Half a century of Kawasaki Robotics:

The Kawasaki Robot Story

1968 - 2018

Robot Division, Precision Machinery & Robot Company

Kawasaki Heavy Industries, Ltd.

CONTENTS

50 Years in and Still Aiming Higher —

The robotics business of the Kawasaki Group began in 1968 with the establishment of the Office for Promoting Domestic Production of Industrial Robots (IR). In the following year, we successfully produced the first industrial robot in Japan. Since then, together with the growth of manufacturing in Japan and while garnering enormous support from our customers and partners, we have developed our robotics business to become the pioneer in the industrial robot industry. I would like to express my deepest gratitude and appreciation to our customers for their continuous advice and guidance, as well as our many stakeholders for their unwavering support—it is because of you that we are able to celebrate the 50th anniversary of our robotics business here in 2018.

The social issues arising as a result of aging society have become serious, and actions for counteracting a diminishing workforce or improving the medical system are needed as a present-day challenge society faces. This has led to high expectations on Kawasaki's robotics business from industries to deal with those challenges.

Also, with the Fourth Industrial Revolution and the "New Robot Strategy" initiative by the Japanese government both currently getting underway, people are taking much more notice of robots, anticipating a new society where humans and robots co-exist through the integration of robots and new technologies such as artificial intelligence (AI) and the Internet of Things (IoT).

In order to meet such expectations, we have made robotics one of our company's core businesses and will continue taking on challenges. We also believe that our robotics business will further promote the Kawasaki Group's corporate slogan and social mission of "Powering your potential".

Taking our achievement and the credibility we have gained over the last half-century, we are aiming even higher for the future. I humbly ask our customers and partners for your continued support for our growing robotics business.

June 2018

Yoshinori Kanehana

President of Kawasaki Heavy Industries, Ltd.

Timeline of Kawasaki Robotics History as Seen Through Social and Industrial Events

Prehistory of Kawasaki Robotics

From the Birth of an Industrial Robot in the United States to Its Launch in Japan

1954
George Devol applies for a patent for the "Programmed Article Transfer" in the United States

1954
Japan enters into a period of rapid economic growth

1961
Devol and Joseph Frederick Engelberger, an entrepreneur, establish a company named Unimation, Inc. which specializes in the development of industrial robots

1962
A prototype of the world's first industrial robot, the Unimate, is completed

1968 ➡P.05

An Encounter with Unimation and Technical Partnership Negotiations

The world's first industrial robot, the Unimate, was born out of an encounter between an inventor and an entrepreneur in the 1950s United States. Unimation, the company which developed the Unimate, begins delivering its industrial robots to GM and other major American car manufacturers in the late 1960s. Concurrently, the founder of Unimation visits Japan in search of a new business partner and crosses paths with the Kawasaki Group. The history of industrial robots in Japan begins with Kawasaki becoming the first to completely manufacture the Unimate domestically.

Chapter 1

A Project to Make Japan's First Domestically Manufactured Industrial Robots Begins

From the 1960s onwards
Japan begins **full-scale motorization**

1969 ➡P.09

Japan's First Domestically Manufactured Industrial Robot Debuts and is Implemented into the Automotive Manufacturing Process

After signing the technical license agreement with American company Unimation, Inc., the Kawasaki-Unimate 2000, the first domestically manufactured industrial robot, is completed. It would consequently be brought in to work in the Japanese automotive industry where there was serious labor shortage during the period of rapid economic growth. Despite its performance and reliability not being satisfactory enough to meet the strict demands of Japanese car manufacturers, further improvements are made to the Kawasaki-Unimate 2000 while working hand-in-hand with each customer, all of whom believe in the potential of robots, and implementation moves forward.

1969
Japan's **GNP becomes the second largest in the world**

1970s
Households owning cars becomes increasingly common and demand for small, fuel-efficient vehicles grows

1973
The first oil crisis occurs

1979
The second oil crisis occurs

Late 1970s
A shift in industrial robots **from being hydraulic-powered to being electrically-driven** occurs as a result of **improvements in servo motors**

1980 ➡P.11

Opportunities to Streamline Due to the Oil Crises Help Make Way for a "New Era of Industrial Robots"

Economic downturn during the first oil crisis in 1973 pulls back investing on facilities, eventually causing the stationing of robots to slow down significantly. On the other hand, when the second oil crisis occurs in 1979, calls for streamlining push the implementation of robots forward.[1]

1980
VAL (Variable Assembly Language), the world's first **robot programming language**, is introduced

1982 ➡P.13

In-House Development of Large Motorized Robots

With an increase in demand for motorized robots with characteristic advantages including only consuming one-third of the power of hydraulic robots, reduced vibrations during operation and easy maintenance, there was a need for motorized robots for the scope of work performed by the hydraulic Unimate. The EX100, developed while struggling with control and actuating methods fundamentally different from those of hydraulic robots, would become a bestselling model for automobile manufacturers.

Chapter 2

Kawasaki Robot's Entry to the North American and European Markets

1980
Automobile production in Japan tops 11 million vehicles, making **the country the world's largest manufacturer**[2]

1980s
Japan-United States trade friction becomes notable.
Japanese car manufacturers progressively expand into the United States and begin local production

1986 ➡P.15

The First Overseas Base is Established in Detroit in Preparation for Expansion into the American Market

In the mid-1980s, the operational stock of industrial robots in Japan surpassed 93,000 units, which accounted for approximately 70% of all units worldwide, and the country would grow to become a "Robot Kingdom". With a wealth of application technologies, in addition to machine and control technology accumulated over the years, Kawasaki engages in a full-fledged expansion into the North American market where the automobile industry is so gigantic that it is said to encompass one-sixth of the entire American workforce. The first overseas base is established in "Motor City" Detroit.

1988 ➡P.16

A technological license is provided to a Korean Heavy Industry Manufacturer

1989 ➡P.16

Local Offices are Established in Multiple Countries in Anticipation of a Full-Scale Expansion into the European Market

In the early 1990s, the Soviet Union would collapse, allowing people to freely travel between Eastern and Western Europe, and giving birth to the present-day EU (European Union) economic zone. In search of a new market, Kawasaki heads to Europe. In 1989, overseas representatives are dispatched to the Amsterdam branch in the Netherlands. In 1991, a local office within Kawasaki Motors UK (KMUK) in London is newly formed. And in 1995, the local subsidiary Kawasaki Robotics GmbH (KRG) is established in Germany with the goal of development into markets throughout Europe.





Source (Referred to the original Japanese contents) : ❶ The Institute of Electronics, Information and Communication Engineers "Journal of the Institute of Electronics, Information and Communication Engineers Vol.82 No.10" ❷ Japan Automobile Manufacturers Association, Inc. "JAMAGAZINE-featuring Global Market" (2015) ❸ Society of Semiconductor Industry Specialists "Semiconductor History Museum of Japan" Semiconductor Industry explained in graphs (2016) provided by the Toukeishiryoshitsu

Ever since Kawasaki signed a licensing agreement with Unimation, Inc. in 1968 and successfully completed Japan's first domestically manufactured industrial robot, Japan has progressed on as a "Robot Kingdom". Taking a look at the social trends and industry shifts surrounding robots will reveal how the progression of Kawasaki's robotics business has been parallel with society and manufacturing.

Year in Color | **Red:** History of Kawasaki Robotics | **Blue:** Social and Industrial Events Related to Kawasaki Robotics | **Green:** Trends in the Robotics Industry |

Chapter 3

Full-Scale Entry into the Cleanroom Robot Market as Demand for Semiconductors and Liquid Crystals Increases

1961
The patent for the IC (Integrated Circuit) is granted in the United States

1970
Intel develops the DRAM (dynamic random-access memory)

1971
The development of the 4-bit microprocessor by Intel makes a turning point in the way robots are controlled (*)

1970s to 2000
The semiconductor market records an average annual growth rate of 14%[4]

1990s
The tech boom begins

1990s
Advancements in microprocessor performance improve robot control and information processing capabilities (*)

(*) The development of the microprocessor dramatically improved robots' performance. Since the 1970s, microprocessors have continually progressed from being 4-bit to 8-bit, 16-bit, 32-bit and 64-bit, allowing controlling to be done via software and with high complexity. This evolution would enhance information processing capabilities, and support efforts to create high-performance robots.

1997 ➡P.17

Full-Scale Entry into the Cleanroom Robot Market as the Demand for Semiconductors and Liquid Crystals Rises

With demand for high-performance and reliable cleanroom robots capable of handling larger semiconductor wafers and liquid crystal glasses increasing, Kawasaki begins developing its own cleanroom robots. Although cleanroom robots required completely different technology from the robots used in the automobile manufacturing process, an area Kawasaki had excelled in, Kawasaki would engage in the development and expand its lineup of cleanroom robots. This event builds a foundation for Kawasaki's largest market share in the industry today.

2000 ➡P.18

Kawasaki's domestic facilities prepare for full-scale production of cleanroom robots and in the following year, a business office is established in San Jose, the heart of Silicon Valley in the United States

2000s
The size of LSI expands as the diameter of semiconductor wafers increased

Chapter 4

Emerging Asia, A New Base for the Semiconductor and Automotive Market

Late 1990s to 2000s
Economic Growth in Asia
The economy progresses from being import-oriented to one that is export-oriented, and industrialization in Asia rapidly advances, with a central focus on the electrical and electronic device and machinery manufacturing industries in ASEAN countries and China, which were backed by increased foreign direct investment

1999 ➡P.19

Local business offices are established in Asian countries such as Korea, Taiwan and Thailand where foreign manufacturers were expanding operations and local manufacturing was growing

1999
The electrical and electronics device manufacturing industry surpasses the automotive industry to gain top spot in shipment value of industrial robots by essential industry[4]

2002
The value of Japan-China trade exceeds 13 trillion yen, and the value of trade between Japan and all Asian regions reaches 40 trillion yen[5]

Late 2000s
Large-Scale Motorization Begins in China
The Chinese economic reform transforms China into the largest automobile market in the world, with number of vehicles sold in China overtaking Japan in 2006, and then the United States in 2009

2006 ➡P.20

Expanding into a Rapidly Growing China

Kawasaki successively establishes local business offices in China, a country regarded as the "world's factory" and a rapidly growing market for mass consumption. In order to combat the serious labor shortages facing China, Kawasaki not only establishes sales and services bases but also increases the capabilities of the local business environment with facilities including a highly automated factory based on the concept of "robots creating robots" and an office for parts procurement.

