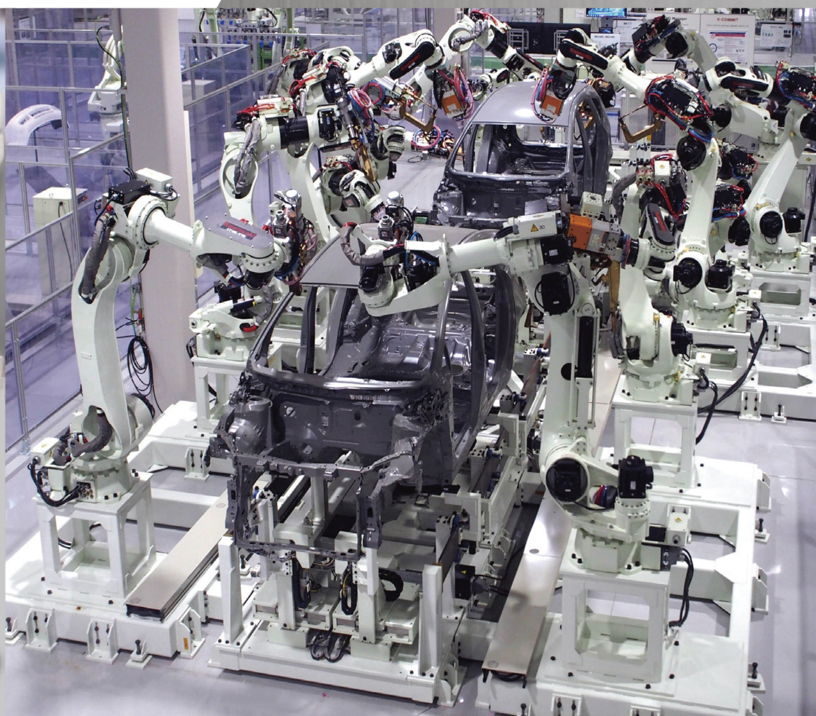
Special Issue on Robot Systems







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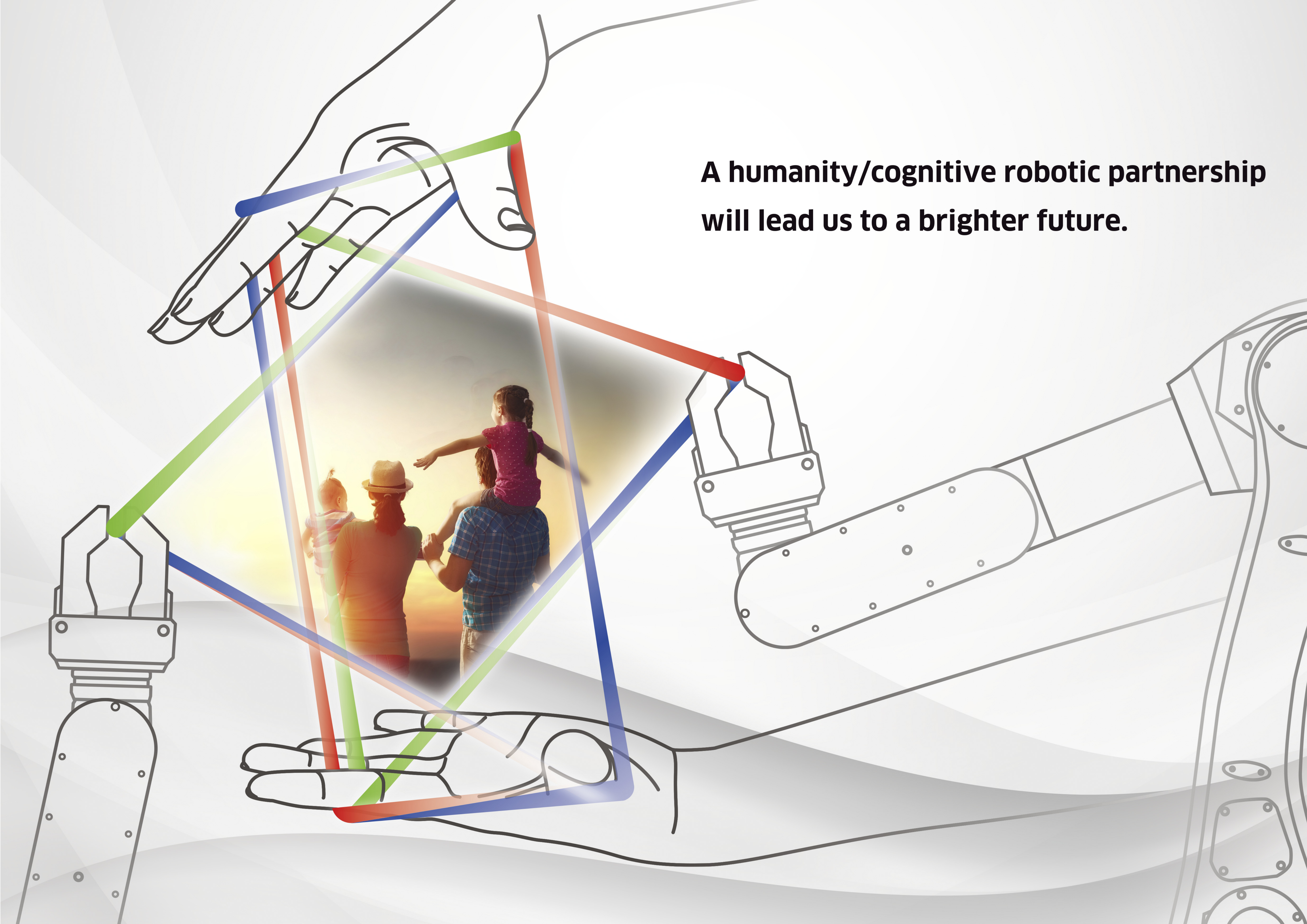
Kawasaki Heavy Industries, Ltd.


A humanity/cognitive robotic partnership will lead us to a brighter future.

Interview with the Precision Machinery Company President

The Present Situation of the Robot Business and its Development Going Forward

Kazuo Hida
Senior Vice President
President, Precision Machinery Company

How is the robot market faring these days?

Despite the increasing uncertainty in the global economy, the robot market is growing at a steady pace. The market is expanding especially in China as a result of labor shortages and rises in personnel costs. In terms of the number of robots installed per country, the Chinese market has become the world's largest, exceeding Japan.

The current quantitative expansion in robot production has been supported by the automobile industry's demand for robots. However, demand for robots has recently started growing in other industries as well. Customers have varying motivations, which include eliminating labor shortages and reducing costs. Despite such variations, the need for automation is more widespread than ever, expanding the range of industries that use robots.

There are also new trends. International standards regarding robot safety have been revised and robots that conform to the new standards are now being proposed as human-supporting and human-collaborative robots. Our company has developed a product called duAro to meet customers' needs. It is becoming more important than ever to meet these new needs and expectations in a timely manner and even to propose solutions.

What do you think about future business development?

I would like to comment on three initiatives for future business development.

First, we need to create a new market for industrial robots. Industrial robots are used for established purposes, such as welding and applying coatings, which form the core of our robot business. We will strengthen this business and at the same time expand the use of industrial robots to a wider range of purposes. There are still many manufacturing processes that have not been automatized. By coexisting and cooperating with human beings, human-supporting, human-collaborative robots may provide a solution to such processes. To this end, we will use duAro as the core to develop new markets.

Secondly, we need to take up challenges in new areas. Our company is focusing on medical robots as one of the new areas of business. In 2013, we jointly founded Medicaroid Corporation, a venture company, with Sysmex Corporation to start a medical robot business. In FY2016, we started selling products developed based on existing robot technologies. In FY2019, we plan to commercialize surgery support robots.

Thirdly, we need to enhance the Kawasaki Robot brand. Producing high-quality products is a given, so we will focus on fostering a sense of security toward Kawasaki robots through new services that use IoT.

In August 2016, we also opened a showroom known as Kawasaki Robostage in Tokyo's Odaiba for the purpose of enhancing our brand. This facility provides us with opportunities to propose new relationships between humans and robots. We invite customers to familiarize themselves with Kawasaki robots through demonstrations, while we learn what direction we need to go in from customers.

Could you make some comments about our company's technological development?

As a comprehensive heavy industry manufacturer, our company owns a wide range of cutting-edge technologies. We also manufacture a large variety of products used in processes that can be automated by robots. Our strength is that we can provide technologies validated through application to these processes as solutions for customers.

Robots are already being used in many production sites in our company, including welding in the manufacturing of ships and vehicles as well as handling in hydraulic machinery production lines. Our company is working with the Corporate Technology Division in a wide range of areas, from basic to applied technologies. By further promoting technological development and by installing robots in aircraft production lines, we would like to use our achievements to provide solutions to a wide range of customers.

Closing comments

Precision Machinery Company aims to become manufacturer of the best motion controller brand in the world, creating and providing total solutions focusing on hydraulic machinery and robots. Our company was founded in 2010 by integrating the former Hydraulic Machinery Department and the former Robot Department. We would like to achieve our corporate goal by producing synergetic effects, thereby continuing to meet public expectations.

The Market Environment of Robotics and Initiatives of the Robot Division

Yasuhiko Hashimoto
Managing Executive Officer
General Manager, Robot Division, Precision Machinery Company

Introduction

For the 50 years since the launch of its industrial robot business in June 1968, Kawasaki Heavy Industries (KHI) has contributed to the advancement of industrialized society by offering robot system solutions.

Social expectations toward robots have changed over time from their initial mission to save manpower and free humans from hostile environments and heavy labor. Today, they are expected to carry out advanced maneuvers as important tools for ensuring high quality.

KHI produces robots that measure up to such expectations through the tireless development of technologies and products. This article provides an overview of the robotics market before describing the technologies and products deployed by KHI in its core business, as well as the company's initiatives with a view to future business expansion.

1 The robotics market environment

(1) Industrial robotics market

Figure 1 shows the actual and forecast annual sales of industrial robots. The dynamic growth of the market over the last few years is clear, with annual sales reaching 250,000 units in 2015. Defying the ongoing global economic uncertainties, growth is expected to continue and to achieve an annual sale of 410,000 robots by 2019.

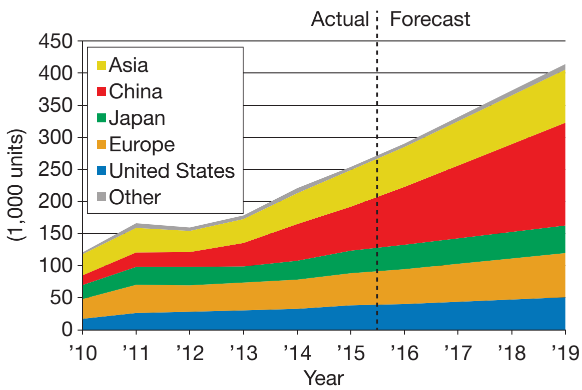


Fig. 1 Actual and estimated global sales of industrial robots
Source: IFR World Robotics 2016

Marked growth is noted in the Chinese market, although sales are growing in every other region as well. Indeed, China is driving the robotics market with a sales growth rate that is more than double that of other regions.

The current growth is primarily due to the Chinese drive toward automation in response to labor shortages and surging wages caused by demographic decline. Another boost is given by the policies of countries seeking to strengthen the international competitiveness of their manufacturing. Examples are Made in China 2025 and Japan's Robot Strategy.

(2) Broadening market

The burgeoning robotics market is also a result of the widening application of robots.

In the past, robots were developing mainly in the automobile industry. Recently, demand is on the rise in other industries. Electric and electronic industries now have the second largest demand after the automobile industry. Their application now extends across metal, machinery, and housewares—even to food. Today's extensive robotics market is the result of new technologies that have expanded the application of robots to address needs in various industries.

In other words, using robots in a wider range of fields is essential to achieving further market growth. There remain many industries without much advancement in automation with robots. The robotic market can be expanded by continuously offering the expected automation solutions in respective industries, which in turn can make positive social contributions.

2 Deployment of KHI's technologies and products

KHI sells various products as a manufacturer of industrial robots. The lineup includes a portable model with a payload of 3 kg, vertical articulated robots with a payload up to 1,500 kg, and various types of clean robots. In combination with high-performance controllers, they cater to a wide range of automation needs.

Using robots in a wider range of fields was pointed out in the previous section as the key task for expanding the robotics market. Many initiatives are taken today in our core business to expand the application of robots. This section presents the latest deployment of KHI's technologies and products.

(1) Automobile assembly

Robots are in much demand for spot welding. A large share in the sales of these robots employed in large quantity entails intense competition among robot manufacturers.

In this area of application, KHI proposes the streamlining of spot welding line by dense installation and joining methods in order to make car body structures of the next generation. These initiatives are described below.

(i) Dense installation

The number of welding spots per process in spot welding car bodies can be increased by employing a greater number of robots. Such dense installation reduces the number of processes and shortens the production line, which significantly benefits customers by holding down capital investment and cutting line operation costs.

The BX Series by KHI caters to such needs. Necessary cables and hoses for welding guns are completely built into these slim robots designed to reduce installation space. Built-in cables reduce the interference area around the upper arm. The slim waist means robots take up less space. Customers can construct a dense installation and highly efficient spot welding system as shown in **Figure 2** by selecting the right arm for their intended purposes from among the BX Series' rich lineup.

KHI is also developing a support tool to facilitate dense robot installation. Multiple robots installed in one process complicates things as their relative positions and allocation of welding spots must be taken into consideration. The ongoing development of our dense installation simulator is intended for performing such complex tasks and provide quality options.

(ii) Friction spot joining (FSJ)

FSJ, which stands for friction spot joining, is a unique technology developed by KHI to join metals with friction heat instead of resistance welding. Commercial application has already begun with the joining of aluminum alloys. Our robot systems have been introduced in automobile assembly processes, and many other places.

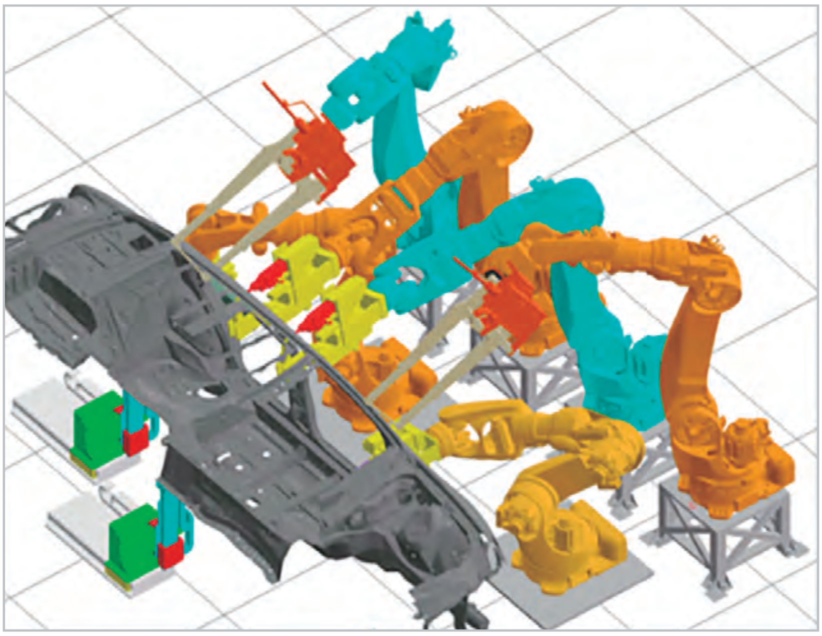


Fig. 2 Example of dense installation (6 BX Series robots on one side)

Presently, KHI is developing technologies for joining ultrahigh-tensile steels and two different materials. Prompted by environmental issues, the automobile industry is pursuing lighter car bodies through wider application of ultrahigh-tensile steel and the use of multiple materials. Because the joining of such steel or materials is very difficult, new methods are being pursued to ensure the necessary strength and productivity.

KHI offers the FSJ robot system (see **Figure 3**) as the company develops different joining processes adapted for different kinds of materials.

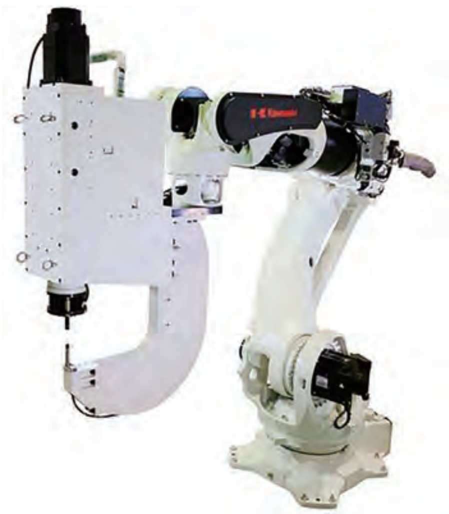


Fig. 3 FSJ robot system

(2) Painting

Painting is a tough, messy, and dangerous task that should be performed by robots. KHI boasts the might of its system engineering built on its wealth of experience. It provides painting systems that can perform various types of jobs.

Special efforts are being made to provide a compact painting booth. The intake and exhaust of a painting booth requires the greatest amount of energy in the painting process. The downsizing of the booth brings significant benefits in reduced energy costs for customers. The KJ264 is a robot designed for automobile painting with a smaller booth by pursuing light weight, slim body, and better maintainability. The interval between robots along the production line and the interference area around the booth wall can be reduced by installing the robots on a wall or on a shelf. In the case of painting an exterior panel of a car, the robot can save up to about 35% of booth area compared to our conventional models (**Figure 4**).

(3) Semiconductors

A clean robot is integrated into a semiconductor manufacturing system for carrying wafers in the system. Since its full-scale entry into this area in 1997, KHI has been developing clean robots that are compatible with various systems, and this is what made it possible to win the top market share.

	Previous models	KJ264
Necessary width of booth	6m	4.5m
Necessary length of booth	12.6m	10.9m

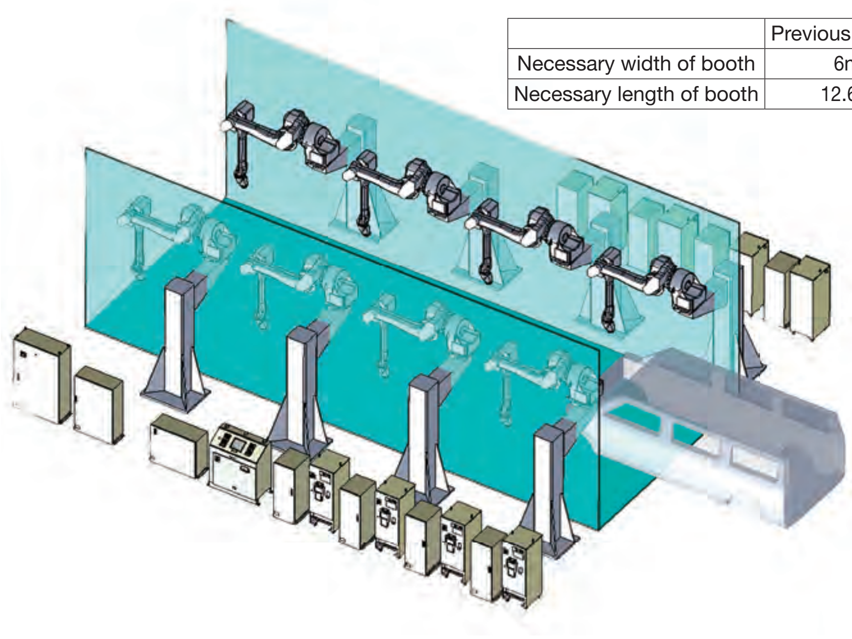


Fig. 4 Dense installation layout for exterior panel painting with the KJ264

† The fast, high-precision transfer system achieved the smallest and lightest robot of industry leading without relying on a travel unit. Power consumption was reduced by roughly 40% compared to previous models.

Figure 5 presents the NT Series, or horizontal articulated robots that form the core of our lineup of clean robots. The greatest advantage this series is that it offers access to all EFEMs* with two to four FOUPs** without using a linear axis. Such robots are employed as common platforms to build product packages with hands and sensors to meet the diverse and individual handling needs of customers.

The design concept for these robots is effectively applied in other models. Products following the NT Series inherited arms with a compact outline and a wide operating range that achieve fast and highly precise transfers. High added value originally derived from the NT Series, such as automatic instructions, self-diagnosis, and collision detection, have also received acclaim from customers.

*EFEM: A module for passing objects from one process to another inside semiconductor manufacturing equipment
**FOUP: An enclosure for wafer transfer

(4) Robot controllers

The controller plays a major role in the effort to broaden the application of robots into new areas. Robots communicate with surrounding devices and operators based on the software implemented in their controllers to perform necessary maneuvers. Application of robots can be broadened when the functions customers need are continuously implemented in controllers in the forms of device interface and software.

KHI's controllers employ the latest hardware technologies to make this happen. The latest high-speed CPUs perform fast processing of increasingly complex software to achieve multiple functions and high performance. In addition, compatibility with fieldbus, fast ethernet, Bluetooth, and so forth has made it possible to construct systems according to customer needs, and to provide new human-machine interfaces such as control systems using tablets.

Figure 6 shows the latest controllers commercialized

Fig. 5 NT Series

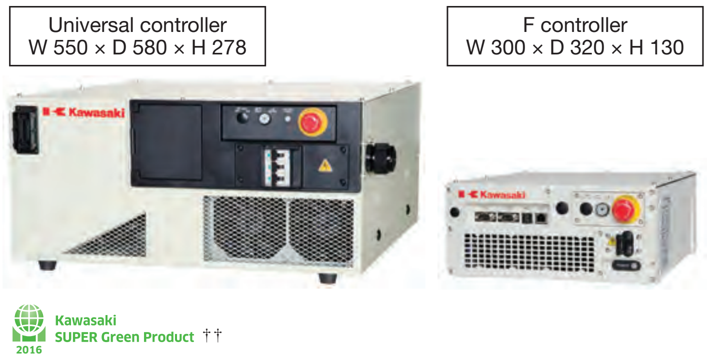


Fig. 6 New controller (Japanese specifications)

†† The functional safety technology significantly reduced electric components needed in the drive circuit. This is the smallest and lightest controller for robots with a payload between 6 and 500 kg.

between 2016 and 2017. Customers highly appreciate that these features are packaged in the smallest bodies among equivalent products.

3 Initiatives with an eye toward the future

The robotics market can only expand through the launching of new technologies in promising areas. The market is giving attention to the application of IoT technologies, as well as cooperative robots and human-cooperative robots that comply with revised safety standards. Many rigorous trials are being made.

KHI also believes these technologies hold the key for the future and thus engages in various initiatives. This chapter describes services we offer with the effective use of IoT technologies, the launch of duAro as a dual-arm SCARA robot for working with people, and our initiatives with medical robots in an entirely new field beyond industrial robots.

(1) Services with effective application of IoT technologies

Various attempts are made in the industrial world of today to effectively use IoT technologies to enhance productivity and competitiveness. By connecting things through the internet, manufacturing is expected to undergo a major change by the fusion with information analysis.

KHI employs IoT technologies in its maintenance services for robots. Elimination of downtime of robotic equipment and reduction of life-cycle costs are major concerns for customers. KHI's TREND Manager caters to these needs by remotely monitoring and predicting the failures of operating robots through the internet, which is offered as a function of our advanced maintenance service called K-COMMIT.

TREND Manager monitors the conditions of robots in operation on a real-time basis to predict possible failures. The conditions of robots are quantified and managed for analysis along with other inspection results to provide necessary information for determining the optimal maintenance cycle and activities.

(2) Collaborative Dual-arm SCARA Robot duAro

According to the revision of ISO standards established for robot safety, various robots are being proposed to work or collaborate with humans. Instead of demanding complete automation by robots, the new attempts seek to enhance productivity by letting humans and robots share the workspace and jobs as they perform tasks each of them are better at.

Toward this end, KHI has developed duAro, a dual-arm SCARA robot designed to work with people, to propose new solutions (**Figure 7**). This human-sized dual-arm robot (designed based on the concepts of "easy to use" and "cooperation and collaboration between humans and robots") can easily take over tasks performed by humans.

The arms of duAro are mounted on a wheeled base with a built-in controller. The robot can be introduced to a workspace to replace a worker without altering the existing production line. The direct teaching functionality and easy operation with a tablet can minimize preparation time from installation to operation, thus quickly building a cooperative

Fig. 7 Collaborative Dual-arm SCARA Robot duAro

††† Peripheral devices were simplified by the safety function that enables the robot to work with humans and the flexibility owing to the dual arms and concerted movement. The time it takes to begin use of the robot was significantly shortened by the simplicity of its installation.

Fig. 8 Robotic operation table “Vercia SOT-100” (Medicaroid)

Fig. 9 Illustration of a surgery assistant robot

production line for the robot and humans.

The ease in instruction and adjustment needed for the installation and operation of duAro lowers the hurdle for customers to introduce the robot. The robot is expected to be effective in applications where people used to be hesitant to use robots, for example, handling of products with short life cycles, seasonal products, and other products with great fluctuation in demand.

KHI considers cooperation and collaboration crucial for meeting social demands. The duAro is a breakthrough for the company to engage in further research to develop cooperation and collaboration technologies, and thereby widen the range of fields in which robots are used.