2013
The number of robots installed in China reaches 36,000 units, making it the largest importing country in the world surpassing Japan

Chapter 5

Closer and Wider - Broadening Opportunities for Robots

2000s
The information age begins as the Internet communication technology becomes more sophisticated

2000
The FDA approves the "da Vinci Surgical System", a surgical system with robotics technology introduced by the American company Intuitive Surgical

2010s
The Fourth Industrial Revolution emerges with trends such as an accelerated innovation process due to evolving AI technology and the widespread adoption of IoT

2010s
The proportion of Japan's elderly population (those aged 65 and over) reaches 23% in 2010, while the total population of Japan continues to shrink from 2011 onwards[6]

2013 ➡P.22

Joint venture company Medicaroid is established to meet the needs of increasingly advanced and diversified medical fields through the development of medical robots

2013
Easing of regulations makes human-robot co-working possible and gives birth to the "collaborative robot" market

2015
The Japanese government announces the "New Robot Strategy" to advocate the use of robot technology in a wide range of fields from manufacturing to nursing and healthcare

2015 ➡P.22

Launching of the Collaborative Robot, duAro

The duAro, a robot with the benefit of being space-saving, cost-effective to introduce, and suitable for multi-product and small-lot productions, is launched as society carries high expectations for collaborative robots to be a solution for labor shortage. It aims to make robot implementation easier and helps contribute to market expansion.

2017 ➡P.23

Introduction of the Successor as a Solution for Fields Struggling to Achieve Robotization

Utilizing Kawasaki's remote collaboration technology and AI, a new robot system, the Successor, is designed for fields previously struggling with robotization. Developing a robotic system that learns human operations and can then operate autonomously or transfer skills provides a solution for an aging society.

2017 ➡P.24

An industrial-academic co-development of a humanoid robot, collaboration with Switzerland-based ABB to widen the collaborative robot market - Innovation speeds up with Kawasaki's open innovation approach





[4] New Energy and Industrial Technology Development Organization "NEDO White Paper on Robotization of Industry,. Business and Our Life (2014)" [5] Ministry of Finance "Trend of Top 10 Trading Partners (total value of trade-export and import- calendar year basis)" [6] Ministry of Internal Affairs and Communications "Statistics on elderly population (Age 65 and over) 2017"

From the Birth of an Industrial Robot in the United States to Its Launch in Japan

The first industrial robot was born from an encounter between an inventor and an entrepreneur in 1956. The term "robot" first originated in 1920. Then about 30 years later, the robot concept came into the real world with the birth of the "Unimate".
The history of industrial robots in Japan began, when Kawasaki Heavy Industries, or Kawasaki, completed Japan's first domestically manufactured industrial robot based on the Unimate.
Let's take a look at the stories behind the birth of industrial robots.

Origin of the Term, "Robot", and Its Concept

The term robot first appeared in the 1920 play, *R.U.R.* (Rossum's Universal Robot), by the Czechoslovakian (now the Czech Republic and Slovakia) writer, Karel Capek. He used "robot" as a term to describe an artificial human. The term robot is Capek's creation combining *robota* (meaning "forced labor" in Czech) and *robotnik* (meaning "worker" in Slovak).

Also, the ending of his play *R.U.R.* was set to the future, in the 1960s, which interestingly coincides with when the first industrial robot made its appearance (the world's first industrial robot, the Unimate, was completed in 1961).

What is the Definition of Industrial Robots?

Although any mechanical devices operating on behalf of humans are often called industrial robots, no specific definition for industrial robots has been established. In the robotics industry, however, industrial robots generally mean industrial machines operated using a teaching-playback method and this originates from the Programmed Article Transfer device invented by Devol in 1954.

According to the Japanese Industrial Standards (JIS)'s JIS B 0134:1998, the term "industrial robot" is defined as "a machine which has manipulation features or mobility functions that are controlled automatically, able to perform various tasks through a program, and is used for industrial purposes".

A Patent for the World's First Industrial Robot

The first person to bring about the idea of industrial robots was the American engineer, George Charles Devol Jr. He applied for a patent for his "Programmed Article Transfer" device in 1954. In the patent description, he published a completely new concept: a machine that puts and takes things through the process of teaching and playback. His application was accepted in 1961 and registered as US Patent No. 2,988,237. This is the world's first registered patent for industrial robots.

Opening the Road for the Practical Use of Robots

In 1956, Devol, who was then 44 years old, met a man at a cocktail party. His name was Joseph Frederick Engelberger, a 31-year old engineer and entrepreneur. Eventually, he would lead not only Kawasaki's robot business but also the world's robotics industry and come to be known as "the father of robotics". Devol told Engelberger about his patent-pending Programmed Article Transfer device while Engelberger was fascinated with what Devol talked about. The two men instantly clicked and decided to work on making practical playback robots which would conduct risky operations in place of humans.

Engelberger on the left and Devol.

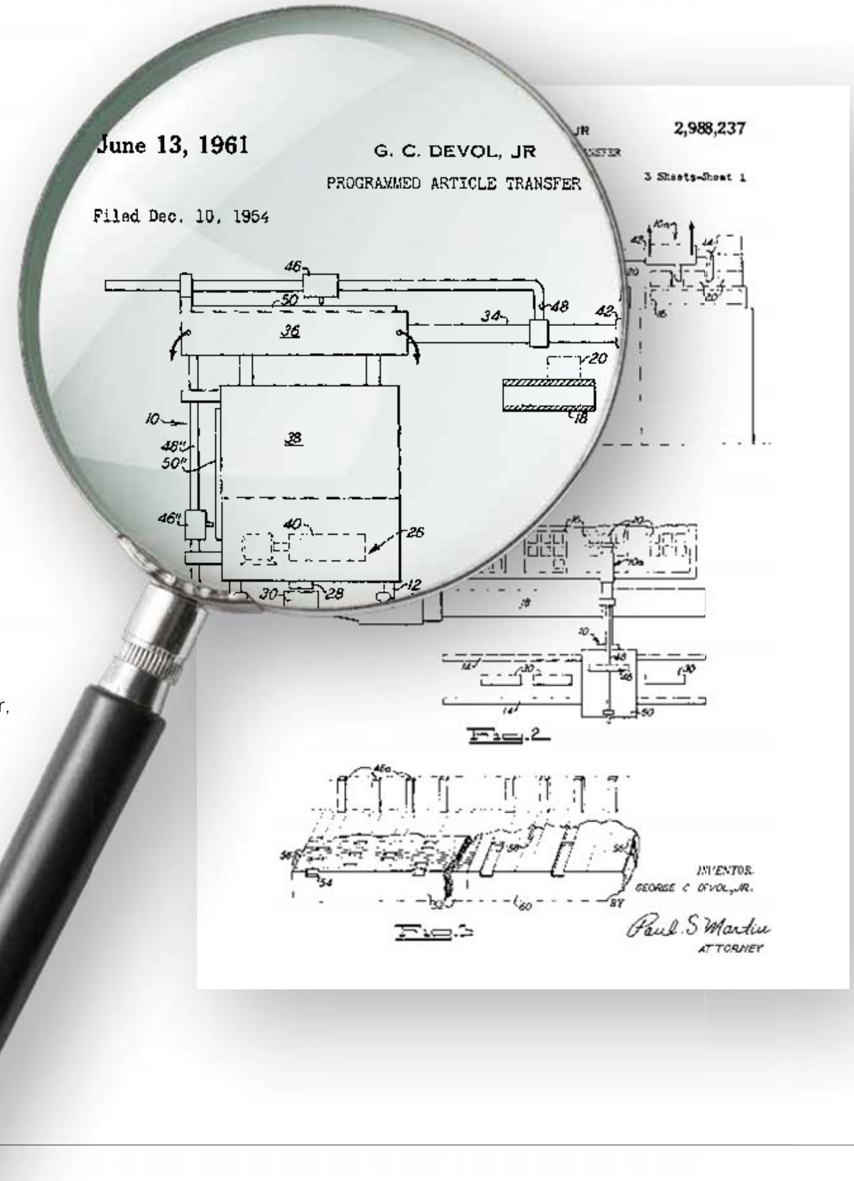
Why was Devol's Invention Valued at the Time?

In the 1950s, about 10 years before their first meeting, the industries were in search for automated machinery that was better, equipped with newer functions, and served as a replacement of specialized machines currently in use had started in the United States. There was strong demand from the automotive industry, in particular, where many of the manufacturing sites were already automated. Like the well-known Ford System, specialized machines sped up factory automation for major American car manufacturers, and by the 1950s, automating any remaining processes was required. Completing one automobile requires spot welding an average of 4,000 points on thin steel plate parts. Although 70% of this time-consuming process had already been automated using a multi-spot welder, a specialized automatic welding machine, the remaining 30% could not be automated by specialized machines and had to be finished by many experienced welders standing ready by the conveyer belt.

Additionally, there was another problem; whenever there was a change in car models, it took a great deal of time and money to modify the specialized setup of the machines or completely replace them with new ones.

Implementation of Robots in the Automotive Industry

In 1957, Engelberger began to look for a partner to develop the teaching-and-playback robot based on Devol's invention, the Programmed Article Transfer device, and the playback robots that would materialize device. He would later convince Norman Schafler, the CEO of Condec Corp., the parent company of Consolidated Controls, where Engelberger was the president, to invest in Devol's invention and managed to obtain approval from Schafler.



Patent description for the Programmed Article Transfer,
US Patent No. 2,988,237
Inventor: G.C. Devol, Jr
Date of Application: December 10, 1954
Date of Registration: June 13, 1961
Source: The United States Patent and Trademark Office

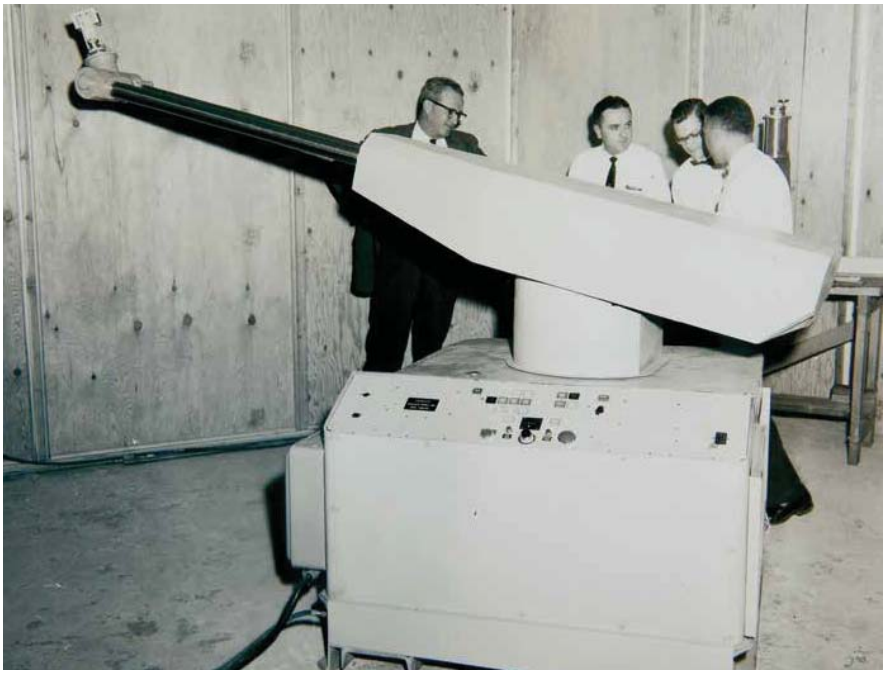
A prototype of the Programmed Article Transfer device was completed in 1959. Engelberger immediately took the prototype and approached major American car manufacturers. The first company showing an interest was the General Motors Company (GM). GM decided to deploy the prototype in its die-casting factory in Trenton, New Jersey and thus began the practical use of industrial robots.