(3) Venturing to develop medical robots

KHI is also developing medical robots to meet the needs of the times. In 2013, Medicaroid Corporation was established jointly with Sysmex Corporation to engage in the medical robot business to underpin Japan’s aging society.

Commercialization is sought mainly with two types of products.

The first type is called applied robots, which is made by applying the technologies of industrial robots. In fact, many robot technologies can be applied to medical purposes. These technologies can make significant contributions to the advancement of medicine, provided that they meet actual needs. The hybrid robotic operating table commercialized for use in operating rooms in fiscal year 2016 is one such example (**Figure 8**). Technologies from industrial robots are applied to the drive mechanism and motion control so that the posture and position of a patient can be freely set.

Another type is surgery assistant robots (**Figure 9**). They reduce the burden on surgeons involved in maneuvering forceps, endoscopes, and other instruments during surgeries. The burden on patients is also alleviated by pursuing shorter operation times. Toward this end, a highly safe mechanism to precisely reproduce the skill and feel of a surgeon is necessary, along with an adequate control and maneuvering system. Development is underway to commercialize such robots in 2019.

Conclusion

Until now, the development of the robotics market was driven by industrial robots designed to completely replace humans. The commercial application of new technologies epitomized by cooperation and collaboration between humans and robots promises further advancement. KHI will steadily pursue the development of such technologies to continuously respond to the needs of customers and our society.

A Collaborative Dual-arm SCARA Robot, duAro, Provides a Production System That Allows Human Beings and Robots to Work Together: Development Concept and Applications

The collaborative SCARA robot, duAro, is a product created as part of our committed pursuit of ease of use. Its development concept is based on two key terms: "easy to use" and "human and robot collaboration and cooperation."

This allows robots to be installed in industries and fields that were considered to be difficult to automate due to limited preparation period and installation space, as well as cost effectiveness issues. This is a production system that effectively addresses the issues of reduced workforce and aging of population.

Introduction

As phenomena such as a decreasing birthrate, an aging population, and a decrease in the working age population advance in Japan, robot technologies hold the potential to solve social issues by solving worker shortages, alleviating workers of excessive work, and increasing productivity in a broad range of fields, including production sites in the manufacturing industry, medical and nursing care sites, and work sites in the agriculture, construction, and infrastructure fields.

1 Background

In the past, industrial robots have been introduced and developed mainly in mass production fields with long product lifecycles, such as the automotive industry. On the other hand, in fields in which product lifecycles are short and model changes occur every few months, such as the electric and electronic fields, automation has been considered difficult due to the limited preparation period and cost effectiveness issues, even though the introduction of robots has been desired.

In addition, although it is said that 300,000 robots have been introduced throughout the more than 40-year history of industrial robots in Japan, most of them were adopted only by major businesses in reality.

In order to solve countrywide labor shortages, it is indispensable that robots be introduced in small- and medium-sized companies, which account for 99.7% of all companies. However, the spread of conventional robots that require safety fences, as well as the acquisition of special handling knowledge, has been difficult.

2 Development concept of the Collaborative Dual-arm SCARA Robot duAro

The collaborative dual-arm SCARA robot duAro has been developed based on the key development concepts "easy to use" and "human and robot collaboration and cooperation."

In order to lower the barrier to the introduction of robots in industries or fields in which automation has been considered difficult due to limited preparation periods and installation space, as well as cost effectiveness issues, duAro has been designed to replace production line workers without any modification. By making it possible for duAro to collaborate with humans, the need for safety fences, which were mandated to prevent collisions for conventional industrial robots, has been eliminated.

(1) Collaboration with humans

In order to enable collaboration between humans and robots, safety was sufficiently ensured through the use of low power motors with an output of 80 W or less and a

† Simplifies peripheral equipment through safety functions that enable collaboration with humans and flexibility achieved by collaborative dual-arm operation. Radically reduces the start-up time through easy introduction.

speed reduction function by area monitoring, after conducting a risk assessment.

The speed reduction function by area monitoring allows the robot operation range to be set to low-speed and high-speed operation ranges, as illustrated in **Fig. 1**. The robot can be operated efficiently by operating the robot at a low speed near areas where humans are working and at a high speed in areas away from humans.

Even if the robot contacts or collides with a human while working, it can be stopped by the collision detection mechanism.

In addition, the robot has a rounded design and arm covers, which conventional robots do not have. The arm covers are made of foamed urethane to provide a cushioning property, enabling humans to collaborate with the robot with a sense of safety.

(2) Space conservation

Each duAro arm is designed to be 76 cm in length, which is approximately the same as the working range of a person, so that it can be installed in a space intended for one person and perform tasks performed by a human using both arms in a single-person space. As illustrated in **Fig. 2**, the robot is designed so that it can be installed in a single-person space by controlling two arms arranged on the same axis by one controller. This coaxial dual-arm configuration allows duAro to perform cooperative operations using two arms that cannot be realized by using two conventional SCARA robots.

(3) Easy installation

The duAro's controller can be stored on a cart to which the arms are attached in order for it to be introduced

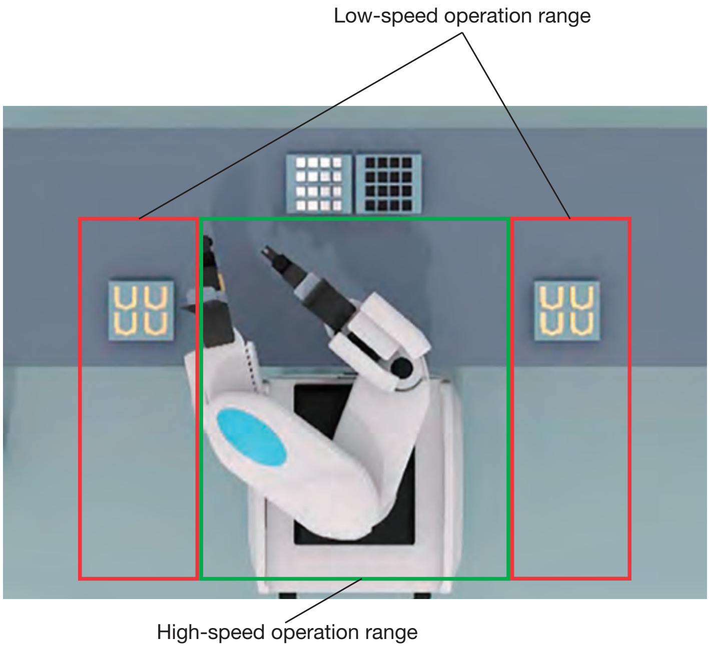


Fig. 1 Speed reduction feature using area monitoring

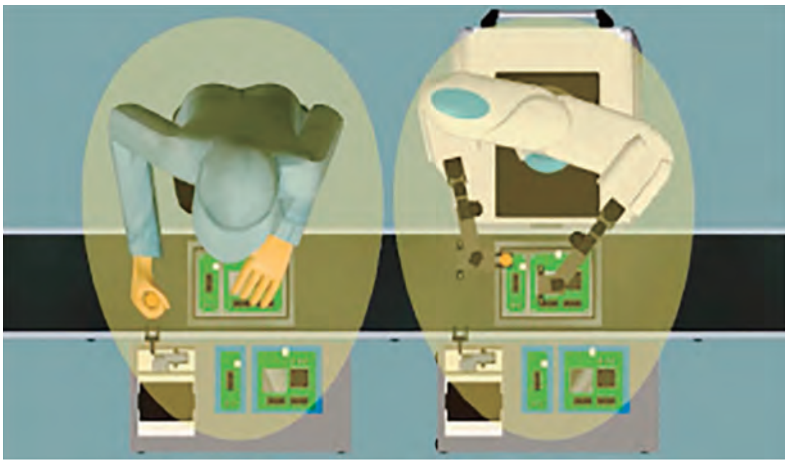


Fig. 2 Co-operation between people and duAro

without modifying the production lines. By moving it with a cart, it can be easily installed in the position where it will be used. This makes it possible to replace a worker at any position on the production line, as illustrated in **Fig. 3**.

(4) Easy teaching

When introducing a conventional robot, it was necessary to teach the work procedures to the robot by strictly defining them using a program. However, with duAro, the teaching operation has been simplified by the direct teach function, as well as by utilizing a tablet.

The direct teach function teaches the robot by moving the robot arm in simulation of the actual movements, as illustrated in **Fig. 4**. Gravity compensation of the direct teach function is set so that the arms can be smoothly moved for teaching not only in the horizontal direction but also vertically. Gravity compensation enables smooth movement on the Z axis according to the weight of the end effectors attached to the extremities of the arms by calculating the compensation value, which done by adding the end effector weight.

In addition, usability is enhanced in duAro by transferring the teach pendant function to a dedicated Android tablet, eliminating the teach pendant used for conventional industrial robots.

(5) Easy introduction at low cost

Many customers who desire automation request that the work environment of the workers that are to be replaced by robots remain unmodified. Therefore, in

Fig. 3 Install robots without production line modification

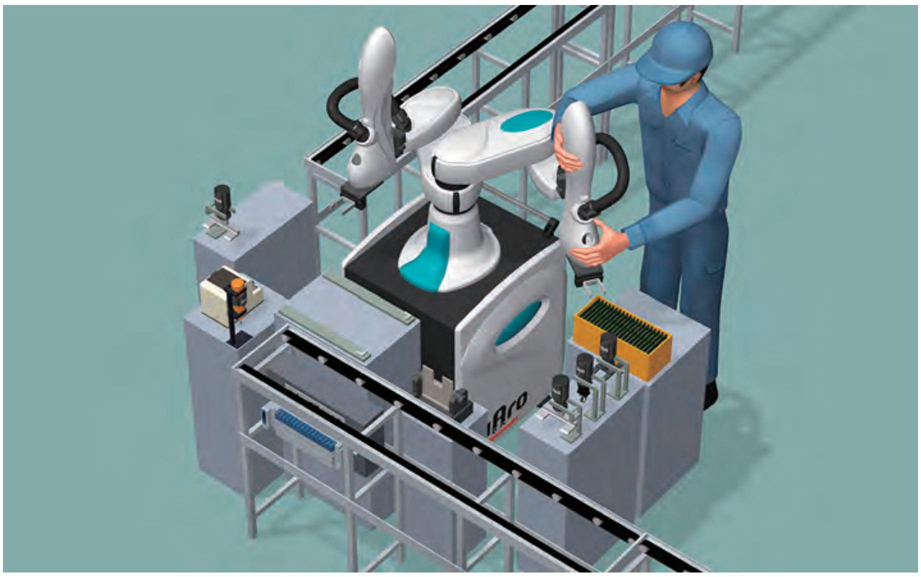


Fig. 4 Direct teaching function

consideration of the types of work that are performed by duAro it is necessary to have an understanding not only of how the workers perform work, but also what kinds of tools they use and how the tools are used.

In addition, some customers desire that the tools or jigs that are currently used by the workers continue to be used to reduce the cost of introduction. With duAro, the tools or jigs used by the workers can be used by attaching the base-chuck shown in **Fig. 5**, which is provided as a standard interface part, to both arms. With the base-chuck, it becomes possible to efficiently switch between different tools or jigs by attaching a part called a conversion adaptor to each tool or jig.

In addition, general single-arm robots cannot perform work properly unless the parts are placed in certain positions when they perform assembly or transport. Therefore, it was necessary to position parts using a different mechanism or supply parts to the specified positions using special jigs. However, duAro can position parts using both arms or perform work with one arm while assisting with the other arm.

For example, when tightening the screws of a printed circuit board into a PC, as illustrated in **Fig. 6**, duAro can tighten the screws while supporting the PCB with one arm as humans do. This eliminates the need for a unit to support the PCB that was necessary with conventional robots.

Moreover, when transporting workpieces of different

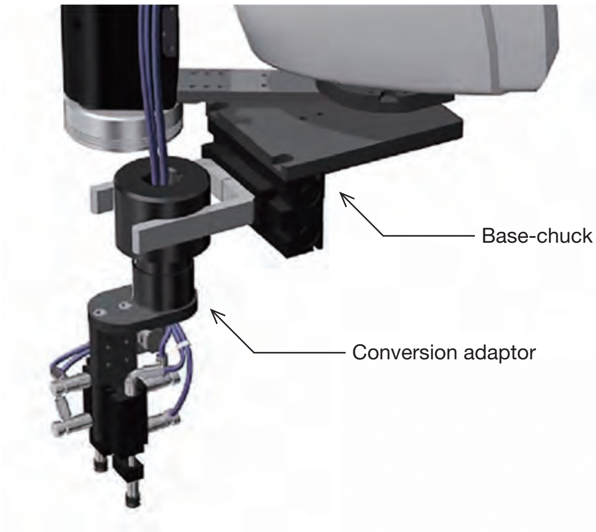


Fig. 5 Base-chuck and conversion adaptor

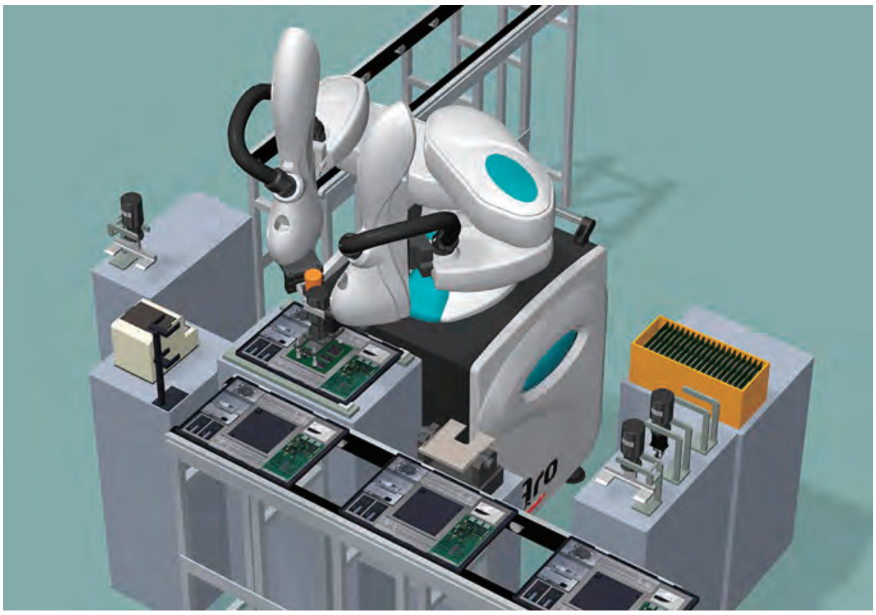


Fig. 6 Tighten the screws of printed circuit board to PC

sizes, it was necessary to design and fabricate dedicated hands for conventional robots for each workpiece size. However, since duAro has a dual-arm configuration, it can perform actions such as "scooping" or "sticking" regardless of the size of the workpiece and transport large workpieces or workpieces of different sizes just using its general hands.

3 Example applications of duAro to production systems

Example applications of duAro in actual work sites are introduced below.

(1) Screw tightening process (collaboration with humans)

When applied to the screw tightening process, "human-robot collaboration" has been realized, and work is shared between the duAro and workers. In this application example, a duAro has been introduced in place of the worker who was originally in this position, and it tightens screws with the electric screwdriver that the worker previously used while supporting the workpiece with one arm.

The introduction of duAro has brought various benefits. Taking cycle time as one example, work that used to take 14 seconds when performed by a human worker is performed in 9 seconds after introducing the duAro.

(2) Loading/unloading (easy installation)

When applied to loading/unloading for the pressing machine illustrated in **Fig. 7**, "easy installation" has been realized.

In this application example, duAro loads and unloads an automobile part called a sleeve yoke into/from a pressing machine. Since the pressing machine requires mold

Fig. 7 Application of loading/unloading for pressing machine

Fig. 8 Application to rice ball packaging

changes depending on the part type, there was a problem in which the mold change operation became a hassle when a loading/unloading mechanism was installed for automation. However, since the duAro can easily be transported with the cart, it can easily be pulled out of the pressing machine when changing the mold.

(3) Rice ball packaging in food trays (space conservation)

In the food industry, the reduced workforce and aging population have become issues, and there is a pressing need for automation. However, it is often the case in food factories that many workers and pieces of equipment are arranged side by side in a limited space and there is not enough space to introduce machines. Due to these circumstances, the space duAro can save is attracting attention, and many inquiries.

In the application to rice ball packaging in food trays illustrated in **Fig. 8**, the work of packing triangular hand-rolled rice balls transported from upstream into food trays is automated while saving space.

In addition, food-grade grease is used in duAro to ensure sanitation. Moreover, it is also possible to cover duAro with a clean suit for robots.

Conclusion

The spread of co-existing, cooperative robots is accelerating, and it is believed the that production system realized by duAro, which allows human beings and robots to work together, will become an effective countermeasure against the reduced workforce or aging population in the future. We are planning to further shorten the preparation period for the introduction for applications that are frequently requested by offering duAro packaged cells. We will continue to work to realize greater production to allow humans and robots to work together.

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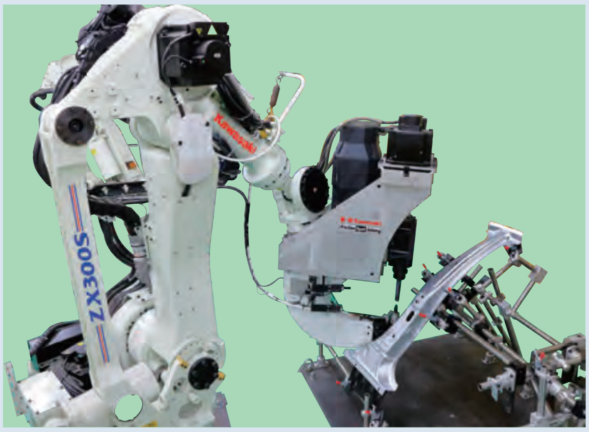
Application of Friction Spot Joining Technology to High Strength Steel: FSJ Robot System for Steel



One of the main application areas of industrial robots is spot joining in the assembly process for car bodies. We are selling resistance spot welding robots. In addition, friction spot joining (FSJ) robots that include our unique technology are already being offered on the market. The FSJ is used for joining of aluminum alloys in the field of manufacturing.

We are currently developing a "FSJ system for steel," with the aim of applying it to ultra-high-strength steel, whose utilization in car bodies has been increasing.

Introduction

It has been a while since global warming first started gaining prominent attention as a social issue. Regulations on greenhouse gases such as CO_2 have been getting stricter globally, affecting cars, which already number in the millions in advanced countries and are increasing in developing countries year by year.

1 Background

To meet the strict CO_2 emission control regulations for cars in recent years, it is required to improve the fuel efficiency of cars, and thus, car manufacturers are focusing on improvement of transmission efficiency, reduction of air resistance, and making car bodies weigh less. Luxury cars manufactured in Europe and the U.S. are currently in the process of replacing the materials they use for car bodies with aluminum, CFRP (Carbon Fiber Reinforced Plastic), or other lightweight materials, while Japanese manufacturers, etc. are also promoting the use of steels as much as possible, which are advantageous cost-wise. Steel has a wide range of strengths, so various types of steel materials are available. For example, soft steels with a tensile strength of 270 MPa are used for external panels, and hard steels with a strength of 1500 MPa are used for car body frame members such as pillars. In particular, applications of ultra-high-strength steels with strengths of 780 MPa or higher have been increasing rapidly (**Fig. 1**).

However, such ultra-high-strength steels are becoming harder to weld with the resistance spot welding method alone, which is currently the main method used for car body welding. This is because the ultra-high-strength steel contains a lot of added elements, which help improve hardenability and increase the tensile strength, and thus, when the steel is melted and then quickly cooled during welding, the welded part is noticeably harder. Therefore, the joint strengths, especially the peel strength, are likely to vary. It is also difficult to obtain adequate strengths, which is an important issue to resolve if one is to use steels as much as possible.

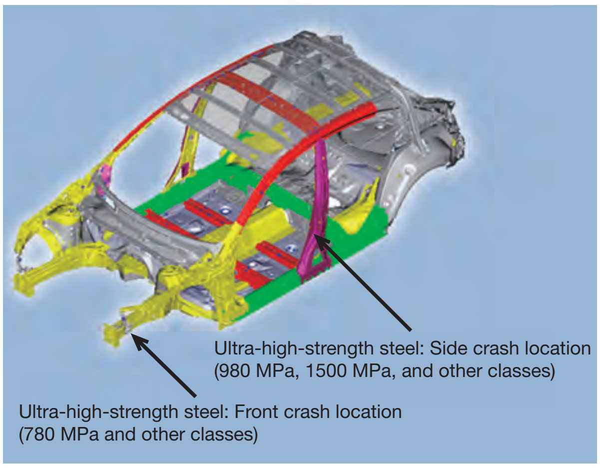


Fig. 1 High-strength steel applied to car bodies

In these circumstances we are developing friction spot joining (FSJ), which applies friction stir joining (joining materials by using heat caused by friction and plastic flow) to spot joining, and a "FSJ robot system." They are increasingly being applied to car parts made of aluminum alloys.

2 Overview of the FSJ robot system

Figure 2 shows the fundamental process of FSJ. In this joining method, a rotating joining tool is pushed against the workpiece to generate frictional heat and the heat softens the workpiece. A pin at the tip is then inserted into the workpiece to generate plastic flow around it to unify them.

The FSJ robot system is used to produce car hoods and doors made of aluminum alloy and over 300 systems have already been introduced in the production lines of car manufacturers.

Currently, in order to apply this system to ultra-high-strength steels, we are developing an "FSJ robot system for steel."

3 Application to ultra-high-strength steels

Since ultra-high-strength steels are harder and have a higher softening temperature than those made of aluminum alloy, it has been difficult to apply FSJ to them. In particular, when compared with resistance spot welding, it was very difficult to extend the life of the joining tool, which corresponds to the electrode tip of the resistance spot welding, and secure an adequate joint strength. Therefore, we have carried out the development focusing on making a "practical high-durability joining tool" and "FSJ joining process that is suitable for ultra-high-strength steels" (**Fig. 3**).

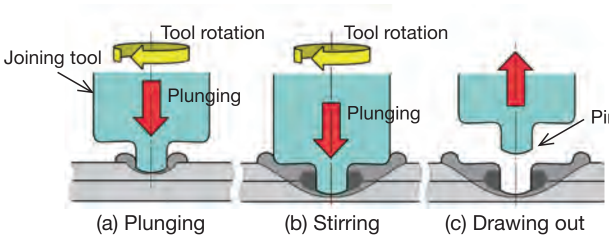


Fig. 2 Fundamental process of FSJ

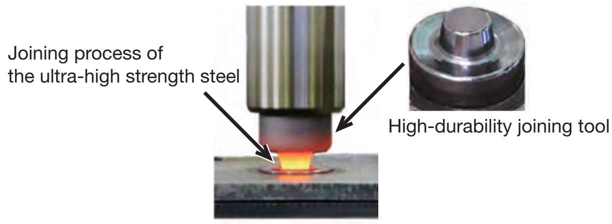


Fig. 3 Development theme

(1) Development of a practical high-durability joining tool

(i) Materials of the joining tool

One of the basic requirements for the development of a long-life and inexpensive tool is to have a cycle time that is equivalent to that of the resistance spot welding currently being used, especially in the automotive industry, while maintaining a similar joint cost.

The following lists the main characteristics of the materials required for the joining tool.

① Ability to withstand a rapid heat cycle that reaches over 1,000°C from room temperature in several seconds
② Low responsiveness with the materials of the object being joined to
③ Superior oxidation resistance
④ Stable organization even at high temperatures with sufficient strength, hardness, and toughness

When joining ultra-high-strength steel, a large axial load of 20 kN or more may be applied to the tool. Therefore, the steel must withstand a high axial force and torsional stress in temperatures from room temperature to high temperatures. In addition, since ultra-high-strength steel used as a material of the object to be joined to is harder than aluminum alloy even at high temperatures, the tool wears easily and it is also important to secure wear resistance.

Candidates for the tool material include cemented carbide mainly consisting of tungsten carbide (WC), ceramic such as silicone nitride (Si_3N_4), and PCBN (Polycrystalline Cubic Boron Nitride) made of sintered cubic boron nitride particles. During the development, in order to make the tool industrially acceptable, we set the first goals for its life when used for joining ultra-high-strength steels to be approximately 5,000 joints and the cost for each joint to be 1 yen or less. In addition, for joining using robots, a joining gun that is as compact and lightweight as possible is desired because there are limitations on the weight capacity, operation speed, etc. Therefore, we also considered the selection of the coefficient of friction and thermal conductivity to be an important point so that even small axial loads can generate sufficient frictional heat.

(ii) Evaluation system for tool durability

When developing a tool, tool durability must be evaluated. In the tool durability evaluation, it is required to not only implement a continuous joining test, but also to observe in detail and record the dimensions, the profile, and the external appearance of the tool, which change during the test. It is also required to periodically obtain the transition of the joint strength as the tool dimensions change. If a human being carried out such evaluation work, he could only make about 1,500 joints a day maximum. To promote tool evaluation and development efficiently, we developed an evaluation system for tool durability testing using three robots, as shown in **Fig. 4**. This system automated a series of tasks and data collection, ranging from supply of test pieces to the joining jig and their removal after joining, to monitoring of the joining status, dimension measurement and taking photos of the tool and test pieces, and implementation of the tensile test. This allowed 10,000 joints to be made in the continuous joining test in a day at maximum, which enabled accelerated tool development.