GM proactively installed industrial robots. For example, GM implemented the Unimate, an industrial robot that would later be launched on the market, for spot welding in Lordstown, Ohio in 1969 and effectively doubled the factory's productivity by making it possible to assemble 110 cars per hour.

Foundation of Unimation, Inc. and the Success in the First Prototype Production

In 1961 Engelberger, together with Devol, established Unimation, Inc., a venture company as a subsidiary of Condec Corp., specializing in industrial robots, in the town of Danbury, Connecticut. In the following year they succeeded in the trial production of the world's first real industrial robot, the Unimate.

It is said that the Unimate's characteristic long arm was designed by Engelberger inspired by tank guns. According to its basic specifications, it was a 5-axis polar coordinate robot controlled by hydraulically actuated vacuum tubes and its payload was 12 kg.



Devol, Engelberger and their team working on the development of the Unimate.

Origin of the Name, Unimate

Unimate means "working mate with universal capability" and was a nickname used to personalize the robot. People who saw the Unimate extend, retract and rotate its long arm and bend its wrist thought the name suited perfectly, and soon after, many other companies followed naming their products the same way. By the way, the company name, Unimation, is an abbreviation of "Universal Automation".

Looking for a Partner in the European and Asian Markets

Having settled a management policy that would entrust a capable local company in the region with the manufacturing and sales of its products in order to develop its industrial robot business overseas, Unimation looked to expand its business in Europe and Asia. Concerning the Asian market, it set the target at Japan, which had technical capabilities and market potential.

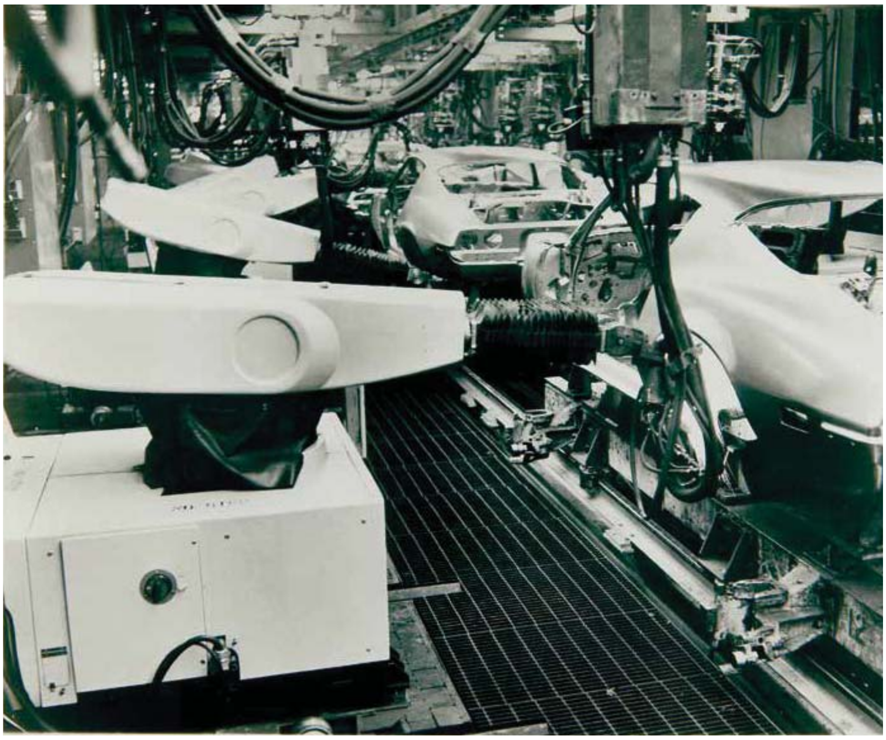
In 1966, Engelberger was invited to Japan where he gave a speech in Tokyo on industrial robots and introduced the usefulness of industrial robots. When he made a similar presentation back in America, only a handful of people showed up. However, his presentation in Tokyo was very successful with a showing of approximately 700 executives interested in robot applications, and the question-and-answer session following his lecture lasted over two hours.

Kawasaki Aircraft Industries and Unimation Meet —Behind the Technical Partnership Negotiations

In the 1960s, one of the major products of Kawasaki Aircraft Industries (predecessor of Kawasaki Heavy Industries; in 1969, Kawasaki Dockyard, Kawasaki Aircraft and Kawasaki Rolling Stock Manufacturing merged to become Kawasaki Heavy Industries) was an industrial machine for chemical synthetic fiber. However, due to a downturn in the fiber industry after the war and a trend seeing the labor-intensive fiber industry moving to Southeast Asia, it was forecasted that demands for the machinery in the fiber industry would further decrease, so Kawasaki Aircraft considered promoting its machinery to alternative industries instead. The company started market research in the early 1960s and selected a few machines including excavators and industrial centrifuges as options for new markets. Among them, the company looked to "playback devices", which were expected to see more demand in the future as a solution for improving productivity and labor shortage during the period of rapid economic growth, and decided to focus on robotics as the most important target.

Management at Kawasaki Aircraft, who recognized early on the great potential for these then-unknown industrial robots, immediately started negotiations on a technical partnership with the American Unimation in 1967 when they knew Unimation was looking for a technical partner for its industrial robots in Japan.

Unimation initially short-listed seven companies, most of which were electrical manufacturers, as a possible technical partner. As electrical manufacturers had the upper hand in terms of machine control, Kawasaki Aircraft was not included in that list at first. But the management at Kawasaki Aircraft visited Unimation in the United States and aggressively began negotiating. As a result, explanations about the technical capabilities Kawasaki Aircraft accumulated over the years combined with the passion management showed won Engelberger over and Kawasaki Aircraft was chosen by Unimation to become their technical partner in Japan.



The Unimate in operation at a car production line in the United States.

Unimation required its technical partner to accurately manufacture Unimate according to design specifications provided by the company, and in that respect, selecting Kawasaki Aircraft was the inevitable choice. As the fundamental elements of playback control, three essential elements: 1) hydraulic servo valve, 2) position tracking encoder, and 3) data storage drum memory, played the key roles for the Unimate. Among those three, the hydraulic servo valve in particular was where the technology used in the fiber machines developed by Kawasaki Aircraft could be applied. Kawasaki Aircraft had the technology to control the production of fiber spinning pumps with micrometer precision, and it was deemed applicable to the production of hydraulic servo valves as well. At that time, no other company had the same technology. Combining the Kawasaki's machine mechanism and the Unimate's control mechanism paved the way to making the Unimate practical.

In June 1968, prior to the effective date of the technical license agreement in October, Kawasaki Aircraft established the "Office for Promoting Domestic Production of Industrial Robots (IR)". This division is the predecessor of the present Robot Division of Kawasaki, and handled the license agreement with Unimation.

In October 1968, four months after the establishment of the "Domestic Production of Industrial Robots (IR) Promotion Office", Kawasaki Aircraft and Unimation officially entered into a license agreement on the Unimate, which led to the development of Japan's first domestically manufactured industrial robot, the "Kawasaki-Unimate" in 1969.

This is where the history of Kawasaki Robot as well as industrial robots in Japan began.

Reference:

- Westerland, Lars "The Extended Arm of Man" (2000)
- Robotics Industries Association, "A Tribute to Joseph Engelberger"

Images from:

- The Collection of The Henry Ford

1

The Kawasaki Robot Story

The First Industrial Robot in Japan

A Project to Make Japan's First Domestically Manufactured Industrial Robot Begins

For about 20 years starting in 1954, Japan was in a period of rapid economic growth. Thanks to the success of the 1964 Tokyo Olympic Games and the Japan World Exposition, Osaka in 1970, proclaiming to the world its recovery from the War, Japan managed to achieve economic growth of more than 10% a year and Japan's GNP became the second largest in the world in 1968.

The manufacturing sector, which accounted for 30% of the GNP, focused on investing in their facilities and increasing human resources.

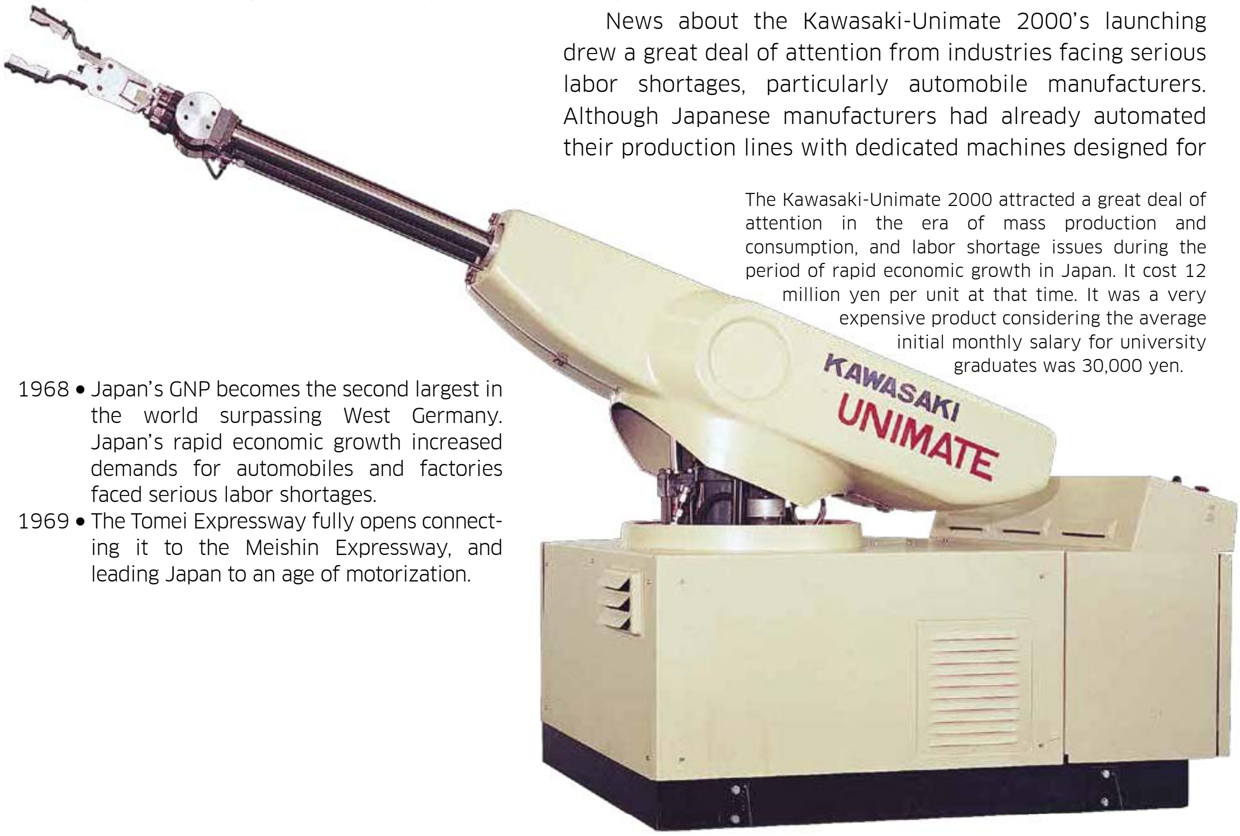
As production capacity was urged to be increased in order to catch up with the rising demand due to rapid motorization, the automotive industry faced serious labor shortages. Ever-increasing demands unquestionably opened the doors to labor shortage; automation and streamlining processes with machines to compensate manual labor in automotive manufacturing sites had become urgent.

Debut of the First Domestically Manufactured Industrial Robot

The "Office for Promoting Domestic Production of Industrial Robots (IR)", was established in June 1968 during the period of rapid economic growth. This office is the predecessor of the present Robot Division and handled the license agreement with Unimation in October of the same year.

In the following year, a sample Unimate machine was delivered from the United States while Kawasaki itself sent an electrical designer, a mechanical designer and a production engineer to the United States. Development was accelerated through human-product exchanges. The three engineers sent to the United States learned manufacturing techniques at Unimation while staff back in Japan conducted detailed structural analysis and operational checks in preparation for domestic production. In May, Japan's first domestically manufactured industrial robot, the first "Kawasaki-Unimate 2000" model was completed. The Kawasaki-Unimate 2000 was a 5-axis polar coordinate hydraulic robot with a payload of 12 kg. At that time, the performance of electric motors was insufficient and hydraulic power was considered the best power source.

News about the Kawasaki-Unimate 2000's launching drew a great deal of attention from industries facing serious labor shortages, particularly automobile manufacturers. Although Japanese manufacturers had already automated their production lines with dedicated machines designed for



The Kawasaki-Unimate 2000 attracted a great deal of attention in the era of mass production and consumption, and labor shortage issues during the period of rapid economic growth in Japan. It cost 12 million yen per unit at that time. It was a very expensive product considering the average initial monthly salary for university graduates was 30,000 yen.

In this year:
1968-1969

- 1968 • Japan's GNP becomes the second largest in the world surpassing West Germany. Japan's rapid economic growth increased demands for automobiles and factories faced serious labor shortages.
- 1969 • The Tomei Expressway fully opens connecting it to the Meishin Expressway, and leading Japan to an age of motorization.

specific purposes, the industries were interested in the Kawasaki-Unimate 2000 for its ability to adapt to various operations.

The first promotional catalogue introduced the Kawasaki-Unimate 2000 as "a new type of worker that would solve labor shortage issues" and highlighted the following points:

"The Kawasaki Unimate is

1. Durable enough for working in forging where heavy, heated billets are handled,
2. Yet, dexterous enough to handle and pack very delicate glass tubing.
3. Clever enough to memorize very complicated spot welding patterns and accurately repeat a series of operations,
4. Yet, patient enough to accept boring, simple tasks and continue working without becoming tired or complaining.
5. Also, versatile enough to easily adapt to organizational production changes in the factory."

In a time when the public was not yet familiar with robots, Kawasaki took this concept and suggested applications for robots in order to introduce them into the market.

The cover of the first Kawasaki-Unimate 2000 brochure.

The Motorization Trend Brings Robots to Automobile Production Lines

Japan, making its way to becoming the country with the second largest GNP in the world, began motorization in the 1970s. Automobiles were considered luxurious items and generally used by companies or as personal vehicles for the wealthy. With Japan's economy rapidly growing since the latter half of the 1960s and the real national income per capita increasing, cars gradually started finding their way into the hands of the masses, and motorization took off. Automotive manufacturers riding on this trend accelerated the growth, and from 1972 onward, the Kawasaki-Unimate was being employed more and more. What was behind this movement?

In 1971, the number of cars Japan exported was small—under 2 million cars a year—and Japanese car manufacturers that increased their production capacity faced cost increases due to the rapid rise in wages during the period of rapid economic growth. Particularly for spot welding during automobile assembly, despite having a massive number of workers engaged in the process, the use of a dedicated automated machine called a multi-spot welder could not automate complicated spot welds accounting for 40% of the 3,000 to 4,000 spot welding points, leaving car manufacturers stuck and neither able to work with model changes nor diversify their product lines. More versatile, automated spot welding machines were required.

The Kawasaki-Unimate answered the call, breaking the limits of automation by specialized machines. The Kawasaki-Unimate, which was controlled using the "teaching-playback" method, which an operator was only required one manual demonstration of a robot from a remote location to teach a work procedure just by having the operator press the record button. Then, the recording of the information such as routing and stand-by time into its memory was completed. From the second time on, the robot could endlessly repeat the operations as recorded.

The Kawasaki-Unimate 2000 in operation at a car factory.

With teaching-playback robots, manufacturers could have a model change and all they would have to do is simply teach the new welding patterns to the robot. The teaching process would take less than a day. The unmanned production line capable of spot welding 320 points per minute took over the work of ten experienced welders. Including day and night shifts, it saved the labor of 20 people and as a result, the use of such highly versatile robots freed workers from welding, one of Japan's so-called "3K"(*kitsui*, or "hard"; *kitanai*, or "dirty"; and *kiken*, or "dangerous") jobs.

As Japanese car manufacturers revealed its benefits, the implementation of the Kawasaki-Unimate widened. The first factory to install the Kawasaki-Unimate was Nissan Motor Corporation in 1972, followed by Fuji Heavy Industries (present-day SUBARU), Toyota Motor Corporation and Toyo Kogyo (now Mazda).

However, the Kawasaki-Unimate and its innovative control method still bore a few uncertainties concerning full-scale deployment. The original design concept from Unimation was still being followed during domestic manufacturing, but its performance and reliability were not satisfactory for the demands of Japanese car manufacturers. For instance, its MTBF (Mean Time Between Failures) was less than one-tenth of the standard for car manufacturers. However, despite the situation, the engineers and technicians of major car manufacturers did not abandon their hope for the Kawasaki-Unimate. Kawasaki's Robot Division also made great efforts to improve it. As the situation on robot implementation in overseas automotive manufacturers such as GM which installed the Unimate early on, became clear, major car manufacturers in Japan were in need of facing serious consideration on the implementation of robots. Companies in automotive manufacturing and other industries standing at the forefront of robot implementation together with Kawasaki were eager to pursue the potential and possibilities of robots. Their passion and endeavor accelerated the use of the Kawasaki-Unimate in car manufacturing and it expanded from 1972 onward.

Column

Looking back on the brief history of the Japan Robot Association (JARA), a trade association for industrial robots. In 1971, a voluntary organization with the purpose of nurturing the robotics industry, called the Industrial Robot Conversazione, was established by 35 related companies. It was reorganized into the Japan Industrial Robot Association (JIRA) in 1972 and was formally incorporated in 1973. Through further development, it was renamed again in June 1994 to the Japan Robot Association (JARA).

Column

During the 1970s, the number of robots in operation also increased in the United States. It raised arguments that claimed robots were taking humans' jobs, as can been seen when American Machinist, a trade magazine, featured an article titled "Robots invade Detroit" in 1970.

Dawn of a "New Era for Industrial Robots" after Overcoming the Oil Crises

The world was hit with an oil crisis twice, once in 1973 and again in 1979.

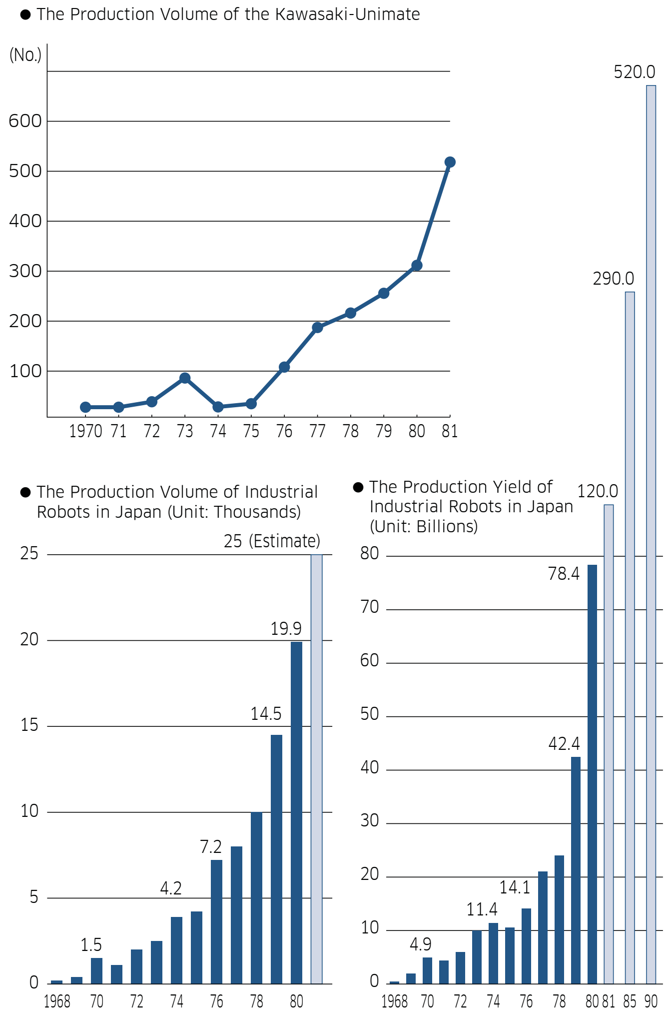
During the first oil crisis in 1973, a sharp rise in oil prices led to stagflation, an economic situation that occurs when inflation is high. Consumers holding off purchasing due to inflation combined with escalating gasoline prices caused the sale of automobiles to dramatically decrease. Surging wages also impacted labor-intensive industries such as car manufacturers, the major customers for the Kawasaki-Unimate. Because the investment in facilities was pulled back, the stationing of robots slowed down significantly.

Amidst this predicament, consumer demands were shifting towards small, energy-efficient cars, and this shift was seen not only in Japan but also in the United States. Japanese car manufacturers noticed this trend and steadily worked on developing and manufacturing smaller automobiles. Eventually, they ramped up exports to the Western markets, while America's Big Three (GM, Ford Motor Company, and Chrysler) were struggling to shift from manufacturing large vehicles. Although the rise in demand of fuel-efficient vehicles was inevitable due to the hike in gasoline prices, American manufacturers got off to a late start and were unable to promptly produce smaller vehicles.[1]

The oil crises in 1973 and 1979. A short supply of oil led to a sharp rise in oil prices, and the Japanese consumer price index increased to 23% in 1974. Despite these "crazy prices", people rushed to purchase daily essentials such as toilet paper and detergent. In 1974, right after the first oil crisis, Japan experienced negative growth for the first time since the War.