(iii) High-durability joining tool

Using the evaluation system for tool durability, we carried out performance evaluation of a huge number of prototype tools. The material used for the tools was PCBN, ceramic, and cemented carbide with coating as shown in **Table 1**. PCBN is very hard and has superior wear resistance. It also showed a relatively long life of 7,000 joints as a result of the test using 980 MPa class ultra-high-strength steel. However, PCBN is a very expensive material. Ceramic can be mass-produced at a lower cost, but has some issues such as the necessity to take countermeasures against breakage due to low toughness. The life of cemented carbide needs to be extended by

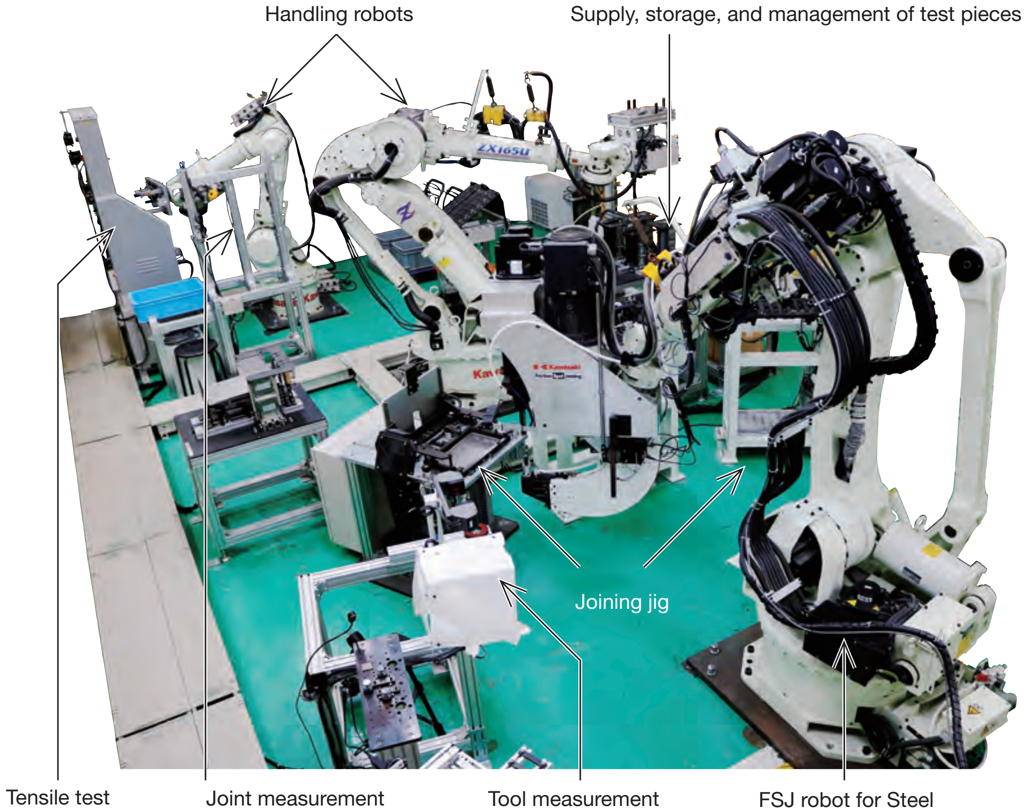


Fig. 4 Evaluation system for tool durability

Table 1 Example of prototype tool

	PCBN	Ceramic	Cemented carbide
External appearance			
Durability	○	△	○
Manufacturing cost	×	○	○
Joint cost	×	○	○
Total evaluation	△	○	◎

using refined materials and coatings, but it has a good balance between durability and cost.

We looked into this cemented carbide and advanced the development of a tool made of it in cooperation with Sumitomo Electric Industries, Ltd. During this development, we refined the material and coating and optimized the joining process in order to improve the plastic deformation resistance, defect resistance, wear resistance, and other properties of the tool.

Figure 5 shows the changes in the pin diameter and tensile shear strength of the joint during the continuous joining test. As the number of joints increased, the pin diameter decreased because the edge of the pin tip was worn. Although the tensile shear strength gradually decreased accordingly, it was still higher than the minimum value for Class A of the JIS standard for spot welding (Z3140), which was our criteria, and durability of at least 13,000 joints was confirmed.

At the beginning of the development, the tool was judged to reach its life when no more than 2,000 joints were carried out because the pin of the tool was worn, which lowered the joint strength. However, by developing a tool made of improved materials and a joining process that reduces loads to the tool, the amount of wear reduced and the joint strength defined in JIS was satisfied even after 13,000 joints, which results in a lifespan six times the first tool or longer. Considering that it is said that the electrode tip used for resistance spot welding is to be replaced after approximately 10,000 joints, the tool has a life that is equivalent to that electrode tip, and we can say that the tool has made progress toward practical realization.

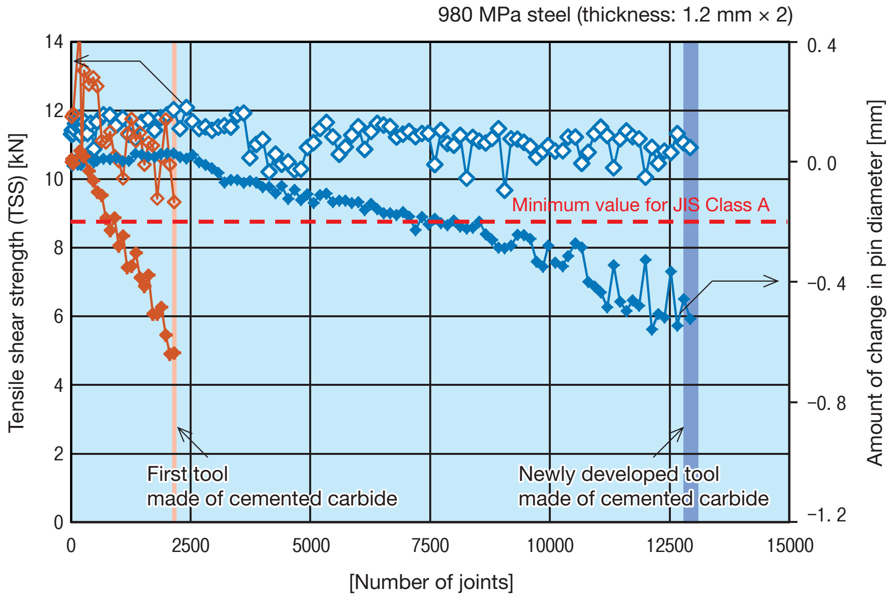


Fig. 5 Test results of continuous joining

We will continue to implement durability evaluations using even higher strength steels and review the stability of the tool quality and cost savings.

(2) Development of a joining process suitable for ultra-high-strength steels

Carbon is used to increase the strength of steels. Ultra-high-strength steels contain an especially large amount of carbon. In addition, to improve the hardenability, some elements such as manganese are added. Although the amount is set in consideration of weldability, the weld strength varies in reality and it is difficult to secure the joint strength itself. This is a welding issue that is specific to ultra-high-strength steels, and its solution is an important key to using steel materials as much as possible.

In welding methods known as fusion welding such as resistance spot welding, since the steel materials are heated up to the melting point or higher, the welded part is hardened during cooling and embrittlement occurs. Therefore, the hardened welded part is heated up again in the same or a different process to temper it and recover its toughness. However, it requires careful heat input control because the characteristics vary depending on the hardening that occurred after welding, the heating method, and the heating temperature and time.

On the other hand, FSJ does not melt the steel materials but joins them in the solid state by using plastic flow. Therefore, the highest temperature during joining can be kept below the hardening temperature, and it may be possible to realize joining without hardening the joint. This

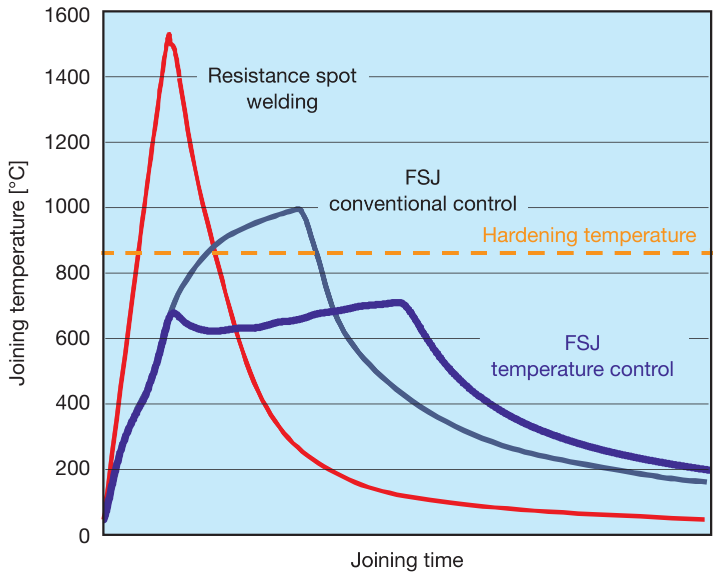


Fig. 6 Thermal history of joint during FSJ

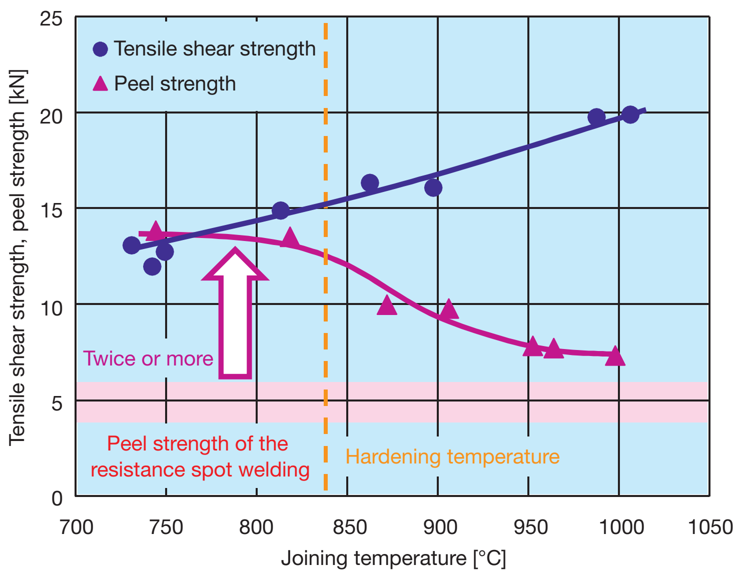


Fig. 7 Joining temperature and joint strength

is a characteristic advantage of FSJ, a form of solid-state joining, and it is an innovative method that makes a clear departure from conventional welding methods.

Focusing on the innovativeness of FSJ, we developed a unique joining temperature control process that monitors the temperature during joining and changes the joining conditions to keep the temperature constant.

The history of the joining temperatures is shown in **Fig. 6**. For comparison, it also schematically shows the temperature histories of resistance spot welding and FSJ using conventional controls. For resistance spot welding, the joining temperature far exceeds the hardening temperature and hardening occurs during cooling, which results in embrittlement. For FSJ using conventional control, the temperature goes above the hardening temperature. On the other hand, for FSJ using the joining temperature control, joining is possible without exceeding the hardening temperature.

Next, **Fig. 7** shows the tensile shear strengths and peel strengths of a joint on 1500 MPa class ultra-high-strength steel (thickness: 1.8 mm) when the joining temperature is changed by the joining temperature control. Both strengths change characteristically depending on the joining temperatures. When the joining temperature is high, the peel strength is low while the tensile shear strength is high. In contrast, when the joining temperature is lower than the hardening temperature, the tensile shear strength is low while the peel strength increases drastically. We confirmed that the peel strength at that time was at least twice that of resistance spot welding.

The tensile shear strength and peel strength have a trade-off relationship. In this way, the desired characteristic can be obtained in each part by controlling the temperature so that the parts that require shear strength are joined at a high temperature and parts that require peel strength are joined at a low temperature.

In addition, use of this joining temperature control enables joining of high-carbon steels, which are considered difficult to weld due to the significant embrittlement, and during dissimilar materials welding, it may be possible to control the thickness of the intermetallic compounds on the joint interface. As described above, FSJ using joining temperature control is a brand-new second-generation FSJ, and an innovative joining method that will dramatically expand the applicable range of the materials that can be joined compared to the conventional welding method.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Conclusion

It started to show signs of the practical realization of long tool lifespans, which was the biggest issue for the application of FSJ to steel materials. In addition, we succeeded in the development of our proprietary joining temperature control process that is suitable for joining ultra-high-strength steels. Now, we will focus on the "FSJ robot system for steel" for the production of car bodies, accelerating its development toward practical application.

Part of the development was implemented with the support of the Innovative Structural Material Association (ISMA).

Ultra-high Payload, High Rigidity Robot MG10HL and Its Use in Production of Airplane Parts

As the global population increases and developing economies expand, the demand for airplanes are expected to increase. However, the majority of their production is still carried out manually and thus, it is required to promote automatization in order to strengthen productivity. In these circumstances, we are working on introducing MG10HL in the production of large airplane panels in order to increase production efficiency to meet the increasing demand and reduce production costs by using automated robots.

Introduction

As the global population increases and developing economies such as those in Asia, South America or Africa expand, it is expected that there will be a demand for nearly 40,000 new airplanes over the next 20 years. On the other hand, however, the majority of airplane production work is still carried out manually, and the productivity necessary for satisfying the future increase in demand has not been secured at this point.

1 Background

Hopes are high for production automation using robots as a means to support the increased demand for airplanes. Robotization will bring various benefits such as improved production efficiency, reduced production costs, stable product quality, and reduced production space.

2 Issues facing the production of airplane parts using robots

The sizes of airplane parts run the gamut from small to large. Automation is limited with only some of the production of large parts being automated by large specialized machines. In order to realize automation using robots, it is necessary for robots to have a large operating range, as well as a payload that can withstand the weight of the work tools and the force generated.

On the other hand, while large robots have a large operating range, their absolute positioning accuracy is difficult to improve as they have large deflections at their movable parts, a result of combining link mechanisms. In addition, in order to improve absolute accuracy, it is also necessary to improve the setting accuracy of equipment or parts other than the robots themselves, such as the transportation systems, which narrows down the selection range for the robot systems.

To address these issues, it is most reasonable to improve the hardware rigidity of the robot arm, while compensating for component errors or deflection in movable parts by using software to improve the spatial position repeatability accuracy and providing a mechanism for correcting the relative positional relationship with the workpiece.

3 Airplane part production by the MG10HL ultra-high payload, high rigidity robot

In the production of large fuselage panels for airplanes, robots are required to have a broad range of motion that enables them to access the entire panel, which has a height of 3 m, high positioning accuracy that enables them to accurately move to the correct machining area, and high rigidity that enables them to maintain their position when a machining reaction force is generated, as well as a load capacity that can withstand the generated machining reaction force. In the FSJ (Friction Spot Joining) system using opposing robots suggested by Kawasaki as a new

† An arm with a unique structure, employing a hybrid link and ball screw drive. It simultaneously achieves a payload of 1 to 1.5 t without a counterweight and reduced body weight.

panel joining method, a large machining reaction force of over 10 kN is generated. Our MG10HL ultra-high payload, high rigidity robot can withstand this force.

(1) High rigidity hardware

The structure and operating range of the MG10HL are shown in **Fig. 1** and **Fig. 2**. The MG10HL needs to have a payload of 1,000 kg, a reaction force resistance of 15 kN, and rigidity that minimizes deflection when a reactive force is generated. To realize these properties, we used high rigidity ball screws in the second and third axes, which have a large effect on deflection, in combination with our unique fixed parallel link structure to simultaneously achieve an operation range and rigidity that accommodates large panels. Compared to the differential reduction gear that is usually used in large-sized robots, the ball screws in the linear motion mechanism make the joint rigidity of the second and third axes approximately twice as great. Meanwhile, we have realized the industry's smallest size and lightest weight by eliminating the counterweight.

Moreover, we have also reduced the cost while realizing a high payload by applying dual control using two

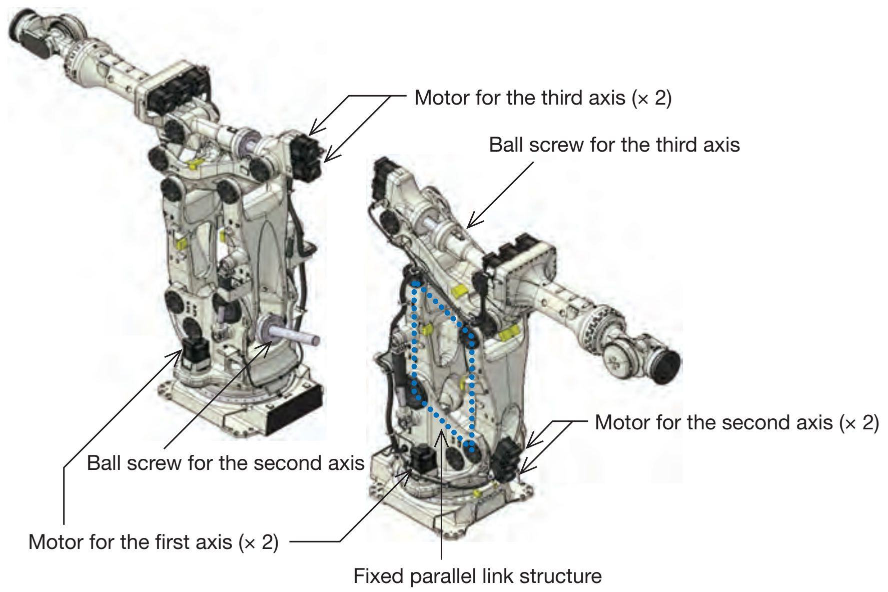

Fig. 1 Structure of MG10HL

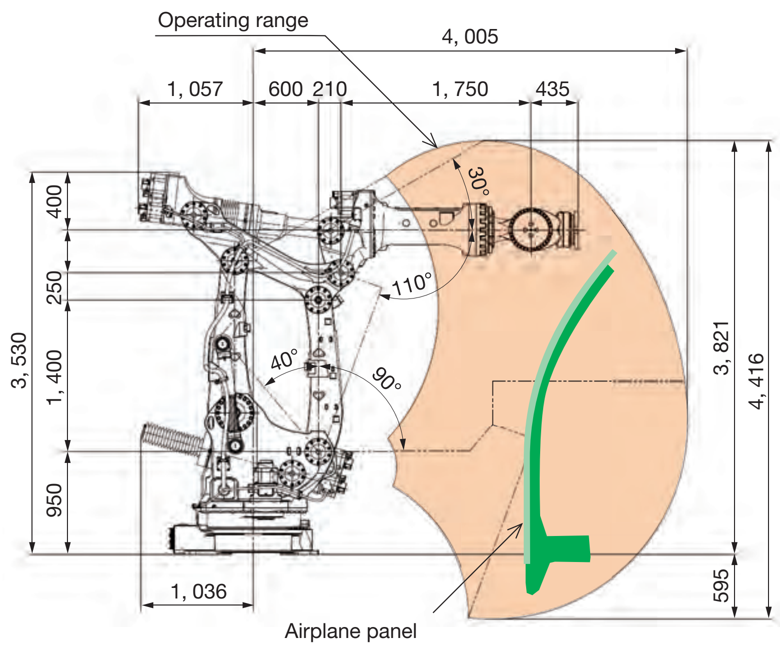

Fig. 2 Operating range of MG10HL

of the standard motors used in our other robots to the first, second and third axes. The same maintainability as that of our previous robots is also ensured with the MG10HL.

(2) Improvement of absolute accuracy using software

Although the MG10HL has a highly rigid arm structure, deflection occurs due to tools or its own weight. Due to this deflection and dimensional errors of parts or assembly errors, deviation from the ideal position occurs. The ideal position refers to the spatial coordinates specified by offline teaching, and the accuracy with respect to this position is what is known as absolute accuracy. We provide a position and deflection compensation function using software for improving the absolute accuracy. The part dimensions and spring constants of the joint and arm are identified by measuring the end position of the robot wrist in several postures and calculating the difference from the ideal position for each robot. Using the identified value, positional compensation is performed as shown in **Fig. 3**. Using this absolute position compensation function, the MG10HL has achieved a high repeatability accuracy of ±0.7 mm with respect to the ideal position within its normal operating range.

4 Case example of applications to airplane part production

(1) Drilling holes in airplane panels

Components of an airplane panel are joined by rivets or other fasteners, and the main wings are connected by large diameter fasteners. In areas where rigidity is required such as at the bases of the main wings, large holes with a diameter of approximately 20 mm are drilled in a panel with a thickness of approximately 75 mm in some cases. When drilling such a large hole, a large reaction force is generated against the worker holding the drill. Therefore, automation of this process is desired.

A robot that drills large holes for assembling components with airplane panels is shown in **Fig. 4**. Although high repeatability accuracy is required in this

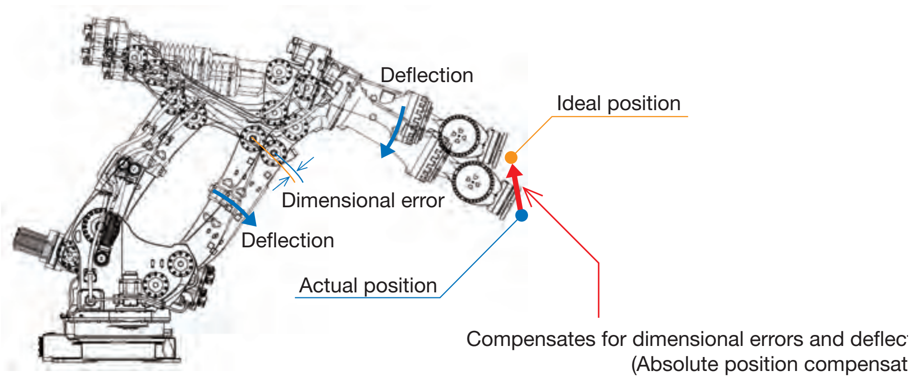

Fig. 3 Compensating for location and deflection

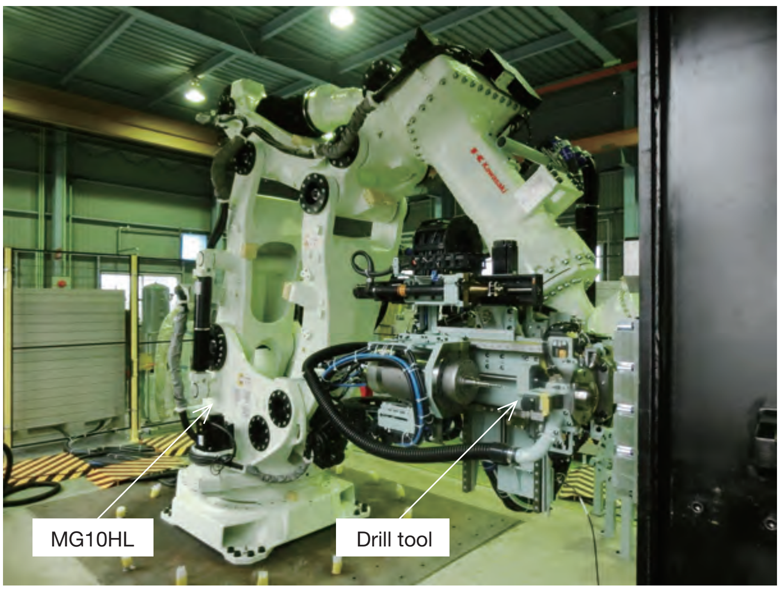

Fig. 4 Drilling robot

application, this is affected by the machining accuracy of the workpiece and the relative positional relationship between the robot and workpiece, as well as the repeatability accuracy of the robot itself. For this reason, the relative position accuracy for the workpiece is ensured by using position compensation technology with two types of sensors, as described below, in addition to the previously described absolute position compensation function.

① Hole position compensation by the two-dimensional sensor

First, the position of the base hole provided near the hole positions in advance is detected by the two-dimensional sensor mounted to the drill tool, as shown in **Fig. 5**. Next, based on the detected position of the base hole, the positions of the holes to be drilled are calculated. In this way, the accuracy of the hole positions with respect to the workpiece is ensured.

② Slip compensation by the force sensor

This function compensates for slipping of the drill tool that occurs when pressing the tool against the airplane panel. As shown in **Fig. 6**, the force sensor is mounted between the drill tool and the robot, and the force that causes the drill tool to slip generated by the pressing reaction force is detected. Based on the value of the force sensor, the robot is operated in the direction that cancels out the slipping to prevent displacement.

These compensation functions give the robot the required repeatability accuracy for drilling holes, as shown in **Fig. 7**.

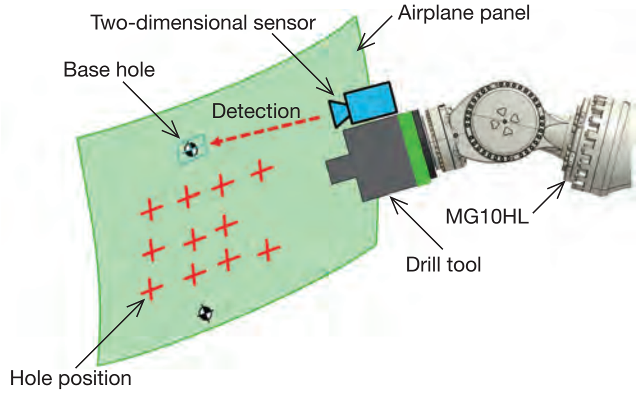

Fig. 5 Sensing base hole positions

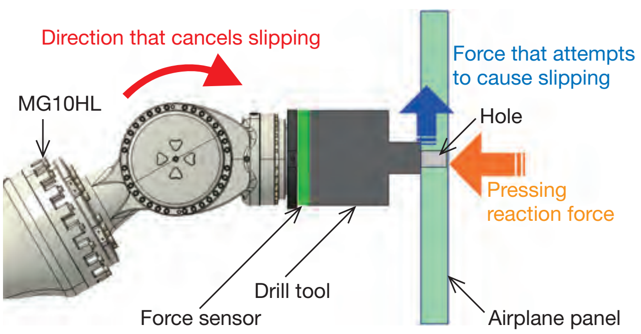

Fig. 6 Mechanism of slip compensation

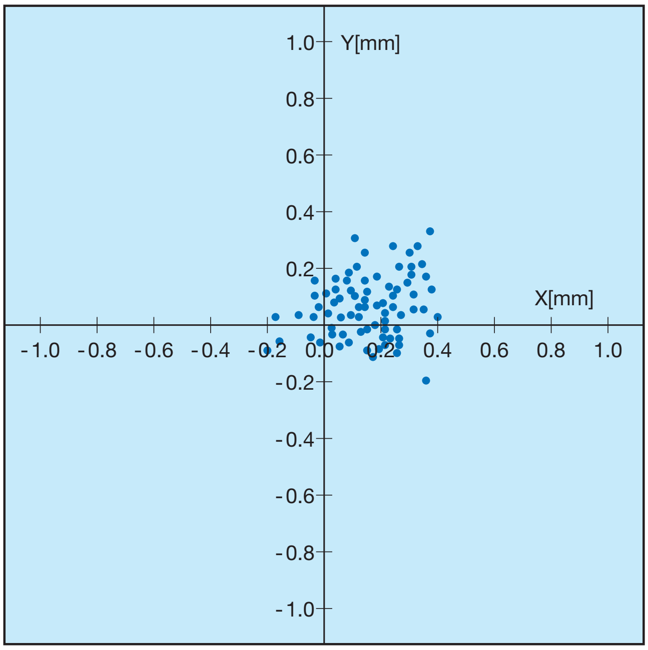

Fig. 7 Repeatability accuracy of positioning

(2) FSJ of airplane panels using opposing robots

As mentioned previously, components of airplane panels are joined using rivets. However, it is expected that the cost of airplane production can be significantly reduced in the future by replacing these rivets with the FSJ system developed by Kawasaki.

To implement it with robots, one robot holding a joining gun is placed on the interior side of the airplane panel, and another robot holding a backing anvil gun is placed on the exterior side of the airplane, as illustrated in **Fig. 8**. FSJ is performed by cooperatively operating these two opposing robots to sandwich the skin material and frame material between the joining gun and backing anvil gun from either side of the airplane panel. The joining gun and backing anvil gun press against each other with a pressure exceeding 10 kN while remaining completely perpendicular to the frame material. In addition, it is also required that axes of the two guns be centered to within 1 mm.

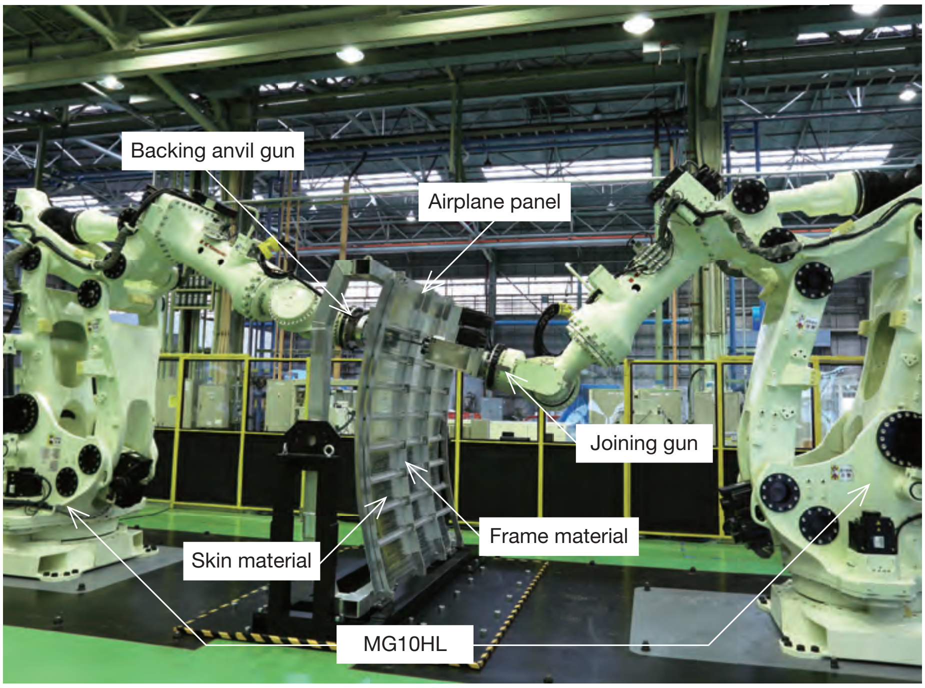

Fig. 8 FSJ System using opposed robots

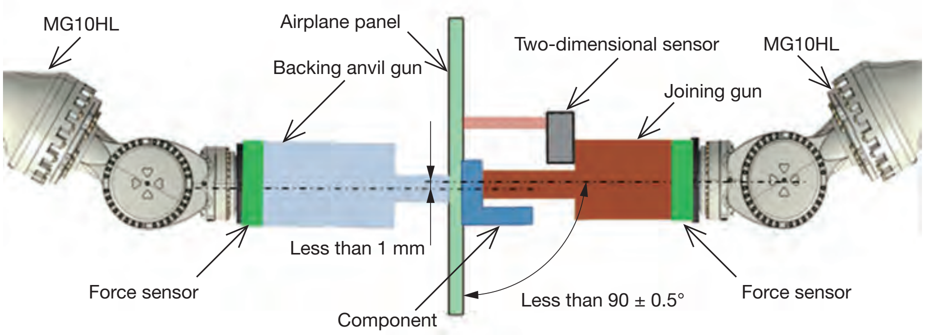

Fig. 9 Compensating for gradient of opposed robots

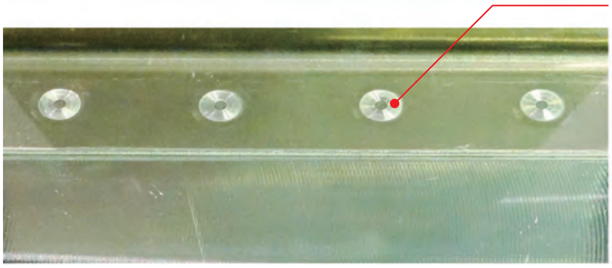

Fig. 10 Work sample of FSJ

To satisfy these requirements, position compensation is performed by two types of sensors described below, as in the case of drilling.

① Position compensation by the two-dimensional sensor
As shown in **Fig. 9**, the joining surface of the frame material is detected by the two-dimensional sensor, and perpendicularity compensation is performed so that the joining gun maintains the specified perpendicularity ± 0.5°.

② Slip compensation by the force sensor
Compensation is performed for slipping of the gun that occurs when it is pressed against the airplane panel during joining.

Figure 10 shows an area joined by FSJ on the inner face of an airplane panel. This joining system also achieves a panel outer face that is smooth enough for practical application, which contributes to improvement of the aerodynamic performance of the airplane.

Conclusion

Robotization has begun in the field of airplane production, a field in which it had not made progress before. We are a manufacturer that operates both an airplane business and robot business, and by integrating technologies that have been accumulated in each field, we will continue to promote automation of airplane production. Meanwhile, we will also apply new technologies produced through this integration to other fields such as the automobile field.


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Robot Production Factory with Robots

In June 2015, we started operating a robot production factory in Suzhou, China. This factory is intended to leverage the power of robotics based on the concept of "Producing robots using robots."

The robots are involved with processes that require high quality and heavy-duty assembly that human beings are not good at, while people are involved with simple work such as preparation and allocation of parts. This realizes high levels of both quality and productivity.

Introduction

With the rapid economic growth in China, serious issues such as labor shortages have been emerging in the manufacturing industry in recent years.

As one issue in the manufacturing industry in China, it is becoming difficult to secure a high-quality workforce. In China, the turnover of workers is high, and workers are not loyal to their companies even after being trained for a long period of time. Therefore, management is always facing the issue of securing high-quality workers.

Controlling labor costs is another serious issue. The manufacturing industry in China has been increasing its production amount based on the advantage of its labor costs. Now, however, the issue is how to improve profits, which have been tight because of increasing labor costs.

1 Background

The most effective means of solving these issues is the introduction of robots. When using robots, product quality can be stabilized without being dependent on the skills or experience of humans, and production is not affected by fluctuations in labor costs.

In order to inform our customers of the advantages of robots, we opened a production factory in Suzhou, China in June 2015, which is based on the concept of "Producing robots using robots." We aimed to give the factory the role of showroom for potential customers considering the introduction of robots by realizing a highly automated cutting-edge factory using robots.

2 Factory concept

In this factory, the processes that used to depend on human workers, from picking of parts to assembly, painting, and inspection were highly automated to simultaneously achieve both high product quality and productivity. In addition, safety, the most important matter when using robots, was ensured. Moreover, the factory was given a showroom structure that could be observed by visitors.

① Stabilization of quality

In this factory, stable product quality with processes that are affected by the skill or experience of workers, such as the insertion of gears into reduction gears, is performed by robots that always operate accurately.

② Enhancement of production efficiency

In this factory, higher productivity than that in the case of full automation is achieved by dividing processes according to what humans and robots are good at. For instance, a formation in which humans insert bolts and robots manage the torque and perform final fastening.

③ Ensuring safety

By adopting Kawasaki's unique safety system, the coexistence of operating robots and workers in one area has been enabled.

④ Showroom structure

Normally, an automated production line has a structure in which products are accessed from both sides of the production line. However, in this factory, a structure that rotates products was introduced and robots are placed only on one side to realize a showroom line that can be easily observed by visitors.

3 Each piece of equipment of the robot production factory

In order to realize ① through ④ described in the previous section, we composed each piece of equipment in the robot production factory by integrating existing technologies and cutting-edge technologies, taking full advantage of being a robot manufacturer.

As illustrated in **Fig. 1**, the robot production factory consists of a sub-assembly cell, a main assembly line, a painting line, a harness assembly line, and an operation inspection line.

(1) Stabilization of product quality

There are three robot models produced in this factory (the CP high-speed palletizing robot, the BA small arc welding robot, and the CX large payload robot; shown in **Fig. 2**) that have been newly developed to accommodate robot assembly and complete painting of robots, and all these models are produced using the same equipment.

In assembly work, the skill or experience of the workers may affect the product quality. However, by having assembly work performed by robots instead of humans, it has become possible to always perform accurate operations and management, and stable product quality has thus been achieved.

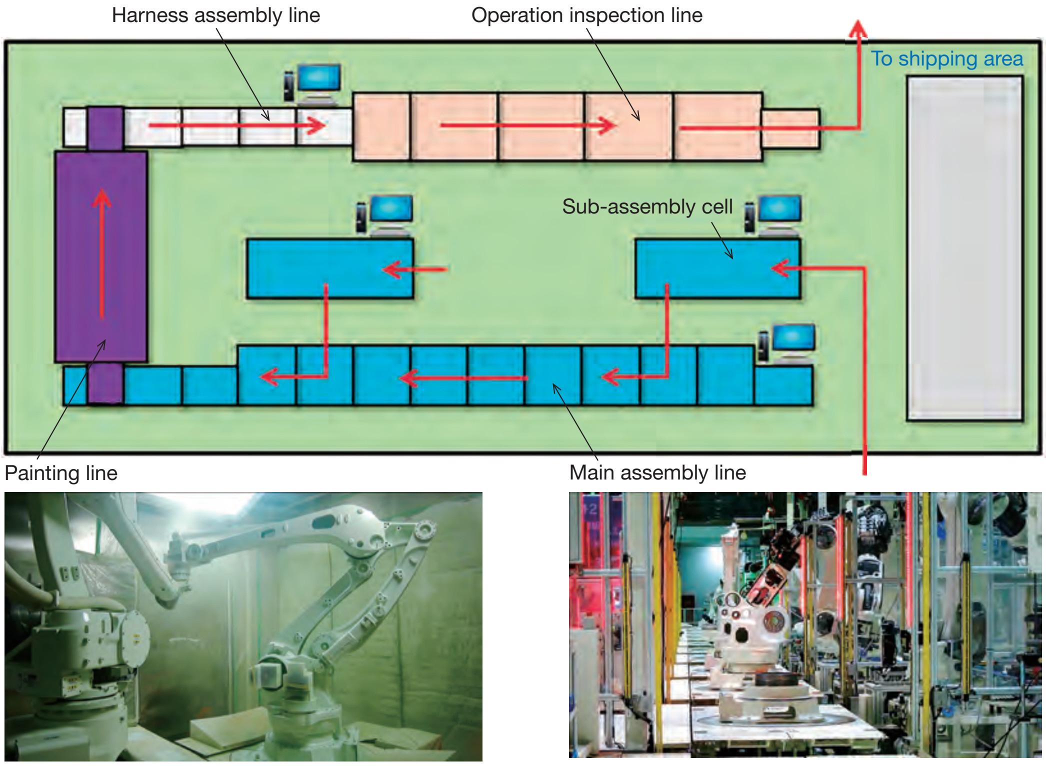

Fig. 1 Robot production factory

Fig. 2 China production model

In this factory, robots perform the bolt fastening work. We have developed and introduced a device in which the robot control axis is incorporated into the main body of the nutrunner, so that management of the fastening torque can also be performed by the robots (**Fig. 3**).

In addition, in order to insert gears into reduction gears without damaging the tooth flanks during the assembly of servomotors or other parts, the gear teeth inside the reduction gear are measured by a two-dimensional camera (**Fig. 4**). Similarly, the tooth phase of the input gear on the motor side is also measured (**Fig. 5**). By identifying the tooth phases on both sides and compensating for the phase during insertion, it has become possible to reduce mechanical shocks and scratches during assembly.

Moreover, for work performed with robots, each piece of work data including work history, image data during

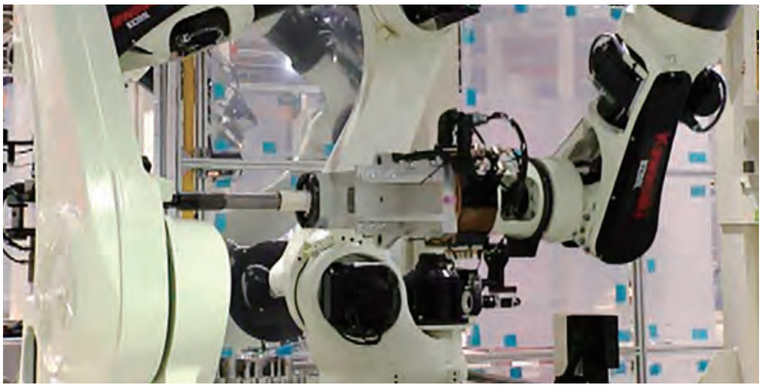

Fig. 3 Nutrunner

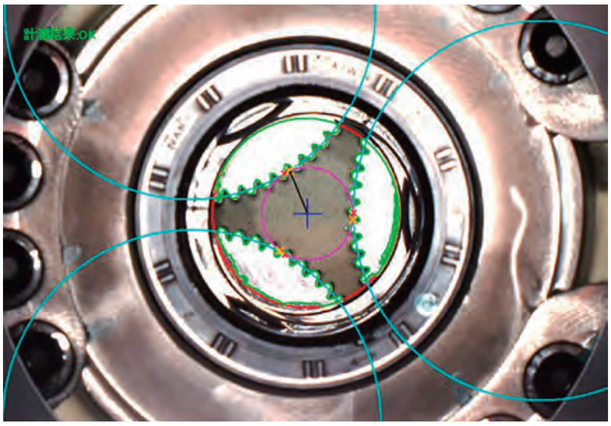

Fig. 4 Reduction gear measurement

Fig. 5 Input gear measurement

sealant coating (**Fig. 6**), and fastening torque data during bolt fastening, is saved so that past work conditions can be tracked later.

(2) Efficiency enhancement

In this factory, work that can be better performed by humans, such as temporary fastening of bolts, and work that can be better performed by robots, such as accurately transporting parts and assembling them, are divided. In addition, production efficiency is enhanced by making it possible for humans and robots to coexist in the same area, so that robots can prepare for the next task while humans are working.

Conventionally, there was an issue in which the maximum part weight that could be transported by a robot was determined by the payload of the robot to be used and that robots with large payloads were large. In order to solve this issue, it has been made possible for robots to transport parts that are heavier than their payloads by incorporating a robot control shaft into the crane driving part and supporting the transported weight with the crane.

In addition to incorporating a robot control shaft into the crane driving part, accurate transportation has been enabled by having the crane operate in collaboration with the robot arm. This system was introduced into processes that require accurate transportation of heavy objects, such as the assembly of reduction gears. The method through which transportation of heavy objects is performed is shown in **Fig. 7**.

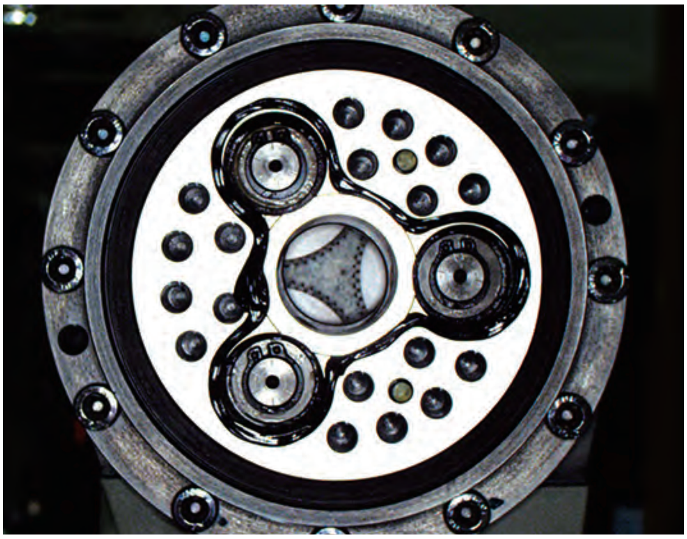

Fig. 6 Reduction gear sealant coating

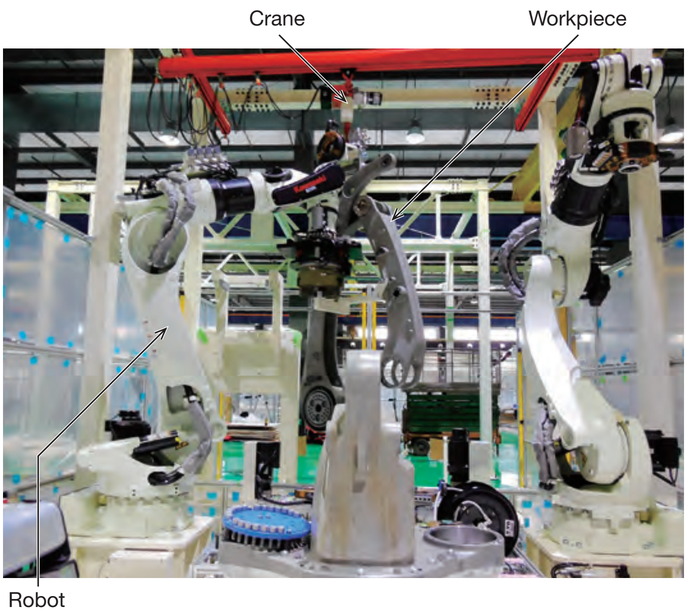

Fig. 7 Transport of heavy works

(3) Ensuring safety

The safety of workers must be guaranteed in order to make it possible for humans and robots to coexist in the same area so that robots can prepare for the next task while humans work. Therefore, in this factory, the safety of workers is ensured by making the robot control circuit a redundant dual channel safety circuit and performing space monitoring, as well as using area sensors in place of conventional safety fences.

(4) Showroom structure

In order for visitors to this factory to observe robot assembly work using robots, transparent panels and area sensors are used to lighten the atmosphere so that the facilities can be easily observed. The views from visitors of the sub-assembly cell and main assembly line are shown in **Fig. 8** and **Fig. 9**.

Fig. 8 Sub-assembly Cell

Fig. 9 Main assembly line

Conclusion

To respond to the growing need for robots in China, we have launched a robot factory in Suzhou, China, with the aim of establishing the Kawasaki brand. In addition, we have also succeeded in making this factory a showroom for the production of robots using robots by introducing many of our robots into the factory and realizing a high degree of automation.

This factory, which serves as a showroom for introducing application examples of robots, has received visitors almost every day since it went into operation, and it has earned a good reputation.

We aim to expand our business in China by utilizing our know-how of robot automation technology acquired through production in China.


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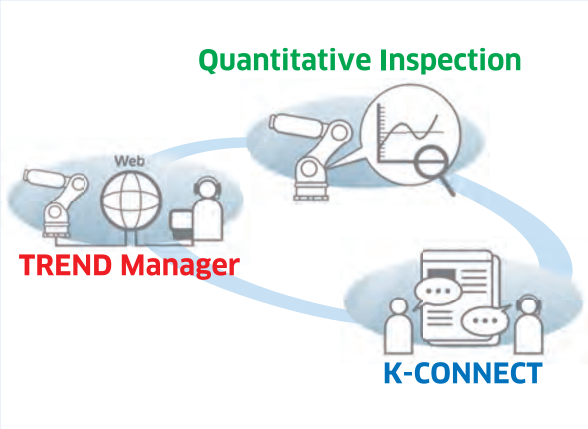
An Innovative Maintenance Service, K-COMMIT



We have developed and launched an innovative maintenance service, K-COMMIT, to eliminate downtime for users' robotic equipment and their peripheral equipment, as well as reducing lifecycle costs. This service can provide users with timely support via constant remote monitoring. This innovative service has been already introduced at many Kawasaki robot users and has achieved an excellent track record.

Introduction

With the increase in the global demand for industrial robots in recent years, the number of shipments is increasing dramatically. Along with this, the number of robots being managed is also increasing. Under such circumstances, conventional services centering on inspection, repair, and maintenance can no longer sufficiently satisfy users.

1 Background

In order to break away from conventional services and enhance customer satisfaction, new, more innovative proposal-based services and the development and practical application of tools and systems for supporting such services are desired.

2 Concept of the innovative maintenance service "K-COMMIT"

"K-COMMIT" (Kawasaki COmmunication Maintenance Management Inspection Total) is based on the concept of "zero downtime," "lifecycle cost reduction" for users and "information sharing" with users.

(1) Zero downtime

Factory equipment requires time for parts replacement after inspections or for maintenance. However, sudden failures cause large decreases in factory utilization rates. K-COMMIT aims to eliminate downtime of users' robotic equipment by avoiding sudden failures by predicting when the failures will occur.

(2) Lifecycle cost reduction

In the past, we have recommended that users perform annual inspections of their facilities from the perspective of preventive maintenance. However, in production sites, the loads put on robots vary, depending on the robot operation speed, operation time, temperature, and ambient environment. Therefore, K-COMMIT suggests the optimal maintenance cycle for each user to reduce lifecycle costs.

(3) Information sharing with users

We are currently rolling out a service based on making proposals to users instead of a service based on waiting for contact from users. To put a proposal-based service into practice, it is essential to closely share information with users in order to know what issues they are facing or their needs in a timely fashion. Therefore, we developed a new information sharing system that replaces conventional communications via telephone and e-mail.

3 Outline of K-COMMIT

K-COMMIT is an innovative maintenance service consisting of three pillars. The first is "TREND Manager," which performs failure prediction via constant and remote monitoring. Second is "Quantitative Inspection," which performs accurate equipment diagnosis. The third is the user communication tool "K-CONNECT." In developing this service, M2M (Machine-to-Machine) and IoT (Internet of Things) technologies were utilized to remotely connect the robots operating in the production field to the service centers, making maintenance via constant and remote monitoring possible.

(1) TREND Manager

TREND Manager is software that performs constant and remote monitoring of robotic equipment to ascertain its condition and acquire and analyze the operation data, in order to predict failures. It is equipped with an automatic e-mail transmission function, and is capable of automatically sending the results of failure prediction through constant monitoring.

(2) Quantitative Inspection

Quantitative inspection is an inspection method in which inspection results are quantified and stored in a database and the equipment conditions are quantitatively managed. In addition to the diagnoses provided in the conventional service, including reduction gear lost motion and iron contamination measurement, "direct-reading ferrography" has been introduced as a new diagnosis method.