When the second oil crisis occurred in 1979, the effects on business were relatively suppressed compared to the time of the first crisis. This was because the automotive and other Japanese manufacturing industries were already executing the counteractions in order to combat oil crisis by the time the second crisis occurred: a change in consumer demands accelerated the streamlining of Japanese companies' operations, and automation improved productivity in manufacturing sites. For Japanese car manufacturers looking to improve productivity to meet ever-changing consumer demands, robots were utilized more and more as they were considered a savior satisfying the timely need for product diversification without increased costs. Previously, it took a considerable amount of time for traditional specialized machines to switch to new models and reestablish production lines. However, with robots, that time could be significantly reduced. Also, they were adaptable to production lines working with mixed car models. These advantages were highly praised by car manufacturers that were responding to changing consumer demands and working on product diversification.

Then in 1980, automobile production in Japan topped 11 million vehicles, making the country the world's largest manufacturer.[2] At the same time, the Japanese industrial robot industry entered into a new era, becoming part of the 100 billion-yen industry in the following year. The Kawasaki-Unimate saw its fair share of action, operating in welding, handling and painting, and by May 1980, Kawasaki shipped out a total of 1,000 units of its mechanical worker. Although it took 9 years to fulfill orders for the first 500 units, the shipment of the remaining 500 units took only 2 years. The business grew rapidly.



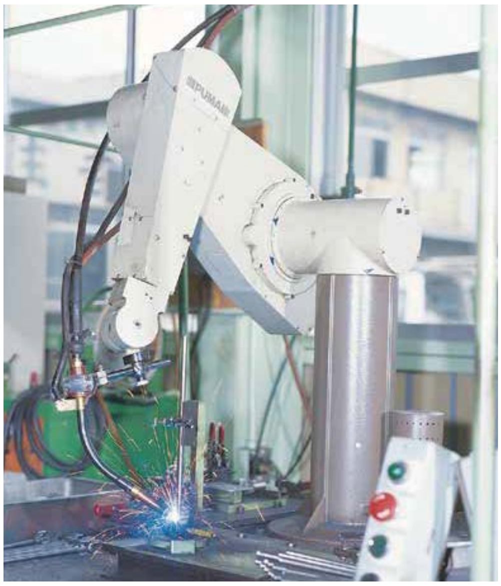
1982 numbers showing Japan's robot production trends in both number of units and value released by the Japan Industrial Robot Association (JIRA), and Kawasaki's production volume trend. There was a rapid increase in production volume, tripling in the 2 years from 1978 to 1980. Industrial robots accounted for 55% of the value and 15% of the volume. Industrial robots were regarded as "high-end robots" at the time and included three types: 1. Teaching-playback manipulators like the Unimate, 2. NC (Numerically Controlled) robots that are in other words manipulators which can be operated using media such as paper tape to follow numeric instructions on order, position, etc. and 3. "Intelligent" robots, meaning sensor-equipped robots capable of making behavioral decisions using sensory and recognition functions.

With the Shift from Hydraulic to Motorized, the Motorized Robot, PUMA, Makes Its Debut

It was the time to replace the power source for robots. As servo motors became bigger and better performing, it signaled a move from hydraulic to electric robots.

In 1979, Kawasaki imported the world's first electrically-driven small articulated robot, the "PUMA (Programmable Universal Manipulator for Assembly)", from Unimation and launched it in Japan in 1981. The PUMA was developed by Unimation West, a company located in Sunnyvale, California, near Silicon Valley. The company was formed by Stanford University students who were studying robotics and later bought out by Engelberger to be his business hub on the west coast.

The PUMA was designed to quickly and accurately transport, handle and assemble automobile accessories, and its footprint was approximately the same as one person. It was lightweight, coming in at 55 kg, and had a working envelope equivalent to that of a human. It was innovative since it was the world's first robot to be commanded using a robot programming language. The language, VAL (Variable Assembly Language), made the teaching process, which traditionally required a great deal of time and effort at the time of initial implementation, less work, yet more sophisticated, and programming made teaching motion patterns to robots easier overall. (After the termination of the license agreement between Kawasaki and Unimation later on, Kawasaki used a similar robot language, AS, and continually worked on



The electric-driven small articulated robot, PUMA, welding.

improving and developing it.) Programming allowed for the use of sensors and expanded the range of applications to include assembly, inspection, palletizing, resin casting, arc welding, sealing and research. The customer base also grew to include industries such as car parts, home appliances, chemical, ceramic engineering and the semiconductor industries.

More companies joined the robotics industry starting from the late 1970s to the 1980s on notice of the performance improvements of servo motors. During this period, manufacturing in Japan was facing a yearly deficit of 500,000 factory engineers. This gave prominence to the use of robots, and electrical equipment manufacturers, precision equipment manufacturers and venture companies rushed to enter the rapid-growing robotics market. In the first half of the 1980s, around 150 to 200 big and small companies arrived onto the soon-to-be-chaotic battlefield. And in the thick of such a market environment, Kawasaki aimed to expand its business to fields where the larger, hydraulic-powered Kawasaki-Unimate was struggling to enter with the small electric PUMA robot into its product line.

Reference: ❶ Cabinet Office, Economic and Social Research Institute "The Japanese Economy and Macroeconomic Policies from the Beginnings of the Bubble to the Overcoming of Deflation" (2011)
❷ Japan Automobile Manufacturers Association, Inc. "JAMAGAZINE-featuring Global Market" (2015)

Increasing Demand Pushes In-House Development of Large Motorized Robots

The shift to electrically-driven robots did not stop with small robots; the large-robot market, where the Kawasaki-Unimate belonged to, felt the effects as well. Motorized robots had characteristic advantages including only a third of the power consumption of hydraulic robots at that time, reduced vibrations during operation, and easy maintenance, all of which would satisfy customer demands. At that time, as large electric servo motor technology progressed, other companies were also pushing to develop and launch motorized robots into the market.

The only electric robot Kawasaki had at the time was the PUMA, the small 5-10 kg payload capacity robot. Spot welding guns, where robots often were applied, became larger and the PUMA was no longer up to par to meet demands from car manufacturers for larger, motorized robots. Unimation, Kawasaki's partner, was no longer able to provide support with reliable technology, so in 1982, Kawasaki began in-house development on large electrically-driven robots depending entirely on its own technologies and skills.

Despite struggling with control and actuating methods fundamentally different from those of the Unimate, Kawasaki developed the company's first domestically manufactured large motorized general-purpose E series robot in the following year. Transitioning from a hydraulic robot to one that made use of electric motors, all while using in-house technology, was a contemporary feat for the company.

It is no exaggeration to say that the development of the E series was made in close collaboration with car manufacturers. Kawasaki developed the E series according to requirements set by car manufactures, extended the range of application to include spot welding, stud welding (pressure spot welding using a single-direction gun) and sealing, and gradually increased its product lineup.

The first domestically manufactured large motorized E series robot, the EA65.

The EX100 was also a hot seller overseas. It was widely used for spot welding by car manufacturers.

The EX100 in particular became a bestselling model for car manufacturers. It was a robot developed specially for spot welding, an area where Kawasaki's robots had been widely implemented, but was based on an entirely new design. In addition to improving performance and functionality with features such as an expanded working envelope, improved short-distance operation speed, an optical hybrid position encoder for precise positioning and software that can automatically configure itself for welding, Kawasaki was also exhaustive in improving quality and keeping costs down. Kawasaki's reputation steadily grew in Japan as well as overseas, with the company's robots being installed in major Japanese car manufacturers one after another, followed shortly with expansion to the United States.

Launch of the World's First Direct-Drive SCARA Robot to Broaden the Application Range

The 1980s were a period when demand for semiconductors dramatically increased. American company Apple Computer launched its Macintosh computer in 1984, and in the following year, the Nintendo Family Computer (or Famicom) became a running success. This set off a rise in demand for the semiconductors used in the CPU of those products.

Under these circumstances, Kawasaki signed a technical licensing agreement with American company Adept Technology in 1985, and manufactured and launched a domestic version of the company's direct-drive SCARA robot, the AdeptOne, the next year. Kawasaki started its delivery of the AdeptOne, a robot specializing in semiconductor mounting and accessory assembly, to semiconductor equipment manufacturers and car part manufacturers. The AdeptOne, whose name means "experienced person", was the world's first SCARA robot to incorporate a direct-drive motor. Being gearless meant reduced friction and rattling, and it was capable of ultra-high-speed (9m/s), high-accuracy operation. Its advanced intelligent vision system allowed the robot to operate while instantaneously pinpointing the location of parts.

AdeptOne on display at the International Robot Exhibition 1985.

The world's first direct-drive SCARA robot, the AdeptOne. Its high-speed and high-precision operation drew a great deal of attention. However, the cost, nearly double in price compared to common SCARA robots of the day became a barrier to widespread adoption.

However, as newcomers flooded into the already congested robot market, adoption of the AdeptOne was tough due to in-house robot production at semiconductor and electronic device manufacturing companies, coupled with the AdeptOne being priced less competitively against the crowds of inexpensive SCARA robots available on the market, and with the widespread production of the insertion mount machine which is a dedicated semiconductor mounting machine.

2

The Kawasaki Robot Story

Expansion to the Western Market

Kawasaki Robots, a Driving Force in Making Japan a "Robot Kingdom" Entered the North American and European Markets

In the middle of the 1980s, the number of robots in operation in Japan surpassed 93,000 units, which accounted for about 70% of the global units which made Japan a "Robot Kingdom".[1] Kawasaki, driving the growth of Japan, consistently accumulated know-how and experience since 1968 when the company signed a technical partnership with Unimation.
For further business expansion, the next market which Kawasaki looked to was the United States, the birthplace of the world's first industrial robot where the gigantic automobile industry was developing.
More Japanese car manufacturers entered the North American market and accelerated local production due to the Japan-US trade friction during this time.
Kawasaki had increased its robots' marketability and gained a great deal of experience.
It was time to enter the North American market.

Termination of the 18-year License Agreement with Unimation

By the end of the 1970s, Kawasaki had already developed its own technical competencies. In the early phase of the partnership with Unimation, Kawasaki manufactured robots based on the design provided by Unimation. However, as the implementation of the Kawasaki-Unimate widened in Japan, Kawasaki began in-house development to meet various customer demands and gained technical competencies and experience. In addition to mechanical and control technologies, Kawasaki gained a thorough knowledge of application technology. It often conducted robotic system engineering along with production engineering managers from the customers of Kawasaki, car manufacturers. Therefore, while comprehending the drawings of car bodies and understanding their welding methods and factory facilities, Kawasaki could simulate spot weld distribution and angles and study its cycle time on the desk, which were unique skills to the automobile production engineering. Then for further business expansion, Kawasaki looked to the United States with the gigantic automobile industry where one sixth of its labor population were a part of, as well as Europe.