(3) K-CONNECT

With the conventional service, the person in charge on the user side and our service staff would carry out person-to-person communication for maintenance purposes. In contrast, the communication tool K-CONNECT enables the user and service center to share information with each other and communicate in a systematic fashion, while allowing robotic equipment maintenance history information and maintenance proposals to be managed on the K-CONNECT web browser. Moreover, manuals and technical materials are now viewable on the web browser.

We will describe TREND Manager and Quantitative Inspection in the following sections.

4 Detailed functions of TREND Manager

TREND Manager utilizes the high-security network environment realized by the after-sales service support information infrastructure (K-Cube) of the Kawasaki Heavy Industries Group.

(1) Constant monitoring function for robotic equipment

As illustrated in **Fig. 1**, TREND Manager is capable of constantly monitoring multiple robots operating in the

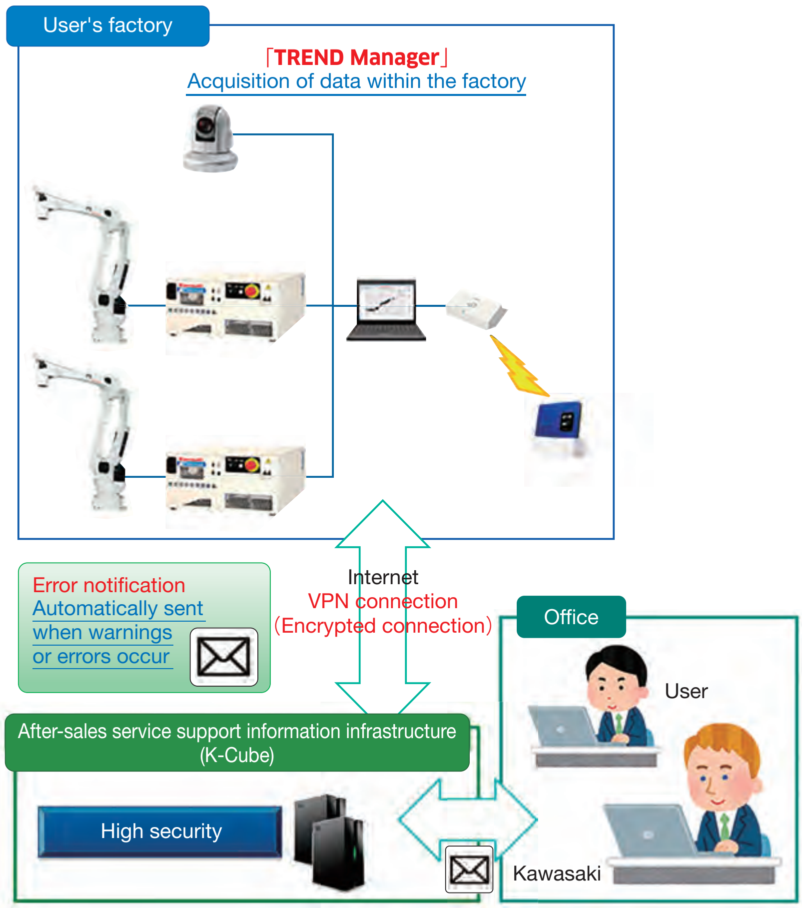


Fig. 1 TREND Manager system diagram

user's site. In addition, it obtains data for predicting the robots' operations and load conditions and creates a database. It analyzes the acquired data and performs failure prediction, enabling accurate and optimal preventive maintenance.

(i) Example of failure prediction (current value analysis)

For example, TREND Manager can predict the failure occurrence date and issue a warning by performing statistical analysis of changes in its current value and the trend of the servo motor. Since this allows the user to implement preventive maintenance by planning maintenance before the predicted failure occurrence date, it becomes possible to avoid sudden failures. From the trend graph of TREND Manager illustrated in **Fig. 2**, changes in the current value over time and its trend can be grasped.

(ii) Enhancement of the failure diagnosis function

In order to respond to more requests from users, we are working to enhance the functionality of TREND Manager. In order to identify the failure parts of the reduction gear that significantly affects downtime, FFT (FFT: Fast Fourier Transform) analysis of the waveform of the motor current was developed, and we are working to improve the prediction accuracy to utilize it for early diagnosis that matches the users' maintenance plans. We are planning to further enhance the functionality of TREND Manager by incorporating technologies such as machine learning and AI.

(2) Extensibility into systems

TREND Manager is capable of acquiring the data of painting equipment, pneumatic equipment, and the PLC

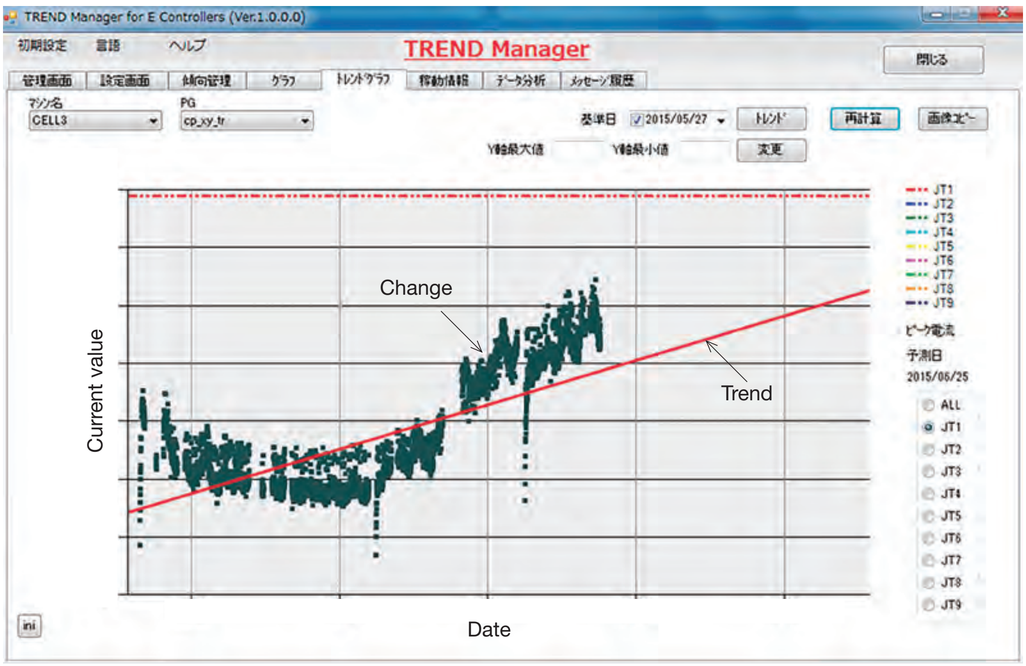


Fig. 2 Trend Graph of TREND Manager

(Programmable Logic Controller) that controls robot peripheral equipment and then performing trend management.

(3) Mail notification function

When an abnormality occurs, TREND Manager issues a warning or an alarm to pre-configured e-mail accounts. In addition, detailed data to be used for analysis, such as the motor current for each axis, is sent.

(4) Traceability function

In addition to the function of comparing the current and past data for each robot, TREND Manager can visualize the operation amount, operation time, and alarm occurrence frequency for each axis and trace past robot conditions from such data.

(5) Remote monitoring/maintenance function

All of the functions described above can also be used through remote operation from the service center via a network. In addition, the state of the robotic equipment operating in the users' production sites can be made visible by installing network cameras. If the robotic equipment stops, and if fixing the problem does not require parts replacement, troubleshooting can be performed through remote control operation by watching the network camera image. This makes it possible to recover robots without visiting the users' sites, bringing significant advantages in recovery speed and cost.

5 Quantitative Inspection

Direct-reading ferrography analysis has been incorporated into the existing Quantitative Inspection as a new diagnosis method.

(1) Direct-reading ferrography analysis

Direct-reading ferrography analysis is a method in which quantitative changes of wear particles in lubricant or hydraulic oil by particle size are analyzed using the analyzer described in **Fig. 3**. We have succeeded in diagnosing the failure trend of reduction gears more accurately than with the conventional iron contamination measurement. Applying this method has made it possible to grasp the ratio of large and small particles in the grease of the reduction gear by diluting the grease using our unique method and analyzing it. We obtained the threshold value from accumulated data, and determine that a failure occurs to the reduction gear when the value calculated based on the ratio between the large and small particles exceeded the threshold value.

Fig. 3 Direct-reading ferrography analyzer

(2) Issues with iron contamination measurement

Conventionally, the state of wear of a reduction gear was determined by measuring the iron contamination of the grease and judging the value to be a "normal value," "warning value," or "abnormal value." Although iron contamination of the reduction gear grease rapidly increases when abnormal wear of the reduction gear occurs, a certain degree of increase was observed in the iron contamination even under a normal state of wear, as iron contamination measurement is a method that measures the total amount of iron particle in the grease. In addition, even for a reduction gear in an abnormal state of wear, the iron contamination value temporarily decreases if the grease is replaced even once, which interrupts judging to be "abnormal." That was an issue with using iron contamination.

(3) Resolution of issues by direct-reading ferrography analysis

In order to resolve the above issues, the direct-reading ferrography analysis method has been adopted. For a while since the use of a robot is started, many particles in the reduction gear grease have a diameter smaller than 5 μm (small particles). However, when an abnormality occurs in the reduction gear and abnormal wear starts, particles having a diameter of 5 μm or larger (large particles) increase in the reduction gear grease. Based on this phenomenon, the IS value (Wear Severity Index) and LWPC (Large Wear Particle Concentration) are calculated by grasping the amount of large and small particles using the ferrography analyzer and they are used as the wear diagnosis index for the reduction gear. As has been described, by evaluating the diameters of wear particles in the grease using direct-reading ferrography analysis, the wear condition of the reduction gear can now be diagnosed more accurately than ever. The distribution of the iron contamination and IS values of collected grease samples is shown in **Fig. 4**. The red points indicate the grease samples from reduction gears in which actual abnormal wear was observed, and region ①, which was overlooked by iron contamination measurement, is now detected as being abnormal.

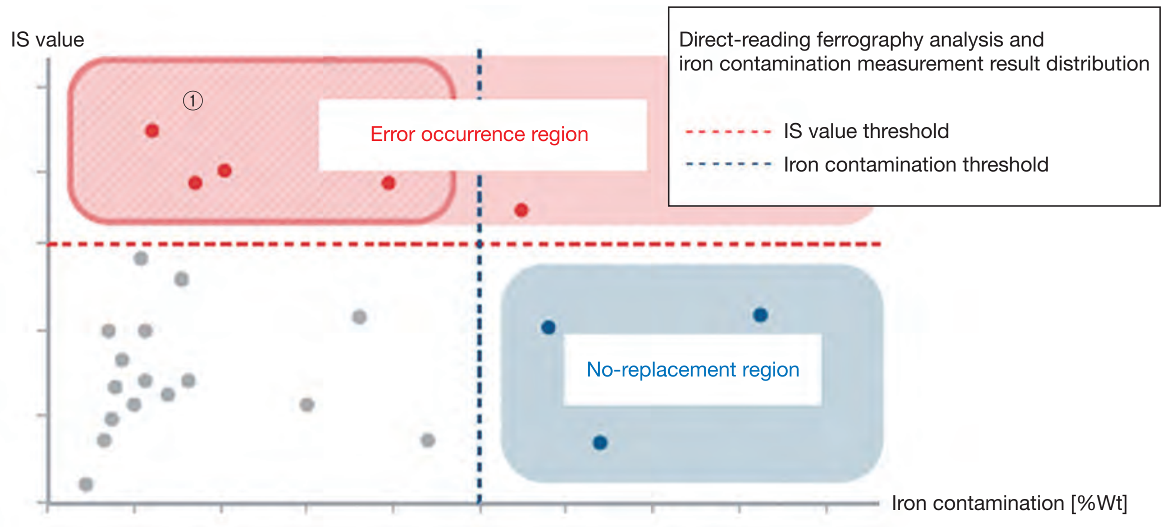


Fig. 4 Regions detectable for ferrography analysis

6 Application example of K-COMMIT

(1) Kawasaki Good Times World

Kawasaki Good Times World is a corporate museum where visitors can learn about some of Kawasaki Group's products in a fun way by seeing and touching them. The robot booth contains different types of robots and various demonstrations are performed. K-COMMIT is used for the robots in this booth.

There used to be issues such as those described below when a robot stopped.

① Upon receiving a notification, our service staff would travel for more than an hour to the site from the service center to investigate the cause of the stop and perform recovery work.

② If it turned out that there was a part failure as a result of the investigation into the cause, the staff would need to return to the service center to get the replacement part.

Due to these two things, a significant amount of time was required for recovery in some cases.

(2) Resolution of the issue by the introduction of K-COMMIT

The introduction of K-COMMIT has made it possible to investigate the causes of failures through remote control operation via network cameras and remote connection. Error recovery used to take a long time before its introduction. However, now minor errors can be recovered in a short time, since it is no longer necessary to go to the site.

In addition, since information on the necessary replacement parts is delivered to the service center via e-mail, quick response has become possible.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Conclusion

The development of K-COMMIT has made eliminating downtime and reducing lifecycle costs a reality. These have been challenges for managers taking care of robotic equipment for a long time. Our aim is to spread K-COMMIT Kawasaki Robot Anshin lifecycle support to more users that is optimally customized for the robotic equipment of each user.

Development of Medical Robot Systems

Medicaroid Corporation was founded with the corporate vision of “By creating our medical robots, we support an aging society in which everyone can live in peace.”

Making use of the machine control technologies that have been built up in the field of robotics, Medicaroid Corporation has developed a robotic operating table for hybrid operating rooms, which enables the simultaneous provision of endovascular treatment and surgery. It is also working for commercialization of robots that assist laparoscopic surgery.

Introduction

The application of robotics is increasingly expected in recent years as needs are becoming more sophisticated and diversified in the medical field in line with the progress of Japan’s aging society.

1 Background

In 2013, Medicaroid Corporation was jointly established by Kawasaki Heavy Industries, Ltd., a leading company in the field of industrial robots, and Sysmex Corporation, which has inspection and diagnostic technologies and a large network in the medical sector.

2 Activities of Medicaroid

Since its foundation, Medicaroid’s marketing activities have been in the inspection, diagnostics, and treatment areas, and it has focused its efforts on meeting specific demands from medical professionals. After FY 2015, we have developed products that embody new robot systems based on demands collected in these areas.

As shown in **Fig. 1**, Medicaroid is not aiming to create robots that replace human beings, but that serve and support them. Our corporate mission is to create robots to support an abundant aging society in which everyone including patients, medical professionals and family members can live in peace.

Medicaroid set up an open platform system for commercialization. In 2016, we founded Medicaroid, Inc. in Silicon Valley in the United States and have aimed to deploy products by making use of the latest findings and many different technologies through collaboration between Japanese and U.S. offices in cooperation with other parties including public, academic and medical organizations as well as private corporations.

Medicaroid addresses two main commercialization targets. Their timeline is shown in **Fig. 2**. One of the targets is the applied robot project which aims to apply industrial robots to the medical and pharmaceutical sectors. An example of results from this project is the operating table with robotics that was commercialized in FY 2016. The other target is the robotic assisted surgery project aiming to develop robots that support surgeons. The first launch of such a robot is scheduled in FY 2019.

Fig. 1 Corporate mission of Medicaroid

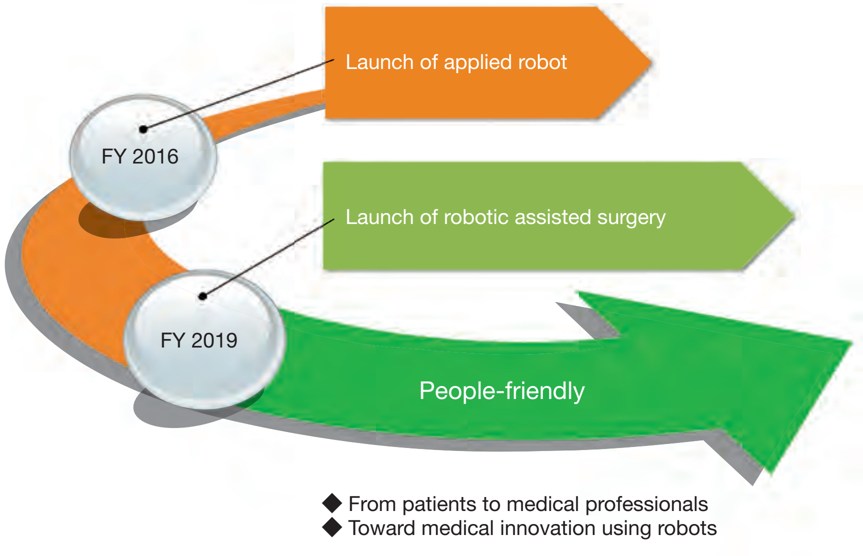


Fig. 2 Product timeline

3 Applied robots

We developed a robotic operating table for a hybrid operating room as one of our applied robots.

As shown in **Fig. 3**, an X-ray fluoroscopic imaging apparatus for angiography and a special surgical bed are installed in the hybrid operating room. The hybrid operating room enables the surgeon to perform endovascular treatment that would have been performed in an angiography room and surgery that would have been performed in an operating room at the same time.

Leveraging X-ray fluoroscopic image information allows for far more sophisticated and precise surgery to be performed as well as treatment that places less burden on patients' bodies by, for example, reducing the operating time, the amount of bleeding, and length of hospitalization. Safer and more reliable treatments can be provided because additional surgical procedures can be seamlessly performed if endovascular treatment is not enough to address the situation.

The hybrid operating room is expected to be used in many areas such as cardiovascular surgery, cardiology, spinal surgery, neurosurgery, orthopedic surgery, and respiratory surgery. More efficient and safer advanced

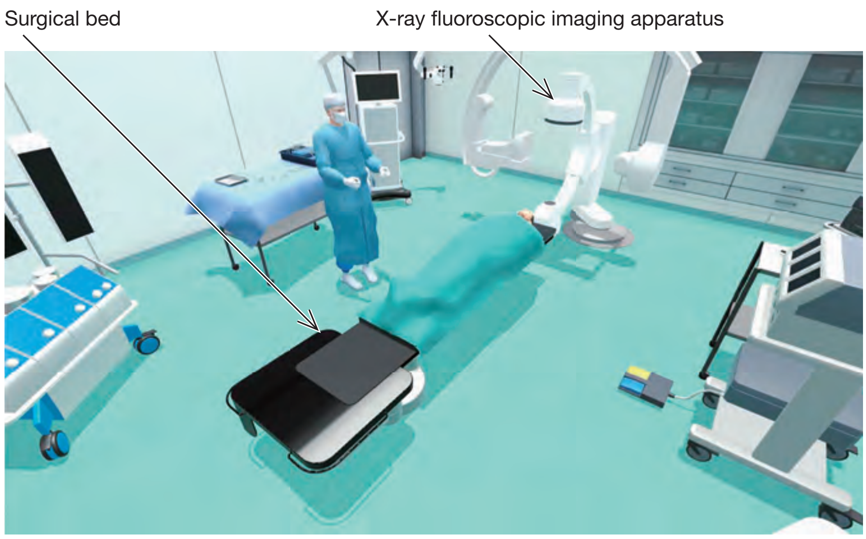


Fig. 3 Image of hybrid operating room

medical care than the conventional treatment system can be provided in the hybrid operating room. In fact, better performance in surgery has been recognized in the hybrid operating room.

To benefit from these advantages of the hybrid operating room, we considered a robotic operating table that makes use of the machine control technologies that have been built up in the field of robotics.

Because this was our first attempt at developing a product to be used in surgery, we had to precisely understand specific user needs and develop a product that exactly meets those needs. Therefore, with “the human-centered design method,” we hypothesized user needs and created a full-scale product mock-up conceived from the hypotheses. Then, we demonstrated actions usually performed during surgery using this mock-up in front of nurses, anesthesiologists and neurosurgeons who actually use the product and listened to their opinions about the product concept, foreseeable challenges and their solutions. We improved the mock-up by repeatedly reflecting additionally identified needs in the next series of evaluations.

Using specific user needs obtained from these efforts as design input, we developed the robotic operating table shown in **Fig. 4**, the “Vercia SOT-100.” In addition, we developed two types of dedicated controllers shown in **Fig. 5** by listening to users and focusing on the operation procedures.

The robotic operating table thus developed by applying robotics to the treatment table used in neurosurgery can be used to freely move the patient without placing a burden on them or medical professionals and save space in the operating room. The introduction cost of the equipment can also be reduced by moving the operating table rather than large equipment such as the X-ray fluoroscopic imaging apparatus. In addition, remote maintenance via network and other measures allow us to provide quick support.

Fig. 4 Robotic operating table

Fig. 5 Controllers

The regulatory application for the developed operating table was completed in March 2017. We believe that the hybrid operating room will spread with the development of the robotic operating table, providing minimally invasive treatment for more patients and accelerating improvement of QOL (Quality of Life).

4 Robotic assisted surgery

As the safety and effectiveness of robotic assisted surgery developed in the United States in the 1990s have been demonstrated in many different clinical studies and tests, their range of application is rapidly spreading. The global robotic assisted surgery market is expected to expand at an average annual growth rate of 30% and reach 20 billion USD in 2019 as shown in **Fig. 6**.

(1) Robotic assisted laparoscopic surgical system

Laparoscopic surgery is a minimally invasive surgical technique that places less burden on the patient and is popular because surgical wounds are smaller than those in conventional laparotomies or thoracotomies and hospitalization after the surgery can be reduced. However, because this surgery is performed by running the camera and surgical instruments through small holes in the patient's body unlike a laparotomy, there are disadvantages such as the difficulty of operating surgical instruments due to the small field of view and the techniques not being intuitive and so requiring a long time to learn.

Even so, about 2,500 robotic assisted laparoscopic surgical systems operate in the United States. This system was also authorized as a medical device in Japan in 2009 and its application to surgery for prostate cancer and other diseases started. The number of cases in which it is used is expected to increase in the future.

A conceptual image of the robotic assisted laparoscopic surgical system developed by Medicaroid is shown in **Fig. 7**. The forceps, which were difficult to manually operate, can be easily operated through the robot. As the growth of robotic assisted surgery is the most anticipated,

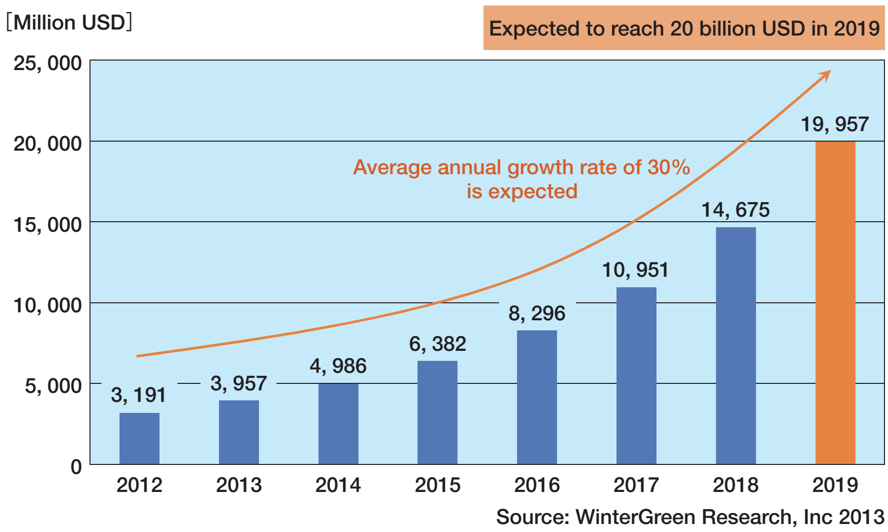


Fig. 6 Market forecast for robotic assisted surgery

Fig. 7 Image of robotic assisted laparoscopic surgical system

we will develop medical robots with new added values as our core products under the design concept shown in **Fig. 8**. We aim to improve the economic efficiency of equipment, running and other costs while reducing the setup time and size in comparison with existing robotic assisted laparoscopic surgical systems. We are also aiming for medical innovations using robots by realizing high safety and reliability and reducing medical risks based on the robotic technologies we have accumulated so far.

In developing this system, we will also repeatedly prototype functions such as a surgery robot that is equipped with forceps with multiple degrees of freedom and operation consoles with the human-centered design method, ask domestic and overseas surgeons to evaluate them, and make further improvements based on their feedback toward commercialization.

(2) Robotic assisted flexible endoscopic surgical system

Peering even further into the future, we are developing a robotic assisted flexible endoscopic surgical system, which is an even greater challenge.

For a high level of safety, more minimal invasiveness and for difficult treatments, we joined the "Flexible Endoscopic Surgery System" project commissioned by the Japan Agency for Medical Research and Development with Kawasaki Heavy Industries, Ltd.

Although the surgery became less invasive and more precise with the advent of the robotic assisted laparoscopic surgical system, it is often too difficult to treat pancreatic cancer or other diseases with laparoscope and endoscope surgery and so laparotomy is still the mainstream. In addition, the assisted flexible endoscopic

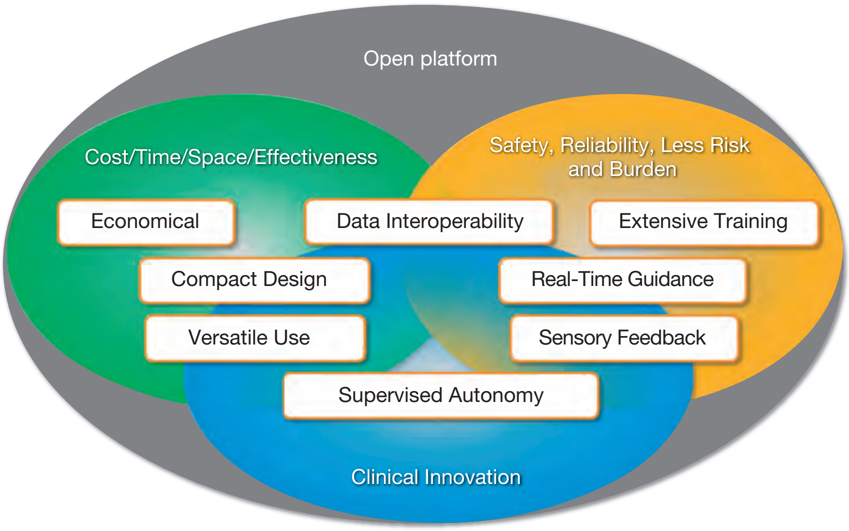
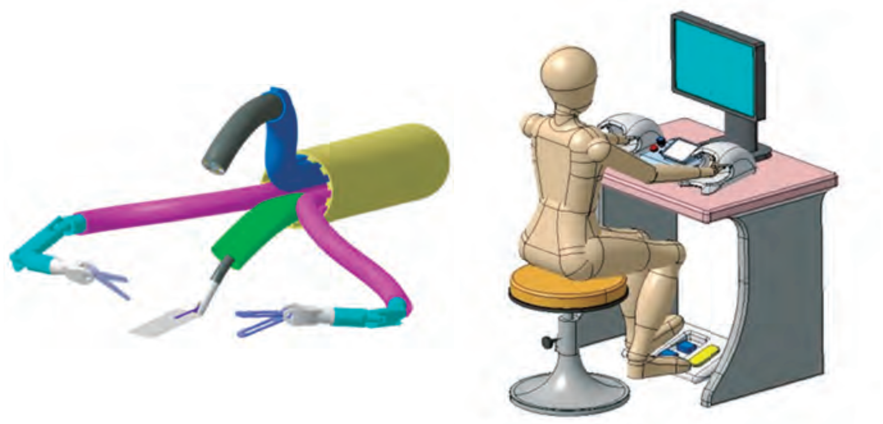


Fig. 8 Design concept



(a) Robotic flexible forceps (b) Operation console

Fig. 9 Image of robotic assisted flexible endoscopic surgical system

surgical system developed as an extension of gastrointestinal endoscopy is not widespread because an extremely high level of skill is required to operate the forceps.

In this context, we are developing a new assisted flexible endoscopic surgical system that the surgeon can intuitively operate while looking down at the surgical field by integrating the flexible endoscope and robotics, which Japan is good at. A conceptual image of robotic assisted flexible endoscopic surgical system is shown in **Fig. 9**. We are currently developing the flexible robotic forceps, which supports a variety of surgery methods with a wide operating range and a high gripping force, and the operation console, which allows for intuitive operations of the flexible robotic forceps.

Conclusion

Medicaroid Corporation is developing medical and pharmaceutical robot systems. We will develop, manufacture, and sell these systems based on the results of thorough marketing activities. Then, we will commercialize robot systems that contribute to the development of the medical and pharmaceutical industry of the world and support an aging society in which everyone can live in peace through these products.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A Robot Operation Safety Monitoring Unit, Cubic-S, Realizes Production Systems That Are Safe for Human Beings

We have developed a robot operation safety monitoring unit, Cubic-S. This enables us to use safety functions using software, perform collaborative operations that were not realized by conventional industrial robots, and build more efficient and safer production systems.

Introduction

Recently, automation with robots is being actively promoted due to factors such as a decrease in the workforce caused by the falling birthrate and aging population, mainly in developed countries, and an increase in labor costs in emerging countries.

1 Background

Safety equipment that supports systems more flexibly than before is required to further improve the efficiency of already automated production systems and to create new application fields.

ISO10218-1: 2006, which defines robot safety requirements, were modified as follows:

① Safety monitoring using software
Software can now be used for safety monitoring where only machines or electrical hardware was allowed in the past.

② Relaxation of operation restriction methods
Software can now be used to restrict joints and the motion area where only machines or electrical hardware was allowed in the past.

③ Relaxation of approach distance
In the past, people were not allowed to enter into the operating range of a robot during automatic operation. However, now you can enter into the operating range as long as the operating speed is slow (250 mm/s or less).

After the revision, some customers specify the motion area restriction function (motion area monitoring) as a delivery requirement. To conform to the revised standards, the important safety-related sections of the equipment must be reliable and the equipment (including software) must go through sufficient evaluation tests and get certified by a third-party organization or the equipment manufacturer itself. To address these requirements, we developed a robot operation safety monitoring unit, the Cubic-S.

After the release of the first Cubic-S in 2011, we have added new safety functions such as the fail-safe communication function (network safety input/output function) based on the IEC61508 functional safety standards and the force monitoring function to monitor the external force of robots for our collaborative robot, the duAro.

2 Cubic-S

The name Cubic-S comes from Supervise, Safety, and Smart. The Cubic-S allows the user to flexibly build the production line at a low cost by using software to provide advanced safety functions that were impossible in the past.

The Cubic-S has the following ten safety functions: motion area monitoring, network safety input/output, force monitoring, joint monitoring, speed monitoring, stop monitoring, tool orientation monitoring, protective stop, emergency stop, and safety status output.

As shown in **Fig. 1**, these safety functions provide

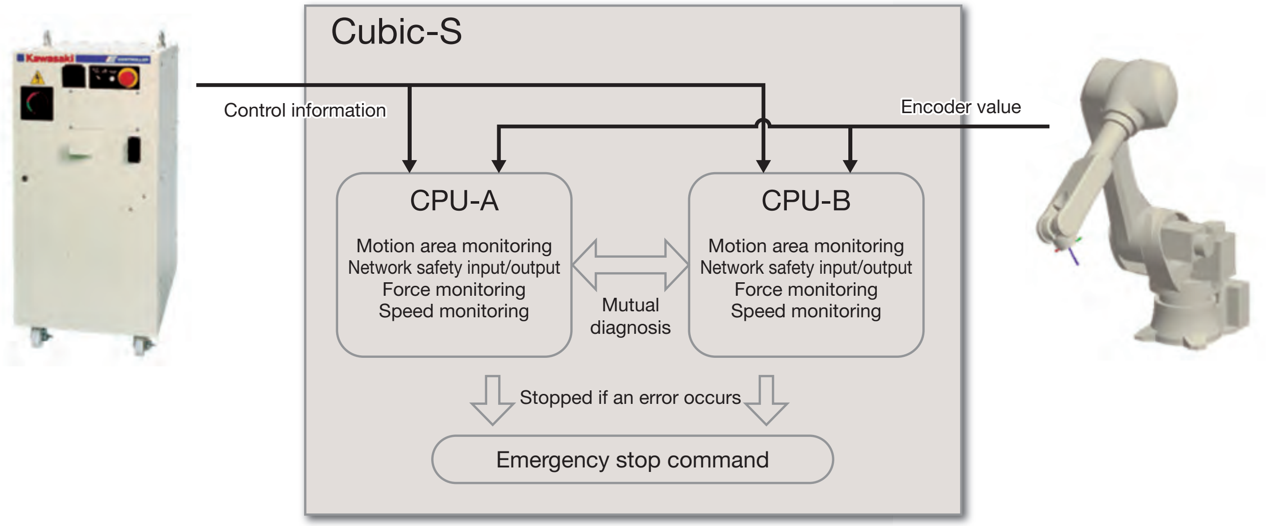

Fig. 1 Basic configuration of Cubic-S

redundancy using two CPUs to realize safety performance in SIL 2 in the IEC61508 functional safety standards and PLd/Category 3 in ISO13849-1 and are certified to conform to the standards by the third-party certification organization, TÜV SÜD.

(1) Motion area monitor function

The motion area monitor function restricts the motion area of the robot to the specified motion area. This function monitors whether monitoring points defined for each robot arm type fall within the specified motion area.

This allows you to minimize the motion area of the robot, and as a result, reduce the installation space of the safety fence.

Conventionally, safety fences had to be installed so that the whole red area, which is the area of motion of the robot, would be included as shown in **Fig. 2**. However, application of the Cubic-S allows the user to limit the operating range of the robot itself to the green area. This means that the safety fence can be installed as indicated by the yellow line. Therefore, the installation space of safety fence can be significantly reduced.

(2) Network safety input/output function

Safety signals can be communicated with the safe PLC based on the "Safety Expansion of EtherNet/IP (CIP Safety)," the field network communication standards managed by the industry group, ODVA. As it supports

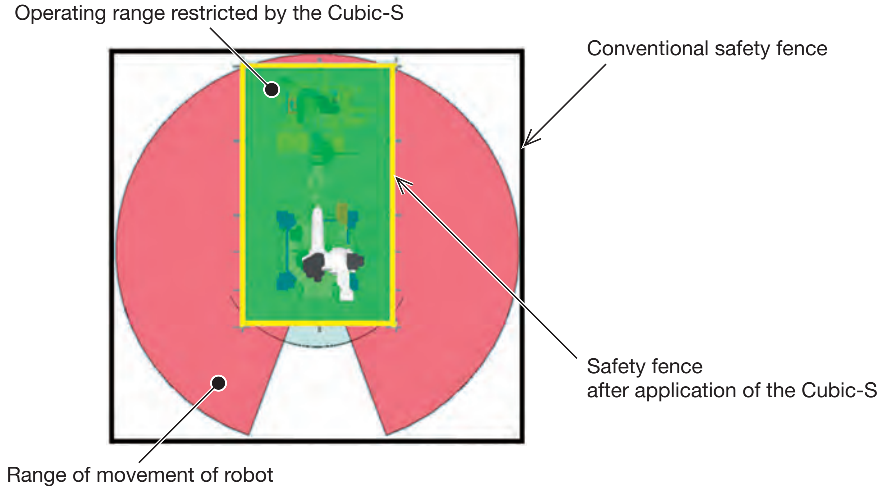

Fig. 2 Reduction of safety fence installation area by Cubic-S

these standards, the Cubic-S can directly exchange safety signals, and therefore, no longer needs safety relays and other such parts.

According to the CIP Safety, redundant communication packets must be analyzed in a redundant system equipped with two CPUs. To satisfy this requirement, the Cubic-S is so equipped.

(3) Force monitoring function

The force monitoring function was developed for our collaborative robot, the duAro. This function monitors the external force generated by the robot and safely stops the robot if the generated external force exceeds the specified value.

Figure 3 shows the processing flow of the force monitoring function. The Cubic-S receives the motor torque value estimated from the robot operation calculated by the robot controller and the actual motor torque value from the robot. The external force generated by the robot is calculated from the difference between these values. The force monitoring function monitors this external force and quickly stops the robot if it detects contact between the robot and a person.

This function was developed and evaluated based on the ISO/TS15066 collaborative robot technical specifications and is certified by the third-party certification organization, TÜV SÜD.

3 Examples of production systems that are safe for human beings

(1) Robot production lines

In FY 2016, we started producing robots in Suzhou in China. (Refer to pgs. 10 to 13 in this document.) In this factory, automation by robots is actively promoted. Robots and human workers collaboratively perform their own tasks in some areas of the assembly process.

In the past, human workers and robots were not able to work at the same time because the robot had to be stopped if human workers were working in that process. However, the Cubic-S can be used to ensure the safety of human workers, while keeping the operation of robots automatic.

Figure 4 shows the layout of the assembly process. In this process, the work area of robots (the area within the red frame) contains the area where human workers work

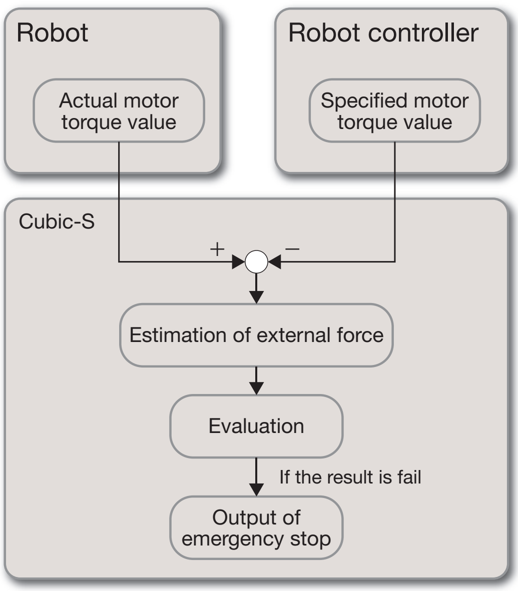

Fig. 3 Process flow of force monitoring function

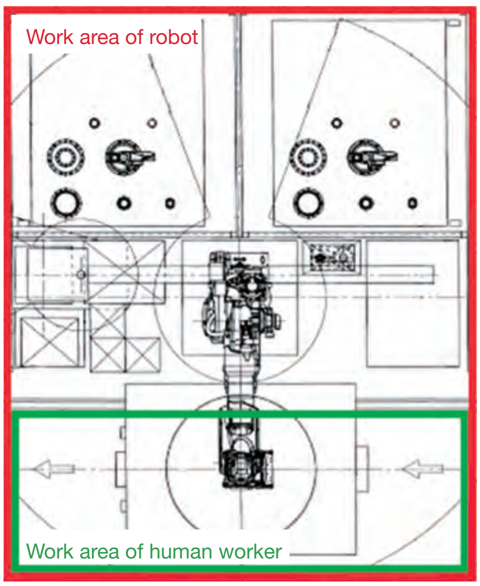

Fig. 4 Layout for assembly process

(the area within the green frame) as shown in this figure. When there are no human workers within the green frame, normal automatic operation is performed. When human workers are working within the green frame, the motion area monitor function is enabled in the Cubic-S and it prohibits the robots from entering into the human work area. The speed monitoring function is also enabled to ensure further safety.

(2) Double-acting friction spot joining (FSJ)

FSJ (friction spot joining) is our proprietary joining technology used for lap joints made of light alloys such as aluminum alloys. The main application examples of this technology are the robot system and the stationary system. In the robot system, the gun is attached to the tip of the robot as shown in **Fig. 5** and the robot joins the joint. In the stationary system, the joining tool (gun) is fixed and a human worker grips and joins the workpiece.

In a robot system, normal robot operation is performed as shown in **Fig. 6**. In a stationary system, after placing the FSJ welding gun onto the fixed base, the robot is stopped with the posture shown in **Fig. 7** below by using the motion area monitor function and the stop monitoring function of the Cubic-S to ensure the safety of the user.

Although these are usually different systems, the Cubic-S allows the operation to switch between the robot system and the stationary system within a single system.

(a) Robot system

(b) Stationary system

Fig. 5 FSJ System

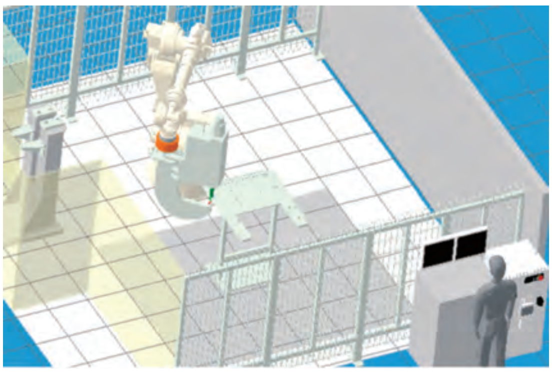

Fig. 6 Operation as robot system

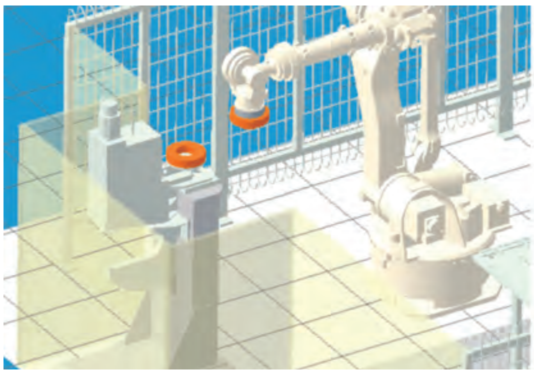

Fig. 7 Operation as stationary system

(3) Collaborative robot, duAro

As shown in **Fig. 8**, duAro is a robot that performs assembly and other tasks alongside human workers.

When realizing collaborative work between robots and human workers, you must take action to prevent harm to human workers even if the robot and human workers contact each other as ISO10218-1 defines provisions for the case where human workers and robots perform collaborative work.

Therefore, we first defined two states of contact with human workers as shown in **Fig. 9**. One state is transient contact, which means that the human body can move after the contact occurs. The other state is static contact, which means that the human body cannot move. The danger of

Fig. 8 Image of collaborative work

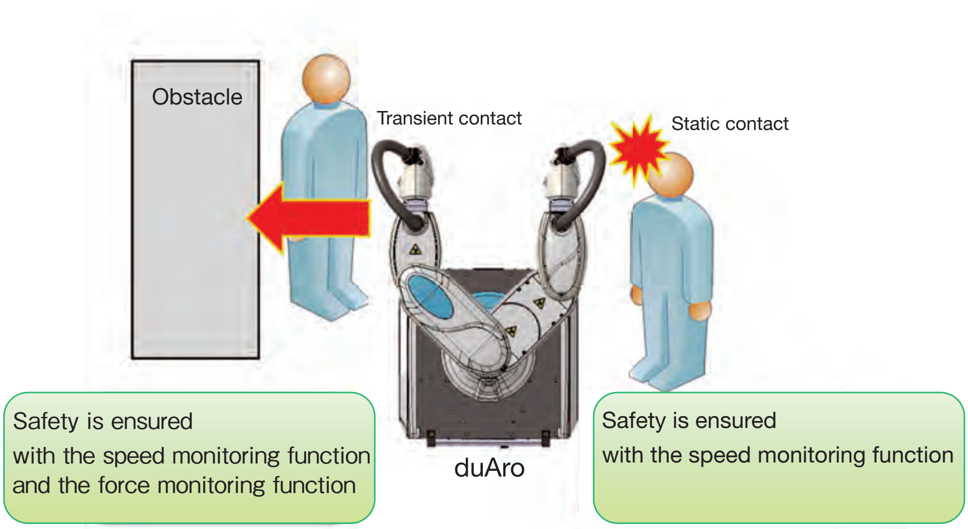

Fig. 9 Integrates with duAro

transient contact is avoided by the speed monitoring function. The danger of static contact is avoided by a combination of the force monitoring function and the speed monitoring function. Specifically, we defined the area where static contact could occur with the operation tablet of the duAro to enable the force monitoring function and speed monitoring function in that area and enable the speed monitoring function in the other areas.

Conclusion

Development of the Cubic-S made it possible to use more advanced safety functions than in the past and to build more efficient smaller-footprint robot systems.

It is expected that the fields in which robots are applied will increasingly expand and that collaborative work with human workers will increase. As a result, functional safety is required in more and more situations. In this context, we will continue to meet social needs and improve the safety of our robots.


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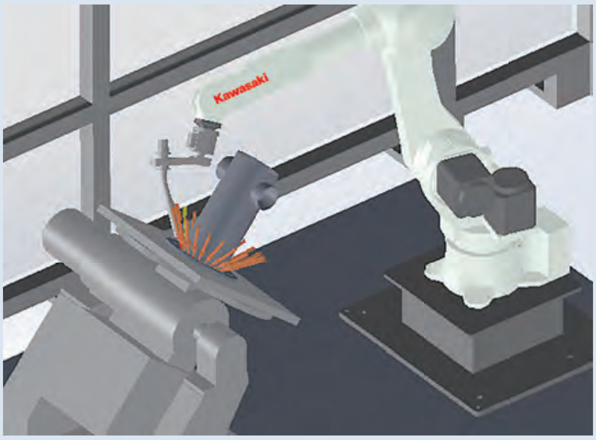
Efforts for Automated Teaching in Order to Expand Applications: Increasing the Sophistication of Offline Teaching Software Utilizing 3-dimensional CAD



While more support for fields of application where robots could not be used previously is being demanded, products to be produced are also becoming more complicated and diversified. In these circumstances, demands for offline teaching where robots are taught using simple operations are increasing.

To expand the applications, we have worked on increasing the sophistication of offline teaching software utilizing 3-dimensional CAD.

Introduction

More and more companies are starting to use industrial robots to address the shortage of workers caused by the falling birthrate and the aging population and to reduce the variations in quality that manual production causes. Combined with the technical innovation in technologies related to robots, the application of robots is expected to expand to fields that were impossible to automate in the past.

1 Background

The manufacturing industry is currently experiencing a movement toward mass customization to address individual customer requirements such as variable production amounts of diversified products that have a complicated shape. In this context, one of the challenges for expanding the application of robots is how easily you can operate the robot in producing increasingly complicated and diversified products.

More and more customers use offline teaching software that leverages 3-dimensional CAD to solve this issue. The offline teaching software allows the user to examine the layout of robots and peripheral equipment and generate robot operation programs based on the 3-dimensional CAD data on the PC. The software can automatically create robot operation programs even for complicated shapes and reduce variations in quality and working hours by workers.

2 Teaching simplified by the offline teaching system

We developed the automatic robot operation program generation software, KCONG, and the robot layout examination simulator, K-ROSET as offline teaching software to support the introduction of robots. Using these software applications on a case-by-case basis, we provide robot systems with the optimal configuration for customers.

The following section describes KCONG.

3 Automatic robot operation program generation software, KCONG

(1) Concept

KCONG is offline teaching software that can automatically create robot operation programs with intuitive operations, that is, selecting working positions on 3-dimensional CAD data of the product and teaching it the process conditions.

(2) Overview

KCONG is offline teaching software that includes 3-dimensional CAD. Therefore, you can start using KCONG at the product design phase. That is to say, you can seamlessly design the product shape and teach the robot how to work on the product for robotic processing as shown in **Fig. 1**.

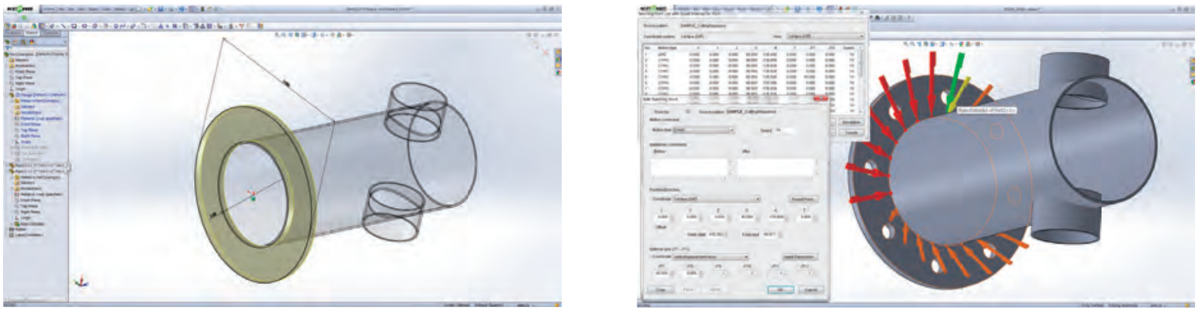
The user finds the work procedure that will achieve the best quality when processing products. With KCONG, you can save how to create teaching positions and process conditions as construction rules in the database in order to make use of it later, and accumulate data obtained by trial and error as expertise. Furthermore, you can refine them into better processing methods as the use frequency increases. The procedure when KCONG is used is shown in **Fig. 2**.

In addition, KCONG has a robot simulation function that includes an interference check as shown in **Fig. 3** and contributes to vertical startup in field applications as the user can examine the configuration and check operations before installing the equipment.

(3) Features

(i) Automatic posture determination function covering external axes

From the beginning of development, we have used KCONG to address user needs by developing functions for tasks such as arc welding, cutting, and chamfering. As it is difficult to cover complicated product shapes in the operating range of the robot alone, it is required to have a system that has external axes that move the robot or rotate the product. As KCONG has a function to automatically determine the operation control of external axes other than the base axis of the robot, you can easily teach it to weld parts with complicated shapes as shown in **Fig. 4**.