At that time, Unimation was acquired by a major American electric manufacturer, Westinghouse Electric Corporation in 1983, became one of their divisions, and eventually lost its robot developing capability. While Westinghouse decided to continue development of hydraulic robots like Unimate after the acquisition, it was left behind in the trend where motorized robots became more mainstream. For Kawasaki, which aimed to expand in Western markets, factors such as restriction on expanding into business area of Unimation in overseas markets and its high royalties made continuing the partnership difficult. As a result, Kawasaki terminated its 18-year license agreement with Unimation in 1986 and prepared for a full-scale expansion into overseas markets. Since the termination of the agreement, Kawasaki has developed its own original robots created using proprietary technology and gone forth to the next phase, where the performance would truly be judged by society.

Unimation in the 1980s

In 1983, Unimation was acquired by a major American electric manufacturer, Westinghouse Electric Corporation. The company faced financial difficulties as the 1980s drew near. Proposed acquisitions were made by four companies; Asea (the present ABB), Westinghouse Electric, Litton and GE, with Westinghouse offering the highest bid of $108 million USD (at the time). Westinghouse continued development of hydraulic robots even after the acquisition of Unimation. Wishing to continue development of motorized robots, Unimation West split with Westinghouse, which was firm in its decision to continue development of hydraulic robots, becoming independent and establishing Adept Technology, Inc. This company later developed its business to specialize in direct-drive robots, focusing on high-speed and high-performance SCARA robots using its unique advanced technology.

The times saw motorized robots becoming more mainstream, a situation contrasting Westinghouse's approach of focusing on hydraulic robots. Westinghouse did develop a large electrically-driven robot, the PUMA760, in 1986 but by then, it was too late to catch up. The division once formerly Unimation was bought out by Swiss company, Stäubli for $5 million USD in 1989.[2]

In this year: 1985

With the Japan-United States trade friction increasing, the United States, which was suffering from deficits in both trade and financial affairs, spearheaded an agreement known as the Plaza Accord to depreciate the US dollar. Japanese manufacturers were obliged to (voluntarily) regulate exports to the United States, and together with the appreciation of the yen due to the Plaza Accord, expansion into the United States and localization advanced.

Reference: [1] International Federation of Robotics (IFR)
[2] Westerland, Lars "The Extended Arm of Man" (2000)

Establishment of the First Overseas Base to Enter the North American Market

The same year when the constructive termination of partnership with Unimation was made, Kawasaki established the North American branch—the first overseas base—in "Motor City" Detroit. It was established as a branch of Kawasaki Heavy Industries (USA), Inc., a US subsidiary of Kawasaki. To develop business with American car manufacturers, Kawasaki was tasked to study robot-related information in North America and served as a contact point for Japan. In the same year, for its application technology competence and experience of establishing production lines for Japanese car manufacturers, Kawasaki started making presentations for America's Big Three car manufacturers and visiting their factories, which opened up a new business opportunity with American manufacturers.

With the Japan-United States trade friction in the background in the early 1980s, Japanese automobile manufacturers initiated local production through capital tie-up and joint production with American manufacturers or through independent production. Kawasaki Robots were introduced in factories in North America and Mexico where joint production by Japanese and American manufacturers was conducted from the early 1980s and Kawasaki Robots, especially "EX100" which performance and function were highly sophisticated and whose quality and cost were intensively improved were also highly reputed overseas. At this point, major American car manufacturers began to seriously consider the introduction of Kawasaki Robots into their factories.

Challenges to Pass the World's Strictest Evaluation Criteria

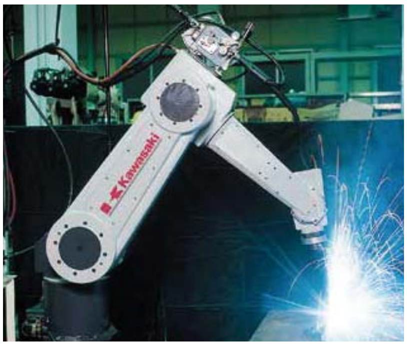
To deliver robots to American car manufacturers, it was required to clear every single item specified in detail for the so-called strictest performance evaluation test in the world established based on their own standards. In fact, the later-established international standard even referred to these standards. Kawasaki sent dedicated engineers from Japan to the United States from early 1986 to pass the test of one of the Big Three manufacturers. They continued effort to satisfy the strict requirements and then eventually passed the test. The performance of Kawasaki Robots was certified. This was the first step for a full-scale expansion into the North American market. In October 1987, the functions of the Detroit branch opened in 1986 were expanded and the Detroit Robot Center was established.

After passing the performance evaluation test, Kawasaki Robots were introduced into the actual production lines of the American manufacturer as a trial, and robot education and operation training for factory workers were conducted several times. It took nearly one year until the manufacturer decided to adopt Kawasaki Robots after passing several evaluation tests with different models. Based on the results of trial implementation, they decided to adopt and introduce the robots upon careful assessment of their capabilities. March 1988 marked the first introduction of Kawasaki Robots in American car manufacturers, and 8 units of EX100 were supplied. At that time, US-made robots ran into several initial problems after installation and took time before becoming operational. Meanwhile, for Kawasaki Robots, there were no discrepancies between the results of the actual operation and the prior test results, adding to the praise from American car manufacturers, and a few hundred units of spot-welding robots were introduced in 1989.

In 1990, as a result of this large-scale adoption, the Detroit Robot Center evolved into Kawasaki Robotics (USA), Inc. (KRI). This local subsidiary was tasked with the role of strengthening sales promotion along with outfitting a training and after-sales system aimed at American automobile manufacturers which had become new major clients. Among them, KRI training facilities (such as robot operation schools and locations similar to training institutes), where many local employees from Japanese manufacturers who expanded to the United States, as well as those from American automobile manufacturers were sent, contributed to the elevation of the know-how concerning industrial robots in the United States. The number of trainees in 1997 surpassed 1,000 people.

In June 1994, the successor to the E series robots, large general-purpose robots of the U series, began US production in the Kawasaki Motors Manufacturing Corp. (KMM) motorcycle factories of the Kawasaki Heavy Industries Group.

KRI provided training to the customers in the United States.



Development of the small general-purpose J series robots began in 1990. The photo is of the JS-10 conducting welding work. Robots of this series were seen to expand the range of application into fields such as assembly handling and arc welding, they were designed with the concept transplanting human tasks in their entirety. Since the latter half of the 1980s, the number of companies considering introducing robots began to increase, the introduction to small-scale factories and the application to more detailed work progressed, leading to an increase in the demand for small robots.

Licensing to Overseas, the Growth from the "Learning" to "Transferring" Phase

Since the early days of the robotics business, Kawasaki had been promoting robot development with the technology provided by Unimation.

Before long, the design and manufacturing expertise Kawasaki accumulated during this time matured, increasing the opportunity for in-house development. After the termination of the agreement with Unimation, Kawasaki shifted to independent product development.

Then, the late 1980s saw the opportunity to apply that expertise for overseas expansion. During this time in South Korea, the demand for the automation and robotization of the manufacturing process increased with the significant rise in labor costs coming from the rapid growth of the automobile industry and the electronics industry. Kawasaki also exported robots to South Korea, but there was a great necessity for insourcing within the country.

In addition, the 1988 Seoul Olympics became a launchpad for motorization. In 1988, South Korea's heavy industry manufacturers offered to manufacture Kawasaki Robots within their country. Kawasaki's 20th founding year of the robotics business marked its first attempt at overseas licensing. It was a turning point, moving from the "learning" to "communicating" phase.

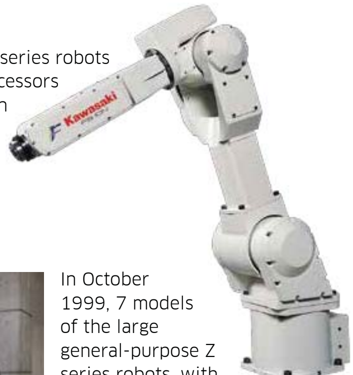
With a foothold obtained in South Korea, Kawasaki provided a technological license to a major heavy industry manufacturer, the second company in the country to receive one, in 1994. Henceforth, Kawasaki would continue consolidating its foundation in the Asian region.

A Full-Scale Entry into the European Market

In the early 1990s, the Soviet Union collapsed, resulting in the liberalization of the routes in East-West Europe, which gave birth to today's EU (European Union) economic zone. This is when Kawasaki headed to Europe in search of a new market. In 1989, overseas representatives were dispatched to the Amsterdam branch of Kawasaki head office, located in the Netherlands. In 1991, a UK local office was established within Kawasaki Motors UK (KMUK) in London, England. In addition to grasping a clue for entry into the European automobile industry, Kawasaki looked into building a business foothold in the European market as the introduction of robots was expected in other industries as well. Moreover, provision of services to Japanese automobile manufacturers already occupied with local production in Europe was also one of the objectives for opening a base.

Initially, Kawasaki provided services to the local bases of Japanese automobile manufacturers and started local sales activities with 4 initial members, but it was difficult to gain ground in the stronghold of competing robot makers. Development with European automobile manufacturers was an arduous task.

Soon after the EU was established in 1993 and the economic activities in the region were liberalized, Kawasaki prepared to start a full-scale entry. First, in November 1995, the local subsidiary Kawasaki Robotics GmbH (KRG) was established in Germany. With a base set up in Germany, the forefront of robot technology, development into markets throughout Europe began. And in 1996, the Robotics Department became independent from the London office in the UK leading to the establishment of Kawasaki Robotics (UK), Ltd (KRUK). Kawasaki would go on to increase its European services and sales network.



16 models of the general-purpose F series robots were launched in October 1998. Successors to the J series, the robots adopted an industry-first modular construction for the arm. (Photo: FS10).

In October 1999, 7 models of the large general-purpose Z series robots, with a class-leading working envelope, were launched. Photo is the ZD250 performing the palletizing work exhibited at the International Robot Exhibition 2013.

The History of the Robotics Industry in Europe

The Unimate, the world's first industrial robot, was commercialized in Europe in 1967, two years prior to its launch in Japan by Kawasaki. It began with Swedish casting industry giant, Svenska Metallverken, whom the country's automobile manufacturer Volvo was an important client of, introducing the Unimate to the die-casting process. Following this, with the advancement of GM to Europe, familiarity with industrial robots would improve further in Europe from around 1972. In the European market, robots from American manufacturers including Unimation were the predominant type in the beginning stages of adoption, but this would change as European robot manufacturers made huge leaps come the late 1980s.

The context here is that robots made by US manufacturers were complicated and fragile. For example, General Electric (GE) was doing its own robot development and developed a 4-armed robot to perform assembly work. However, it had poor durability since it required complicated control. Such a robot was built with 30% more parts than those designed and manufactured in Japan and Europe. This is because European and Japanese companies were better in terms of simplifying the structure.