(a) Product shape design

(b) Teaching

Fig. 1 Seamless design and teaching

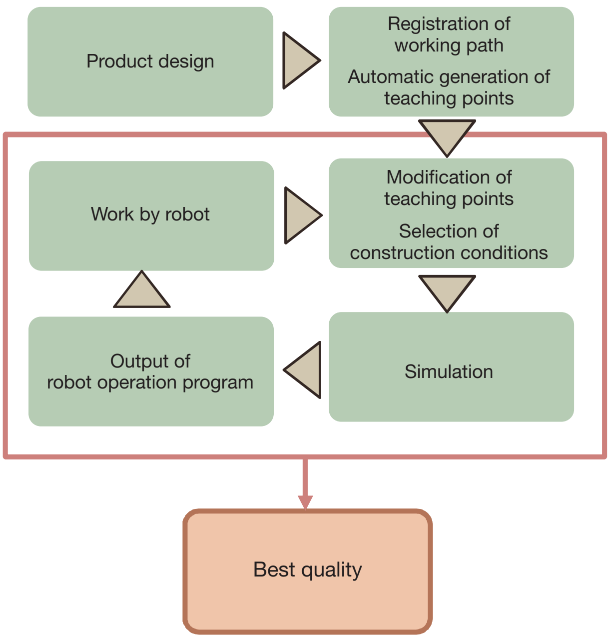


Fig. 2 Procedures for KCONG is used

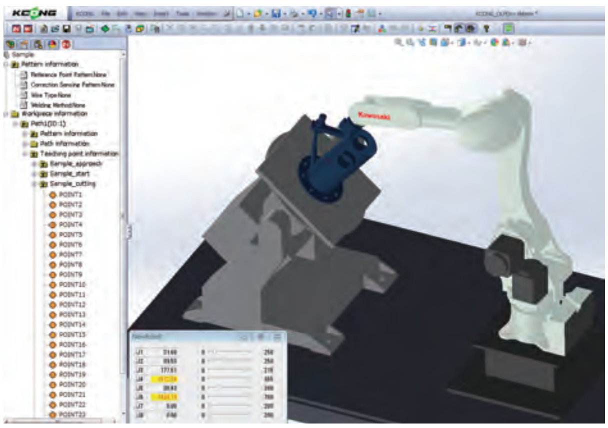


Fig. 3 Robot simulation function with interference check

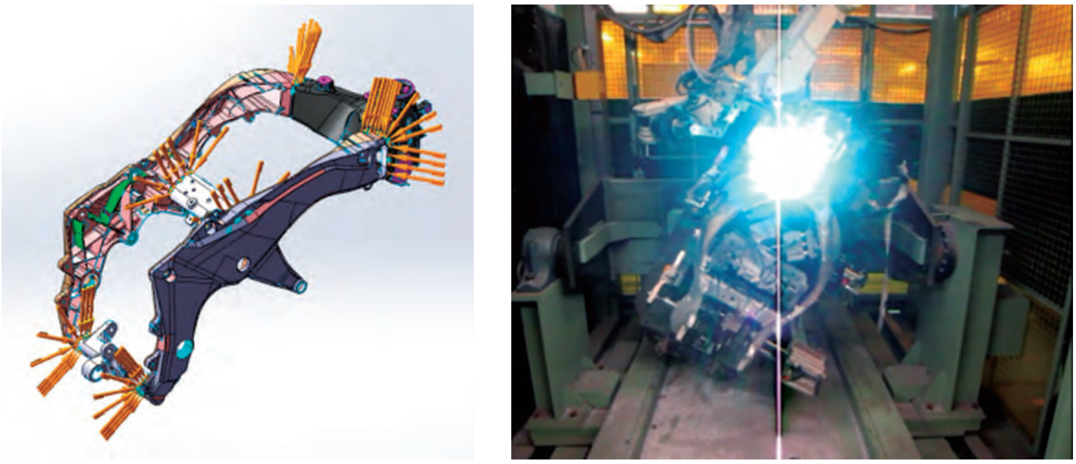


Fig. 4 Motorbike frame joining

(ii) G-code conversion function

KCONG has a function to convert the industry standard format known as G-code, which is output from the CAM software used in NC machine tools, into the operation program for our robot. This function allows our robot to perform the same tasks as NC machine tools. The accuracy is lower because robots are less robust than NC machine tools. However, they are less expensive than NC machine tools, which become expensive in proportion to the size of the object being processed. In addition, the robot can flexibly address system changes. These advantages really set it apart from recently developed 3-dimensional printers. Our robots have been adopted by companies that manually manufacture large objects as shown in **Fig. 5** based on these advantages[1)].

Robots are also used for evaporative pattern casting of prototype molds for industrial machines, camera or printer patterns, and woodwork.

4 Efforts for increasing new applications

When implementing robots in the past, the work accuracy was often an issue or it was cumbersome to teach surface processing. In addition, customers increasingly want to use the DMU (digital mock-up) tool that they had used when introducing the robots.

(1) Speed reduction function (measure for accuracy)

Now that G-code can be used, we receive an increasing number of requests from processing manufacturers to introduce robot systems. However, the accuracy could be a challenge. To solve this challenge, it is effective to improve not only the rigidity of robots, but also the operating characteristics. For example, the accuracy tends to drop due to operating characteristics when the robot arm moves backward or if the angle of the processed

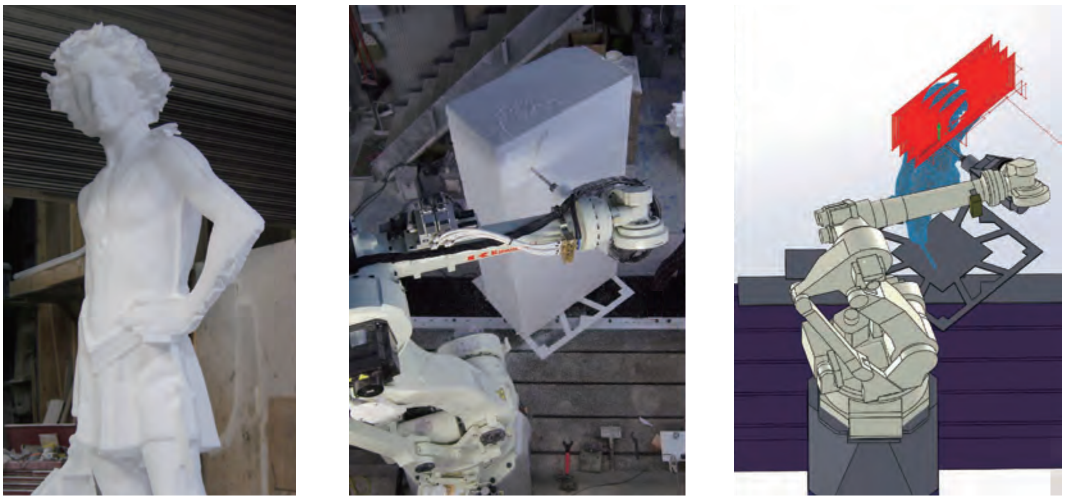


Fig. 5 Tridimensional formative cutting for theme park

curved surface is largely changed. The accuracy drops particularly when these operations are performed above a certain speed. Therefore, we improved this part by adding the automatic deceleration function.

(i) Features

The speed reduction function can be used to specify the speed reduction range. This function changes the operating speed by automatically entering the deceleration command into the robot operation program when the robot is in a posture that would affect the quality.

(ii) Effects

The color map in **Fig. 6** shows the result of applying the speed reduction function to the G-code output from CAM. You can see that the speed changes in straight sections and corner sections. This function allows G-codes, which are CAM data output for NC machine tools, to be used by robots while maintaining necessary accuracy.

(2) Surface treatment function

As force sensors are now available at low prices, it has recently become realistic to use robots for surface treatment such as polishing though it was difficult only with position control. Although surface processing such as polishing was addressed by making the most of advanced CAD operations in the past, we developed a new function that simplifies this operation.

(i) Features

The user selects the working range on 3-dimensional CAD. Then, the user creates a robot operation program by entering data such as the distance between teaching points on the working path as process conditions. Next, the user set parameters required to adjust surface treatment such as the working speed and the overlap amount. Smoothing can be executed to prevent the posture from largely changing between teaching points. This function can be applied to not only polishing but also painting and other treatment as the offset distance from the product surface can be set.

Because this function supports shape data in the versatile STL (Standard Triangulated Language) format, data on products not designed with 3-dimensional CAD can be captured with the 3-dimensional scanner and used.

(ii) Effects

Although an appropriate overlap amount is affected by the difference between individual workpieces, you can achieve desired polishing as shown in **Fig. 7** by feeding back the force measured with the force sensor attached at the tip of robot and adjusting the processing speed and overlap amount with this function.

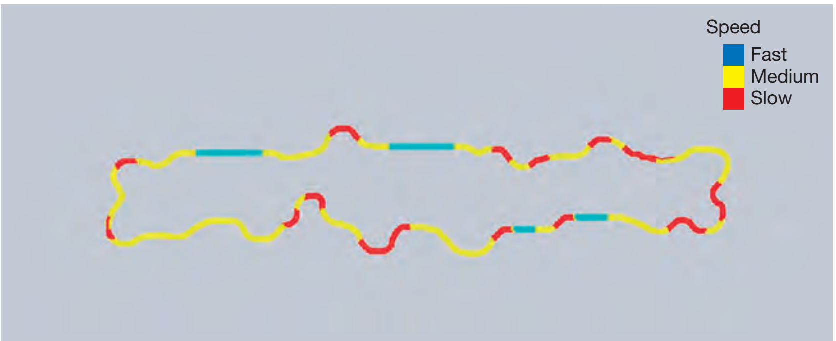


Fig. 6 Result of application of speed reduction function

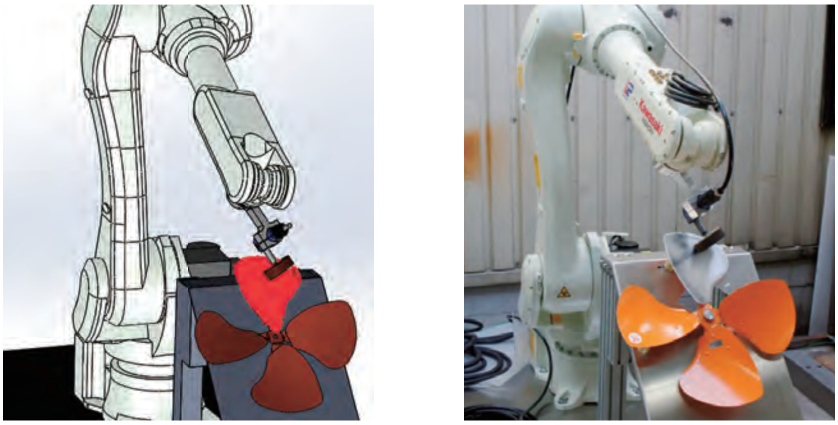


Fig. 7 Polishing operation

(3) Assembly procedure specification function

Since products from home appliance manufacturers have relatively short life cycles, manual work is more applicable and efficient than robot production. For this reason, not many home appliance manufacturers have adopted automation.

Recently, more and more users use the DMU tool to solve quality problems when assembling multiple parts in the upstream design process. The DMU tool enables the user to check the assembly procedure in animation using the 3-dimensional CAD by specifying the layout of parts, assembly order, and used tools. By applying assembly information configured with this DMU tool to creation of robot operation programs, you can reduce the startup time of robot system.

(i) Features

As the DMU tool is mainly intended to improve the efficiency of human work, we developed the function to specify information on tools required for robot automation and product assembly positions.

The workflow is as shown below.

① Prepare 3-dimensional CAD data of the product.
② Load the CAD data into the DMU tool and specify the assembly procedure.
③ Check the assembly procedure with simulation.
④ Specify tool information and product assembly positions.
⑤ Output the assembly procedure.
⑥ Simulate the robot operation including interference based on the assembly procedure.
⑦ Transfer the verified robot operation program to the real controller.

(ii) Checking the assembly operation

When examining the assembly work, you must break it down into processes to assemble parts, fixing the product. When operating the robot operation program output from the DMU tool in the system that uses two robots, the collaborative dual-arm scalar robot, duAro, is suitable for processing such as assembly. This is because duAro is equipped with two arms, which can be moved coordinating with each other's operation. The result of operation check using duAro is shown in **Fig. 8**.

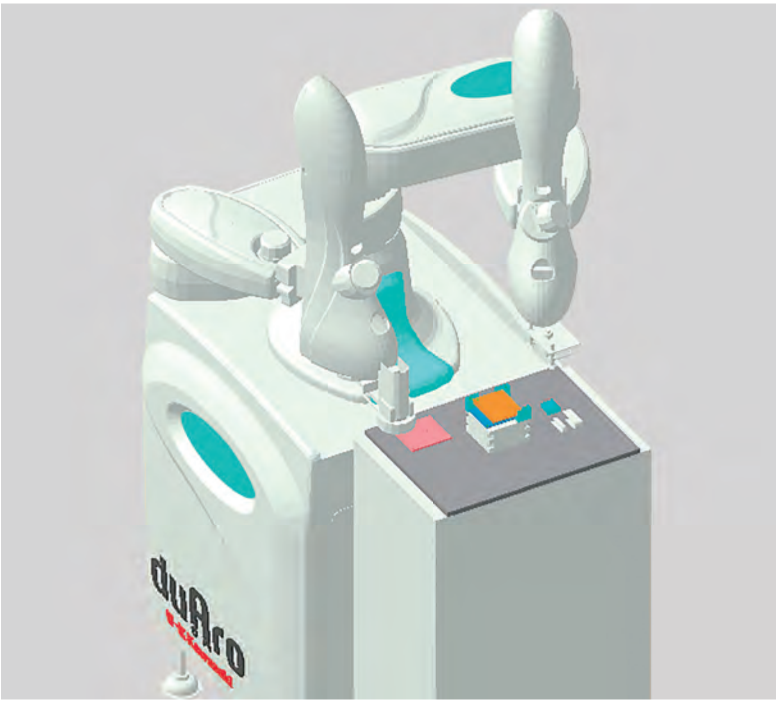


Fig. 8 Assembly using duAro

Conclusion

Tablets and other new input media are recently widespread and leveraged, replacing PCs. It is expected that new application fields of robot will increase as the offline teaching technology develops, absorbing these technologies. Using the offline teaching software as a differentiator from other robot manufacturers, we will continue to sophisticate teaching automation, responding to market needs. We will advance automation of teaching that users can use without being aware of robots.

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The Traverse Unit-less Compact Arm, NTS/TTS Series: Simple Installation in Semiconductor Manufacturing Equipment through Standardization

We have developed a semiconductor transportation robot used to transport wafers in semiconductor manufacturing equipment. In recent years, we have been developing versatile products that can accommodate various customer requests simply by changing the hand, with the "Common Platform" concept.

This time, we developed the NTS and TTS series, which realizes the standardization of not only hardware but also software for compact units that require fewer wafer pods.

Introduction

Semiconductors were mainly in demand for computer memories and other products in the past, but are currently used in more products such as mobile phones. In 2017, the demand for semiconductors is expected to increase in the data center, automobile, communication and other industries.

1 Background

A semiconductor transportation robot is used in an EFEM (equipment front end module). An EFEM is a module that transfers silicon wafers between a FOUP (front opening unified pod), a container that seals and transports them, and processes in the semiconductor manufacturing equipment. Currently, the 2W (two FOUPs) and 3W (three FOUPs) are the mainstream models as a result of optimization of unit processing speed and installation footprint. As this suggests, the semiconductor manufacturing equipment is expected to combine a better processing capacity and compact design.

The NT and TT series[1)] developed under the "Common Platform" concept can address many different customer requirements just by replacing the hands, and they support up to 4W though their arms were made longer to do so. Therefore, there was a demand for a compact robot with shorter arms specially designed for the 2W and 3W to support the design of a more compact semiconductor manufacturing equipment.

2 Product overview

We developed the new NTS and TTS series to support the 2W layout in **Fig. 1 (a)** and the 3W layout in **Fig. 1 (b)**.

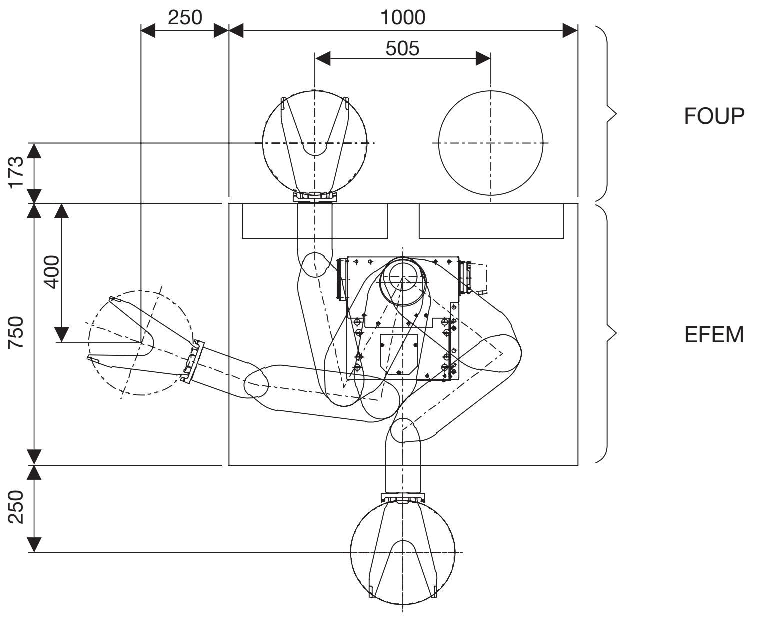
The NTS and TTS series have achieved Cleanliness class 1 defined by the International Organization for Standards (ISO), just like their predecessors. They also inherit the features of the NT and TT series. For example, they do not need the traverse unit and allow the user to effectively use the device space by minimizing the installation footprint of the robot.

Specially designed for the 2W and 3W layouts, the NTS and TTS series have shorter arms than those of conventional products, allowing for more compact unit design. **Figure 2** shows that the NTS and TTS series have shorter arms than the NT and TT series, but maintain the same operating range.

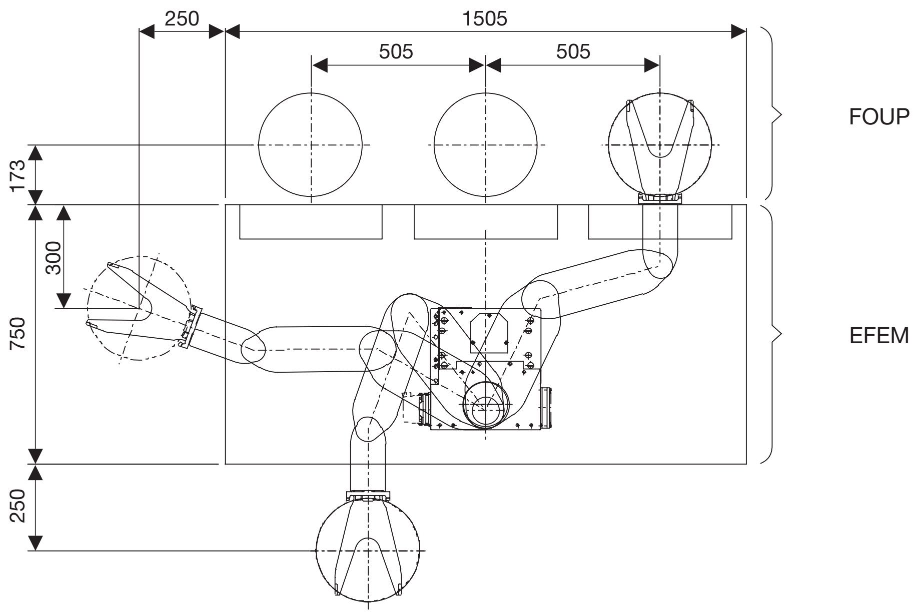
3 Hardware

(1) Compact design

Of the two arms in the NTS and TTS series, the lower arm unit incorporates the gear box that decelerates the gear for driving arms and the motor for two axes. The upper arm unit incorporates the gear box that decelerates



(a) 2W



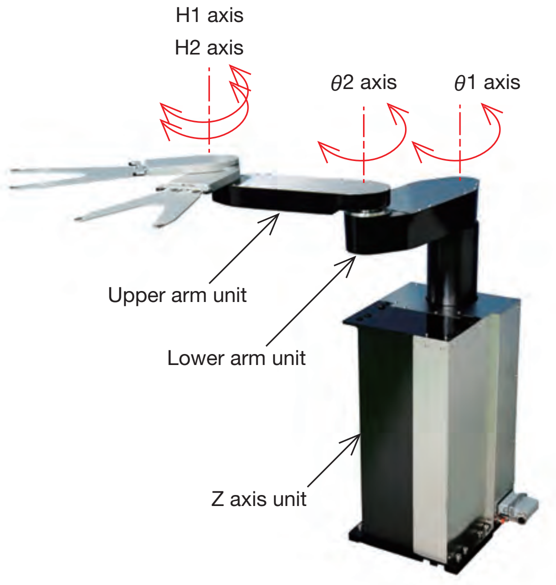
(b) 3W

Fig. 1 Layout in semiconductor manufacturing equipment

the gear for driving the hands of up to two axes and the motor. In other word, each axis section has its own drive-train as a unit to realize a very simple structure, inheriting the design concept of the NT and TT series. In addition, because shorter arms mean less load on the drive-trains, we can design a compact gear box by decreasing the speed reduction ratio, and consequently, further shorten the arms.

(2) High degree of freedom for layout

Each arm axis and hand axis can be independently controlled and the approach angle to each access position can be freely specified. The installation position of robots can also be flexibly changed depending on the position of interfering objects in the unit.



Model		NT520	NTS20	TT220	TTS20
Operating range	Z axis (up/down) 〔mm〕	470	470	740	740
	θ 1 axis (rotation) 〔°〕	340	340	340	340
	θ 2 axis (rotation) 〔°〕	340	340	340	340
	H1 axis (rotation) 〔°〕	380	380	380	380
	H2 axis (rotation) 〔°〕	380	380	380	380
Arm length	Lower arm 〔mm〕	440	360	440	360
	Upper arm 〔mm〕	440	360	440	360
	Hand 〔mm〕	350	350	350	350

Fig. 2 NT, TT Series & NTS, TTS Series spec comparison

(3) Cost reduction

We significantly reduced the costs of the NTS and TTS series. We reduced parts costs by optimizing the layout of electric parts on the board or drive units such as the drive-train, and reducing the number of processes needed to form the robot housing. In addition, we standardized the drive unit by optimizing the speed reduction ratio. Through these efforts, we reduced the number of parts both in the Z axis unit and the lower arm unit by 30% from the NT and TT series. Manufacturing the decelerator units ourselves also contributed to cost reduction.

(4) Reduction in lead time

Inheriting the "Common Platform" concept, the NTS and TTS series widely support the 2W and 3W layouts. Specifically, the NTS and TTS series are standardized except for the hands, which interface with the unit. We also standardized all the products that have a long delivery period to reduce the lead time.

4 Standard application software

Application software is implemented to control the robot according to commands from the unit in order to install the robot in the semiconductor manufacturing equipment. In the past, we adjusted control parameters depending on the unit layout and the type of robot to be installed. Therefore, a long time and expertise were required before the unit could be put into production.

So, we developed standard application software that does not need these adjustment items thereby facilitating installation and reducing the lead time.

(1) Examination and design of the operation path according to the unit layout

We register teaching positions and examine the operation path according to the layout of the customer's unit and embed them into the application software before providing a semiconductor transportation robot. As a tool to separate the items that depend on the unit layout from the application software and further facilitate examination, we developed KRET (Kawasaki Robot Easy Teaching).

We realized the following features by implementing robot data implemented in robot control software and a coordinate conversion logic required to calculate the posture in KRET.

- Layout information (such as teaching positions and the operation area of the robot) can be easily registered.
- The posture of robots used for the transport operation can be easily created by entering the hand angle and other parameters.
- Entered information is displayed as a ground plan as shown in **Fig. 3** and the operation can be visually checked with the animation function.

Knowledge of how to embed data registered in KRET into the application software is not required because that data can be output in a file format that the robot controller can load. In this way, data creation required for robot operation is facilitated and automated.

(2) Automatic correction of side motion in linear operation sections

When robot hands are operated on a line trajectory, side motion of the hands occurs because multiple axes are controlled at the same time. Because the space where the robot can operate in the unit is very small, the side motion must be corrected to avoid interference. In the past, we actually operated the robot, measured the side motion, and adjusted the correction parameters. It took a long time to install, measure, and adjust the robot and measurement hardware. In addition, parameters must be readjusted if the operation path is changed due to layout changes or for any other reasons because the side motion depends on the robot posture.

It was for these reasons that we developed a system to automatically correct side motion. As shown in **Fig. 4**, the system dynamically calculates the torque required for operation based on the inertia force, centrifugal force, and Coriolis force derived from the posture, speed, and acceleration during operation and provides it to individual motors to constrain side motion.

This automation eliminates variations that depend on the proficiency of workers and allows us to provide transport performance with stable quality and a short lead time.