Also, both Europe and Japan excelled at developing robots suitable for on-site manufacturing processes. In many cases in the United States, the developers of robot manufacturers were businessmen who managed manufacturing consignment companies, so there was a separation between robots suited to the worksite and technically superior robots.❸

European robot manufacturers began outdoing manufacturers from the United States, and with the expansion of the market, in 1973, KUKA developed the world's first 6-axis robot, the FAMULUS. ABB also followed suit and entered the robotics business. Both companies gained the support of European automobile manufacturers especially those from Germany, Italy, France, England, and Spain and accumulated achievements. According to statistics in 2012, about 60% of the robots Germany ships is destined for the automotive industry (8,849 units: 5,456 units for material handling, 1,476 units for resin molding, 1,361 units for arc welding, 1,298 units for shipment and 1,161 units for spot welding).❹

Reference: ❸ Westerland, Lars "The Extended Arm of Man" (2000)
❹ New Energy and Industrial Technology Development Organization(NEDO)"Robot White Paper 2014"

3

The Kawasaki Robot Story

With the Growing Tech Boom

Full-Scale Entry into the Cleanroom Robot Market as Demand for Semiconductors and Liquid Crystals Increases

With the introduction of the World Wide Web (WWW) in 1991 and Windows 95 in 1995, the 1990s saw the rapid acceleration of digitization due to the popularization of personal computers, peripheral devices, and other office automation equipment.
Accordingly, the demand for semiconductors also continued to expand.
As the performance of semiconductors and the scale of production increased, it was inevitable for manufacturing processes to be more sophisticated.
Cleanroom robots became the focus amid this situation.

With Rising Needs for Semiconductors, Demand for Robots Increases in Advanced Manufacturing Processes

In spite of the economic downturn caused by the collapse of the economic bubble in Japan in 1991, the 1990s saw the rapid popularization of information equipment, such as personal computers—a period dubbed the "IT bubble". Pushed by these circumstances, the global semiconductor market continued to grow at an annual average rate of 14% from the 1970s to 2000.[1] Along with this trend, semiconductor technology continued to evolve. The vacuum tube, which was used in televisions, radios and other devices in the first half of the 20th century, had evolved over time into the transistor and further into the IC (integrated circuit) and LSI (large-scale integrated circuit). There was no stopping its evolution. Silicon wafers, which are substrate materials for semiconductors, have been increasingly highly integrated and densified in LSI, and have become as large as 150 mm, 200 mm, and even 300 mm in diameter compared to the past.[2]

Along with these changes, applications in cleanrooms such as those for handling semiconductor wafers and liquid crystals rapidly expanded as a new market for robots. And cleanroom robots came into the limelight for their ability to essentially eliminate risks for contamination by dust and dirt and to cope with the rapid increase in size of wafers and liquid crystal glass.

In a broad sense, a cleanroom robot means a robot not only capable of handling semiconductor wafers and liquid crystal substrates but also operational in a clean environment (primarily cleanrooms). In 1986, Kawasaki had already released its first cleanroom robot, the PH260CR (CR stands for cleanroom). Initially, however, robots developed independently by manufacturers of semiconductor-making equipment and inexpensive SCARA robots of other companies were mainstream, so there were only limited sites where Kawasaki's cleanroom robot was used. The opportunity to enter the cleanroom robot market would come once again.

Column

To rival general-purpose 6-axis robots with cleanroom specifications that operate mainly in cleanrooms, Kawasaki's cleanroom robot business, started in 1995, focuses on providing manufacturers with OEM equipment, and has a lineup outfitted with arms dedicated for specific use and applications.

The Cleanroom Robots Specializing in Transporting Semiconductor Wafers and Liquid Crystal Substrate

In the 1990s, as the semiconductor and liquid crystal industries began to show remarkable growth, manufacturers of semiconductor-making equipment concentrated resources in process development and were seeking a third-party cleanroom robot capable of transporting larger wafers and liquid crystal glasses and had superior performance and reliability. Every company needed a robot with great maneuverability and a large working envelope, something beyond the capabilities of conventional inexpensive SCARA robots or internally manufactured robots.

The TL420, a liquid crystal glass substrate-transferring robot.

In response to the demands of this era, in 1995, Kawasaki began developing cleanroom robots which specialized in transporting semiconductor wafers and liquid crystal substrates. Cleanroom robots required completely different technology from the robots used in the automobile manufacturing process, an area Kawasaki had excelled in. While dust and dirt are of no concern in an automobile manufacturing plant, contamination is strictly unacceptable in the manufacturing process of semiconductors and liquid crystals, so general knowledge and presumptions were completely different.

Despite the circumstances, development went on, leveraging the fundamental technologies of manufacturing cultivated at Kawasaki over the years. For example, to speed up the transporting of wafers, a high speed and agile method of transferring wafers was made possible using a full absolute encoder as well as gears and servo motors used in 6-axis robots to drive the arm. This is different from the method of driving the arm with timing belts and stepping motors which was common among wafer transport robots at the time. In this manner, Kawasaki continued to develop using technologies completely different from those used in conventional semiconductor manufacturing, leading to success in commercialization.

In this year:
1991
-1995

1991 • The World Wide Web (WWW) was invented. This was the first step to the global popularization of the Internet.

1995 • Microsoft started selling its Windows 95 computer operating system. This OS enjoyed sparkling sales around the world, sparking the widespread adoption of personal computers and, as a result, the demand for semiconductors. Windows would go on to become the de-facto standard of computers' OS.

In 1997, Kawasaki launched the TS series, vertical telescopic SCARA wafer transferring robots with a unique linear motion arm built in. Since semiconductor manufacturing requires high-speed conveyance in a very clean environment, it was designed to be used in state-of-the-art semiconductor processing facilities. It consisted of a base, a robot arm, a robot hand for gripping semiconductor wafers and other parts, and moved extensively between the process modules in the equipment and the FOUP (Front Opening Unified Pod; an enclosure for transferring and storing wafers) at very high speed while the horizontal articulated arm expands and contracts to transfer wafers. In the same year, in addition to the wafer-handling TS series robots, the liquid crystal glass substrate-handling robots of the TL series were released, expanding Kawasaki's lineup of cleanroom robots.

Starting the Full-Scale Production of Cleanroom Robots

After successfully making a true entry into the cleanroom robot market with the TS and TL series robots, Kawasaki progressed through the ranks, responding to many customer needs such as high-speed transfer, high-precision positioning and automated teaching along the way, to eventually grab hold of the largest market share in the industry.

Moreover, in 2001, a new KRI branch was opened in San Jose, the center of Silicon Valley, on the West Coast. Kawasaki would strengthen its sales activities of cleanroom robots here, in a region driving the global demand for semiconductors. Kawasaki was a company completely unknown for semiconductors at the time, so acquiring the trust of semiconductor device manufacturers in the United States was a rough road. However, frequent visits to customers, listening and understanding their requests, and providing suggestion upon suggestion, have led Kawasaki on a road to offering total, comprehensive solutions highly integrating not only the robots alone, but peripheral functions as well.

Silicon Valley: The Home of the Semiconductor Industry

Silicon Valley is an area in the state of California encompassing cities such as Palo Alto and San Jose, where many IT-related companies are concentrated. Since being nicknamed "Silicon Valley" in the 1970s, this area has given birth to many software and Internet-related companies including Intel, National Semiconductor, Google and Facebook, becoming a supercenter of IT and semiconductor industries. "Silicon" is the main raw material of semiconductors, while "Valley" was derived from the area's terrain which sports numerous valleys.

In 2007, Kawasaki launched the advanced SCARA semiconductor transfer NT series robots that combine high-speed operation and usability (Photo: NTS20).

In this year:
1999
-2000

1999 • The electrical and electronics device manufacturing industry surpasses the automotive industry to gain top spot in shipment value of industrial robots.[3]

2000 • The semiconductor market has recorded an average annual growth rate of 14% from the 1970s to 2000.[1]

Reference: ❶ Society of Semiconductor Industry Specialists, Semiconductor History Museum of Japan "A Graphic View of the Semiconductor Industry, Statistics Reference Room" (2016) (http://www.shmj.or.jp/toukei/pdf/STA2016_01.pdf)
❷ Ministry of Economy, Trade and Industry, "Current State and Issues of the Silicon Industry" http://www.meti.go.jp/policy/nonferrous_metal/strategy/semiconductor02.pdf)
❸ New Energy and Industrial Technology Development Organization(NEDO)"Robot White Paper 2014"

4

The Kawasaki Robot Story

Into the Emerging Asia

Emerging Asia, a New Base for the Semiconductor and Automotive Market

Changes were in the air in Asia, where rapid progress came about through cheap labor costs. While their influence is limited on the global economic scale, emerging Asian countries are growing in comparison to the developed countries, where they face serious issues of declining birthrate and an aging society.
As the rising sales volume of motor vehicles in these areas would indicate, it was evident that they would progress to someday become a major hotspot for consumption.
And amid fierce international competition, electrical and electronics manufacturers sought to secure international competitiveness by looking toward Asia as a production base.

Establishing the First Base in Asia, a New Frontier for Production and Consumption

The 21st century has seen Asian countries accelerate their growth as emerging markets, with approximately 60% of overseas subsidiaries of Japanese manufacturing companies being concentrated in Asia. The automotive industry recognized Asia as not only a base for production, but for consumption as well, and there was a shift towards manufacturing vehicles locally to suit the needs of local demands. Production volume in Asia had tripled from the first half of the 1990s to the 2000s.[1] In the electrical and electronics industry, shifting the production base from Japan to other Asian countries helped reduce labor costs, and gave the industry international competitiveness. With this push for the Japanese manufacturing industry to expand operations into Asia, Japanese automobile manufacturers, semiconductor and liquid crystal device manufacturers—our major customers—began setting foot into Asia one after another, and Kawasaki followed suit, expanding the sales service bases.

In 1999, Kawasaki Machine Systems KOREA, Ltd. (KMSK) was established in Incheon, South Korea, a country showing remarkable growth in the automotive and precision instrument industries in an attempt to strengthen Kawasaki's sales structure for the region.

In October 2001, a service base was newly set up in Taiwan, after Japanese and American semiconductor manufacturing equipment companies, who had become some of Kawasaki's major customers, had extended their reach into Asia. This trend is also proof that a considerable amount of semiconductor manufacturing equipment which Kawasaki's cleanroom robots were built into had begun to operate in Asia. In this time, the region was quickly becoming the "semiconductor factory of the world", especially in South Korea, Taiwan, and neighboring countries such as Singapore and China.

Column

Kawasaki inherited the painting robot business from Kobe Steel in 2000. As of April in the same year, Kobe Steel fully transferred its painting robot business and their team joined Kawasaki. Customers, mainly automotive manufacturers, and employees of the business were also handed over in the process.