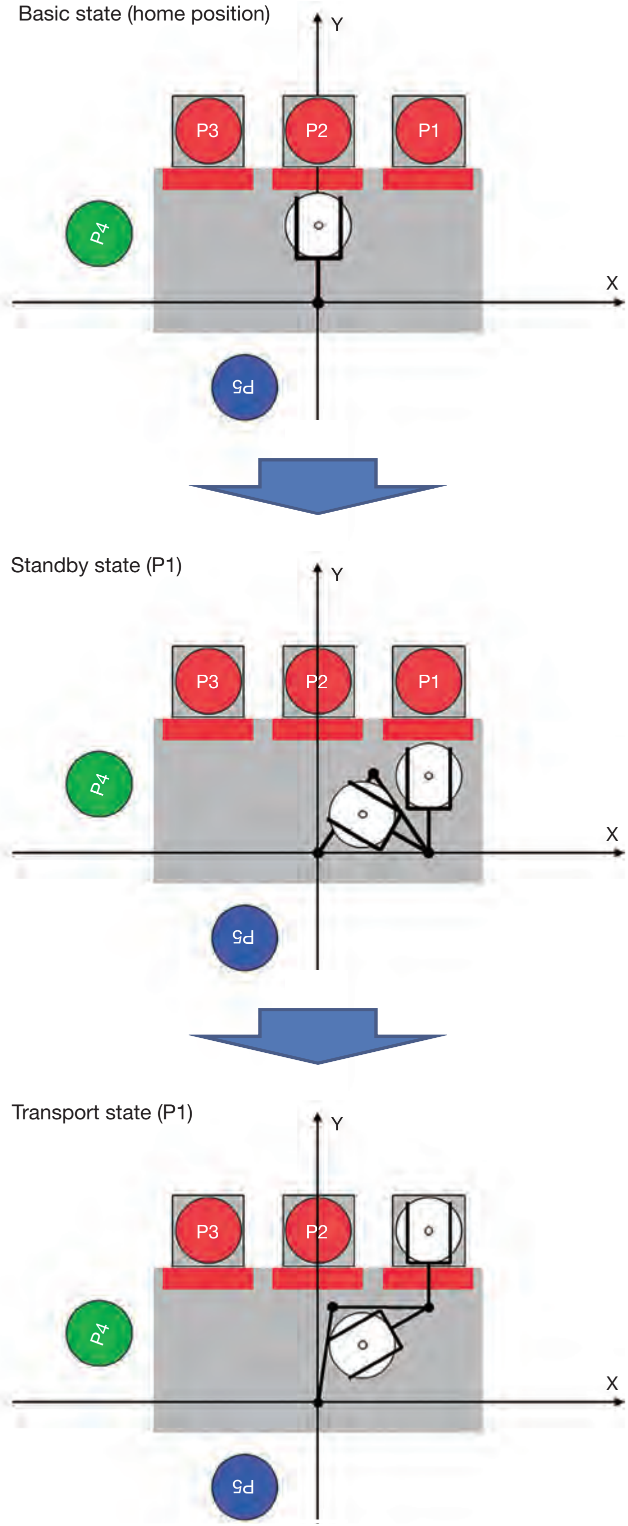


Fig. 3 KRET Operation check image

(3) Automation of adjustment items for homing

Workers are not allowed to casually enter the semiconductor manufacturing equipment once the unit starts production. This is to prevent particles from entering into the unit. Therefore, if the robot stops for some reason, it must return to the defined home position in response to

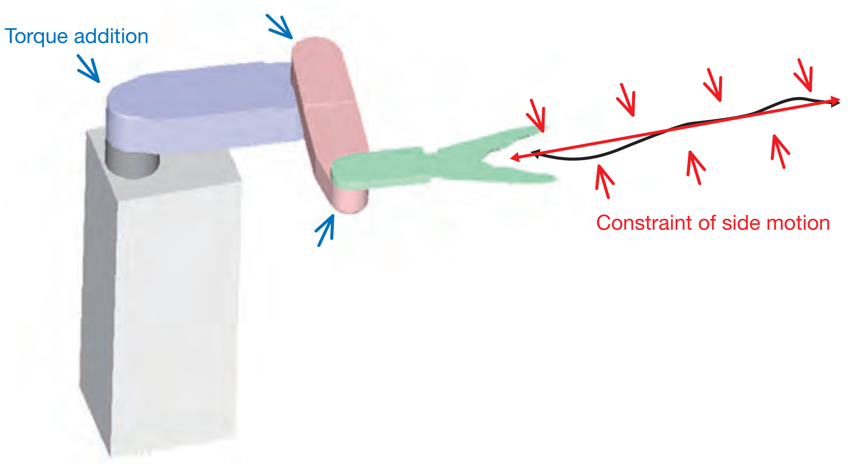


Fig. 4 Side motion correction image

the command from the unit. Our conventional semiconductor transportation robots were able to return to their home positions only when it was determined that the current position is on the transport path so that it would not interfere with the unit during the homing operation. Therefore, the criteria for determining whether the current position is on the transport path had to be adjusted and checked for each project.

For this reason, we developed a function to model the robot and unit layout and automatically return the robot to the home position, while checking for interfering objects. A contour model of the robot is implemented in the application software in advance and the information on the robot operation area registered in KRET is used as the unit layout model. With this function, the robot can return to the home position as described below, checking that the modeled robot does not interfere with the unit layout as shown in **Fig. 5**.

① Select the nearest posture from many different postures that the robot has during transport.

② When models do not intersect by the robot moving directly into the nearest posture, the robot gets into that posture and then moves to the home position along the transport path.

③ When models intersect by the robot moving directly into the nearest posture, the robot moves up to the object that is in the way, avoids it, and then moves to the position to get into the nearest posture. After avoiding the object and getting into the nearest posture, the robot moves to the home position along the transport path as in ②.

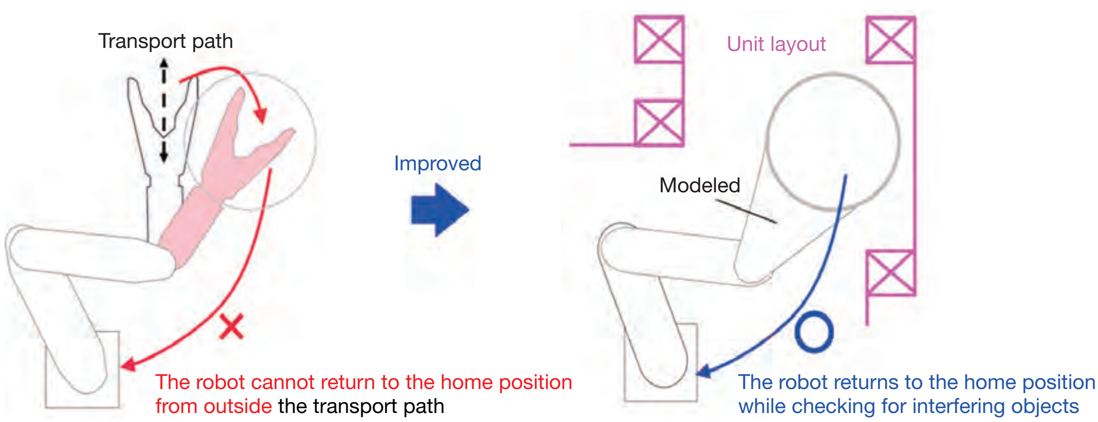


Fig. 5 Conceptual image of homing

Automation of homing eliminates the need to adjust the criteria for determining whether the current position is on the path and the confirmation work associated with adjustment. Because this is area determination, the robot can move to the home position even from a position outside the path without depending on the path.

5 Package software

We developed package software combining KRET and the standardized application software introduced above. Examination results in the application software or KRET can be easily applied to the actual robot using the included terminal software.

We facilitate installation and reduce the lead time by providing this package software to customers.

This software can be easily installed even by new customers because software expertise is not required and it can be provided with a short lead time because adjustment of each unit is not required. In this way, KRET allows customers to examine their layouts by themselves.

Conclusion

Robot systems can now be quickly set up without depending on the semiconductor unit thanks to the new additions to our robot lineup based on the "Common Platform" concept and simplified installation using the standard application software. We will continue to make improvements to provide products that meet many different customer needs with short lead time.

Reference

1) H. Goto, M. Yoshida, M. Inoue, T. Arita, T. Shibata: "NT & NV series advanced semiconductortransferring robot achieving both high speed and ease of use," Kawasaki Technical Review, No.172, pp.25-32 (2012)

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A New Controller for Compact Robots, F60, the Smallest and Lightest in the Industry

Kawasaki robot controllers are entering a new generation. We have developed F60, a controller for compact robots. This product has a size of approximately 77% and a weight of approximately 72% less than those of the conventional E7x series, so achieving the smallest size and the lightest weight in the world for an industrial robot controller. Furthermore, through the utilizing of the latest electronics technologies, functionality, performance, and energy saving have been drastically improved as well.

Introduction

With a reduction of the work force associated with the aging population and low birth rate, small robots are increasingly being applied to new fields and their roles have become increasingly important in recent years. It is expected that an increasing number of robots will be used for more sophisticated or cooperative work with humans as an existence or workforce that is close to humans in the future.

1 Background

Our conventional small robot controllers are the E7x Series for general-purpose robots and the D6x Series for clean robots, which have totally different platforms, and each of these has been playing an active role in its field. However, more than seven years have passed since these controllers were introduced in the market, and further improvements are desired regarding size, functionality and performance. In order to accelerate the development of new functions or new robots in the small robots market going forward, it is necessary to continue introducing more attractive products into the market while accelerating the development through using a next-generation standardized platform.

2 Specifications

The specifications of the next-generation integrated controller F60 are shown in **Table 1**. It supports up to 10-kg payload robots, and a broad range of applications for robots in the medical and pharmaceutical fields and clean robots are currently under consideration. Moreover, the controller has globally universal specifications to realize shorter delivery times.

3 Features

(1) Smallest and lightest in the industry

The number of printed circuit boards was reduced to the extent possible by reconsidering functions without being restricted by the conventional rules of traditional controller design, while optimizing the component layout by configuring the housing structure through aluminum die-casting and resin, in an effort to pursue downsizing while maintaining high extensibility. As a result, approximately a 77% reduction in dimensions (W 300 × D 320 × H 130 mm) and a 72% reduction in weight (8.3 kg) have been achieved, compared to our conventional E7x Series, making the controller the smallest and lightest in the industry (**Fig. 1**). These new features have enabled a significant reduction in the installation space, and allow the controller to be easily transported by a single person and stacked in multiple layers.

(2) Energy-saving

The controller adopts energy-saving electronic components to pursue power reduction in the control circuits and has a larger capacitor capacitance for absorbing regenerative energy generated by the robot, achieving a more than 10% power reduction compared to

Table 1 Specification for F60

Structure		Standard: open structure (enclosed structure available by adding components)
Size (mm)		W 300 × D 320 × H 130
Weight (kg)		Standard: 8.3 (max. 17)
Number of controlled axes	Standard	6
	Additional axis in housing	(2)
I/O signals	External control signal	Emergency stop, external hold signal, etc.
	General I/O signal	Standard: 16 points (In housing: + 64 points [max. 80 points], possible additional points including remote I/O: + 128 points [max. 144 points])
Communication function	PC, network communication	LAN: 1000BASE-T/100BASE-TX/10BASE-T × 2 ports RS-232C × 2 ports, USB 2.0 × 3 ports
	Fieldbus	(CC-Link, DeviceNet, PROFIBUS, EtherCAT, EtherNet/IP, PROFINET, etc.)
Memory capacity		16 MB
Auxiliary storage unit		(USB memory)
Power supply specification		200–230 VAC ± 10%, 1 ϕ , 50/60 Hz
Installation environment		Ambient temperature: 0–45°C, relative humidity: 35–85%, no dew condensation

Items in ( ) are optional

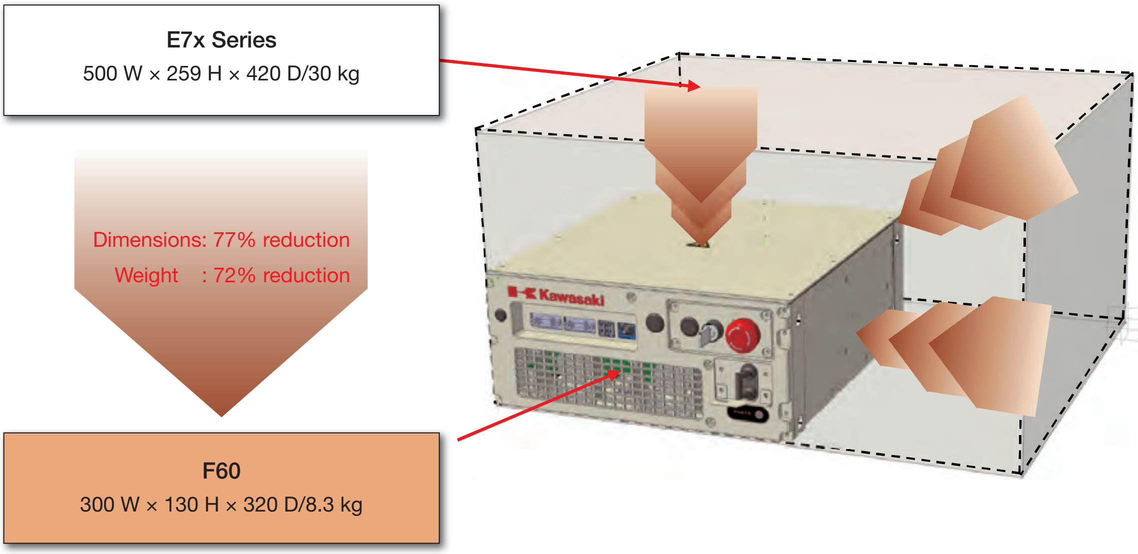

Fig. 1 Size comparison with conventional controller

our conventional products*.

* Compared with the power consumption through the combination of the E7x Controller and RS010N robot in a palletizing motion.

(3) Universal specification/improved safety

It is necessary to divide the conventional E7x Series controllers into different types in order to support the safety standards of each region, such as Asia, Europe and the U.S. The F60 controller has realized universal specifications by standardizing the safety circuit through utilizing the functional safety technology. The safety circuit of the F60 is certified to PLe/Cat. 4 (ISO 13849-1) and SIL 3 (IEC 61508), boasting a higher safety performance than that of the conventional series. Moreover, it supports the Cubic-S robot operation safety unit (refer to Kawasaki Technical Review No. 178 [this issue] pp. 10–14), allowing for the use of small robots that are safer and more secure.

(4) Expandability and new functions

The F60 controller was designed with a high degree of expandability and functionality enhancement in mind, while achieving the smallest size in the industry.

(i) Enhancing the network function

In the F60, easy connection to more networks or devices has been enabled through improving the CPU performance and reinforcing the interfaces. It supports not only the conventional fieldbus but also high-speed Ethernet. Moreover, it can be equipped with a Bluetooth interface as an option, which allows for easy connection to GigE (Gigabit Ethernet)-compatible vision cameras or tablets.

(ii) Incorporating external servo amplifiers for up to two axes

Owing to the housing made of die-casting aluminum that increases heat dissipation of the entire housing, the F60 can incorporate servo amplifiers on up to two axes with its minimal size.

(iii) Implementing the remote I/O function

Conventionally, the general-purpose I/O boards supplied by Kawasaki were mounted within the controller, and it was necessary to draw many wires outside. In the F60, the interface between the boards is serialized, which makes it possible to install the same I/O board or analog I/O board in locations remote from the controller with reduced wiring.

4 Controller assembled by a robot

The development concept for the F60 is a structure that allows for easy assembly and maintenance, with the aim of making it the industry's first "controller that can be assembled by a robot."

(i) The F60 is provided with a structure in which printed circuit boards are stacked from the bottom up, so that it can be assembled by compact robots manufactured by Kawasaki (**Fig. 2**).

(ii) In the F60, the number of electric components and the number of harnesses are minimized, as it is difficult to assemble them using a robot (four compared to approximately 40 in the E7x Series).

The number of components, including printed circuit boards, electric components and harnesses, was radically reduced while enhancing reliability through the realization of i and ii mentioned above. Additionally, due to easy assembly, the F60 is expected to be produced not only in Japan but also overseas.

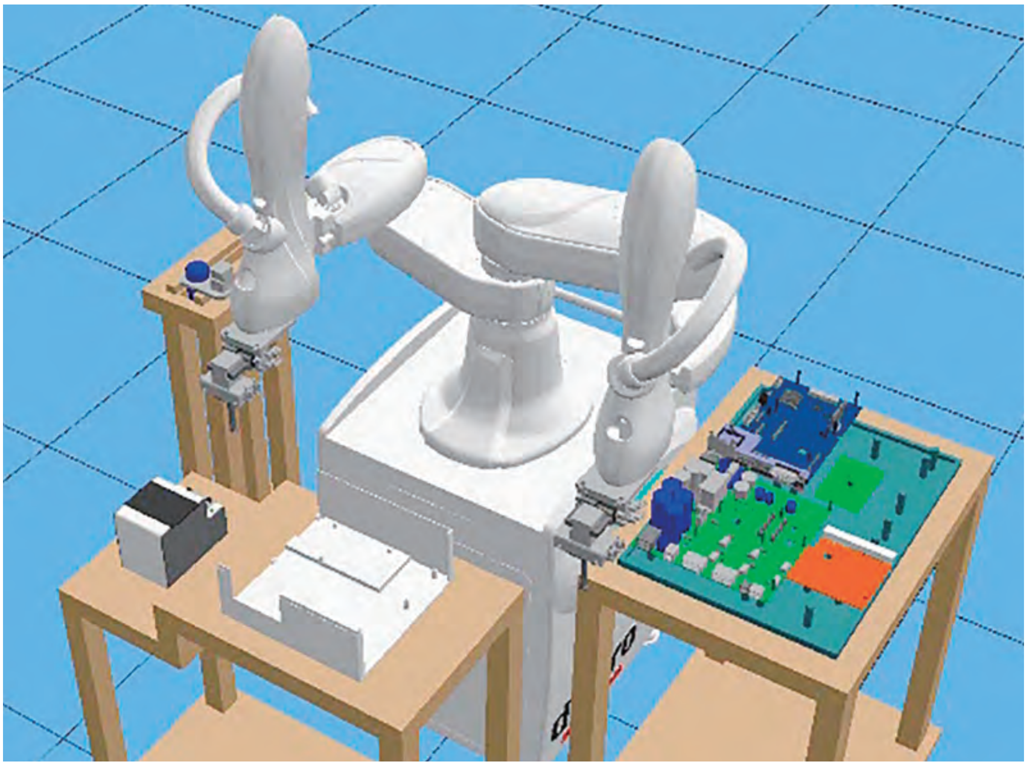

Fig. 2 Image of F60 Assembly using the duAro dual-arm SCARA cooperative robot

Conclusion

Distribution of the F60 controller introduced in this article started in December of 2016. Since then, it has been playing an active role along with many of Kawasaki's small robots. In the future, the technologies that have been accumulated and introduced in this development will be applied not only to small models but also to all of Kawasaki's controllers.

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An Experience-based Robot Showroom, Kawasaki Robostage

An experience-based robot showroom, Kawasaki Robostage opened at Odaiba in the new Tokyo waterfront subcenter area on August 6, 2016. It promotes the potential of our robots by being open to not only our customers but also the public as a space where people can look closely at the collaborative dual-arm SCARA Robot, duAro, and other robot products from Kawasaki Heavy Industries, Ltd.

Introduction

To customers who have specific plans to deploy robots, we have been providing robot-related proposals through demo equipment at our sales offices and our service centers inside and outside Japan, as well as our largest showroom in the country, which we established at Nishi-Kobe Works in October 2014.

1 Background of establishing

The Japanese government set up Japan's Robot Strategy in its Japan Revitalization Strategy Ver. 2014, and this is expected to promote the use of robots in a wide variety of fields in the near future. In addition, there is a plan to transform Tokyo's Odaiba district, which is an area by Tokyo Bay that serves as one of the subcenters for the metropolis, into a showcase that will advertise Japan's advanced technologies to the world. Toyota Motors and Panasonic have already established advertising facilities for the general public in this area, where the nation's government is leading in the preparation for trials of robots such as automated vehicle operation and multi-lingual robot interpreters.

In addition to these activities, 2020 Tokyo Olympics and Paralympics and the World Robot Summit will be held in the Odaiba area. Thus, the Tokyo waterfront subcenter is sure to attract the world's attention. We decided to improve our brand value by quickly setting up a foothold in this area.

2 Concept

The main concept of Kawasaki Robostage is a collaborative coexistence between humans and robots. We will seek the potential of our robots through exhibitions at this location where we hope people can experience new human-robot relationships in the future society, which will be full of robots.

3 Outline of Kawasaki Robostage

The Kawasaki Robostage is located on the first floor of the Tradepia Odaiba skyscraper next to the FCG building (the headquarters of a major Japanese television channel, Fuji TV). Its greenish-toned space with an area of about 132 m2 has screens on each wall showing our advertising videos.

In this place are exhibited the duAro collaborative dual-arm SCARA robot, the BX165N welding robot, and the MS005N and MC004N medical robots. Visitors can enjoy demonstrations of robots and experience programs in order to understand our industrial robots and gain knowledge for the future robotic society (**Fig. 1**).

Thus, Kawasaki Robostage provides a space not only for BtoB but also for ordinary people from many walks of life to gain an understanding of robots.

Fig. 1 Inside view of the facility

4 Exhibits

(1) duAro collaborative dual-arm SCARA robot

The duAro concept is a robot that works in collaboration with humans. Multiple duAro robots are on display. There are demonstrations and also the chance for visitors to interact with robots.

(i) Demonstration

The robot demonstrates duAro's potential for a wide range of applications, such as PC board assembly using various types of hands.

(ii) Portrait drawing

The robot draws visitors' portraits by extracting contour lines from a photograph of the visitor's face taken at the site (**Fig. 2**). The finished portrait is then given to its owner.

(2) BX165N welding robot

The BX165N, a general-purpose large-size robot, boasts a large market share in the market for welding processes such as auto body welding production lines. The exhibited BX165N is combined with VR (virtual reality) technology to provide a hands-on demonstration. A visitor wearing a VR-goggle sits on a seat connected to BX165N, and the image in the goggles and the movements of BX165N are synchronized, allowing the visitor to have a virtual experience (**Fig. 3**).

(3) MS005N and MC004N medical and pharmaceutical robots

Medical and pharmaceutical use robots are attracting attention because demand for them is expected to grow

Fig. 2 Portrait drawing by duAro

Fig. 3 New K-Roboride robot arm ride attraction

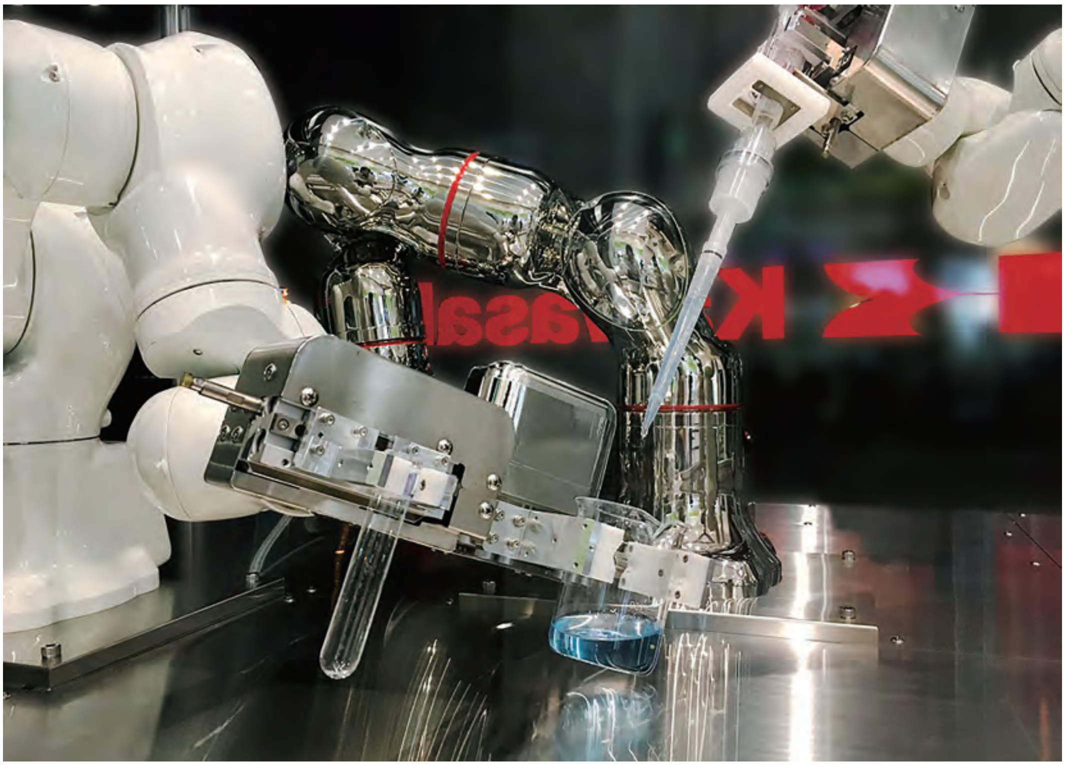

Fig. 4 Demonstration of drug dispensing

worldwide. The MS005N and MC004N medical and pharmaceutical robots are on display. Three robot units in total work collaboratively in a demonstration dispensing work that transfers a liquid from a beaker to test tubes (**Fig. 4**).

Conclusion

Since its opening, this showroom has contributed to improving our brand through activities such as showing robot technologies not only to customers but also to students, government officials, and the general public, and giving press conferences for non-robotic products. We will make this showroom more attractive as a conveyor of information on the full-fledged robotic age, which is just around the corner.

In addition, we will run exhibitions in order to become a place for research into and trials of IoT (Internet of things) products by connecting with plants outside Japan.

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Saturdays, Sundays, and holidays: 10:00–18:00
Mondays and Thursdays; closed
(open when Mon./Thu. is a public holiday)

Tel: +81-3-6457-2800
Admission free
(*Exhibits are subject to change without notice.)