Asia and Horizontal Specialization in Manufacturing

Once priding itself with the top market share in semiconductor production since 1986, Japan started seeing a decline in that share since peaking in 1987, finally losing top spot to the United States in 1998. Similarly, in the DRAM industry, Japan's share continually slipped from the peak of 1987, and in 1998, it was beaten out for market leader by Samsung and other Korean companies. Japan tried to dominate the market with technological developments, but other countries played an intense game of catch-up in terms of technological skills and market development, and ultimately Japan lost its title of world leader. Losing their competitive edge, Japanese electronics manufacturers were forced to shift from domestic production to manufacturing overseas, moving to Asia in particular. At the same time, manufacturing in general was going through a phase of changing itself, rapidly and extensively moving from vertical integration to horizontal specialization. For example, in the PC industry, it used to be mainstream for businesses such as NEC and IBM to offer a complete package of everything from DRAM to software whereas in recent years, higher quality results have been achieved by companies who specialize in specific fields. This situation is similar that now the OS is made by Microsoft while the CPU is from Intel and that Dell specializes in the assembly of systems. As a result of expanding into regions with a competitive edge in certain processes — for example, having products designed in the United States, manufactured and inspected in Taiwan, and then selling them throughout the world as products made by the US companies — Asia has attracted the attention of many companies from all over the world, and is shaping itself to become a base for manufacturing.

The first advancement into the ASEAN countries was made in 2002, when the new base was established inside the Kawasaki Motorcycle Enterprise (Thailand), Inc. (KMT) motorcycle factory. Since the creation of the ASEAN Community in 2003, Thailand has been considered an attractive hub in Southeast Asian regions. It provides many ideal conditions including having a long coastline running from north to south, being blessed with a good natural harbor, and having relatively low barriers to entry. Thailand has been geographically and economically favorable. The country was considered to one day be the core of ASEAN, and is where Kawasaki took its first step venturing into ASEAN.

Establishing Overseas Subsidiaries in Rapidly Growing China

In this year:
2001

China joins the WTO (World Trade Organization).

Twenty-first century China is making incredible strides. Events such as the government-led Chinese Economic Reform being implemented in 1978, encouraging an aggressive introduction to foreign capital and leading China to promote export-oriented industrialization policies; or China's entry into the World Trade Organization (WTO) in 2001, greatly boosting exports of industrial products, are written in the record books. Following this trend, the mechanical industry dramatically expanded as China became the "world's factory", and the manufacturing industry grew in the country. And with an increase in domestic demand due to the country's economic growth, China became regarded as a place of mass consumption and both exports to the country and local production surged.

Meanwhile, in 2006, Kawasaki would establish Kawasaki Robotics (Tianjin) Co., Ltd. (KRCT) in Tianjin, China. It was the first advancement into China, and serves as a company providing support for Kawasaki Robots produced in the country and delivered to major Japanese auto manufacturers.

A branch of KRCT was later established in 2009 to procure robot parts for Japan from local Chinese vendors in Kunshan City. It was a trading company of sorts. In 2013, it became Kawasaki Robotics (Kunshan) Co., Ltd. (KRCK), an independent corporation. KRCK promotes local production and consumption taking into consideration increasing domestic demand in China. It was in the making to transform into a production company.

Going into the Line Building Business to Improve Market Shares in China

Entering the 2010s, competition between robot manufacturers from different countries in China grew even more intense.

European robot makers in particular were able to secure a large share using a comprehensive solution called line building. This is a business model that provides complete support for the design, creation, setup and launching of assembly lines, and can be applied to not only robot production lines, but any line in a factory which incorporates equipment such as automobile body assembly jigs, transferring devices, or control devices. Introducing the line builder as an option would make business negotiations possible even for customers like local automobile makers that are willing to buy integrated manufacturing lines equipped with robots compared to just buying robots alone. Kawasaki was motivated to enter the line building business for it was know-how the company had been lacking and something that is indispensable for expanding sales in China.

In May 2015, Kawasaki Robotics (Chongqing) Co., Ltd. (KCRE) was newly founded and was meant to be a new base in order to rank alongside European builders.

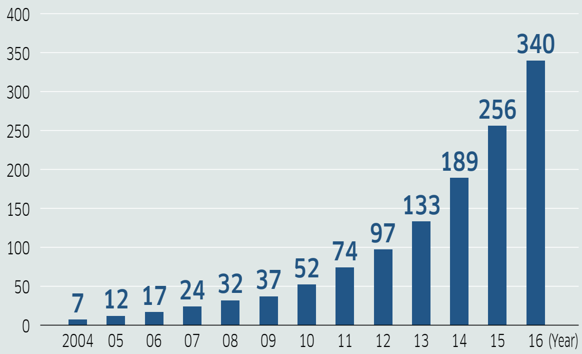
The Growing Robot Market in China

In 2013, the number of robots introduced in China reached 36,000 units, surpassing Japan, the previous leader for number of active robots, for the first time, and made China the world's largest market. While existing markets in developed countries continue to change, focusing mainly on replacement demand, the Chinese market will certainly continue to expand in the future.[2]

Furthermore, the Chinese government announced its "Made in China 2025" action plan set to take place over the next 10 years, highlighting 10 priority fields including information technology, robotics, and biotechnology, and declared to intensively support such industries by using financial and tax financing mechanisms. The Chinese Central Government also developed the Robotics Industry Development Plan and designated four central cities: Chongqing, Shanghai, Guangzhou, and Shenyang.

• Transition of Estimated Operational Stock of Industrial Robots in China

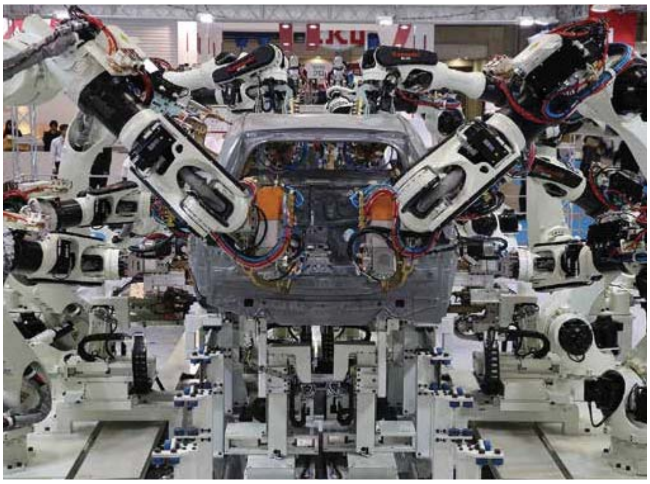
(Unit: Thousands)



Source: International Federation of Robots (IFR)

Chongqing, China's largest city and one developed by the automotive industry.

Reference: ❶ Ministry of Economy, Trade and Industry; "Overseas Business Activities of Japan" ❷ International Federation of Robots (IFR), "World Robotics"



Large general-purpose B series robots launched in September 2011. The spot welding demonstration on an automobile body assembly line was exhibited at the International Robot Exhibition 2013.

Robots Creating Robots - A Highly Automated Factory in Suzhou

Kawasaki Precision Machinery (Suzhou) Co., Ltd. (KPM Suzhou) was established in China in 2015, and in June of that year, manufacturing began at this factory based on the concept of "robots creating robots".

In recent years, with a rapid economic growth in China, labor shortage and soaring labor costs in the manufacturing industry are reaching critical levels. Workers do not stay with companies even after prolonged education and training, and managers are troubled over how to deal with these issues. Because labor costs have climbed due to economic growth, strains are being put on a business structure which has traditionally increased production volume using labor costs as a predominating factor.

Inside the KPM (Suzhou) factory. Human workers perform tasks they are good at such as temporarily tightening bolts, while robots are assigned to tasks they excel at such as precision transporting and assembly.

The most effective countermeasure for such problems is the introduction of robots, and the factory in KPM (Suzhou) aims to communicate the superiority of robots to a wider audience. By highly automating processes which used to rely on human workers—from picking parts to assembling, painting, and inspection—in the factory, high quality can be safely maintained and production can be more efficient. In addition, human-robot collaboration is working efficiently, having a human work in the vicinity of a robot while the robot prepares for the next task through the use of sensors. In order to present these manufacturing processes as a case in point, the factory also doubles as a showroom, and the feedback from the visitors has been positive.

Expanding Asian Bases Further into India and Singapore

As its government is strategically aiming to become Asia's hub for multinational corporations, Singapore has been making headway in nationwide efforts to attract companies. In 2014, Kawasaki established the Singapore Kawasaki Robot Center in Singapore, a country where an increasing number of high-performance semiconductor manufacturing facilities are being established,[3] to enforce its after-sales service system. And in June 2017, the Singapore Kawasaki Robot Engineering Center (SKRE) opened as a facility to support the development of industrial robot applications and train engineers.

Kawasaki has already supplied a total 13,000 units of its cleanroom robots mainly to major semiconductor device manufacturers that have their own manufacturing facilities in Singapore. These contributions earned Kawasaki support from the Singapore Economic Development Board, and the company began providing training for system integrators, SMEs and other end users in Singapore.

The opening ceremony of the Singapore Kawasaki Robot Engineering Center (SKRE).

India, as one of the BRICs (Brazil, Russia, India, and China), countries for remarkable growth in the 21st century, has been achieving a GDP growth rate that outperforms China. Although the Indian market is only one-tenth of the market size of China today, there are expectations that one day it will be comparable to China. And so in 2015, Kawasaki established its first robot division within the Indian subsidiary company, Kawasaki Heavy Industries (India) Pvt. Ltd.. The main purpose of this division is to provide sales and support services to Japanese and American automotive manufacturers that have entered India.

Reference: ❸ Japan External Trade Organization (JETRO), "How the industrial bases have changed – Electrical and Electronics Industry" (2016)

5

The Kawasaki Robot Story

The Collaborative Future

Closer and Wider - Broadening Possibilities for Robots

As the world sets foot into the 2010s, the declining birthrate and the aging population in Japan and a number of European countries are becoming serious issues.
This situation, unsettling in itself, is revealing many other significant social concerns including labor shortage, loss of technical skills due to experts retiring and increasing medical expenses because of aging.
As a counter solution to these problems, robots are expected to play a key role.
And with the integration of continually evolving technologies such as artificial intelligence (AI), IoT and communication networks, the potential of robots is broadening.
By taking experience cultivated from manufacturing sites throughout the years, and promoting cross-industrial cooperation, Kawasaki is committed to continually following its social mission of offering robots that support people in a wide range of fields.

Establishing the Joint Venture Company, Medicaroid, to Serve Needs in Medical Fields

In response to the wave of the declining birth rate and aging society, expectations are mounting for robots to play an active role against social problems in the medical field. In the case of Japan, the population aged 65 and older is expected to continue increasing at a pace of 7.09 million people annually from 2010 to 2025.[1] Consequently, there is a need to increase the number of doctors and nursing care staff as well, but labor shortage is reaching serious levels and the physical burden on those engaged in medical practices and nursing is also high, making this an urgent issue.

Considering this, in 2013, Kawasaki established Medicaroid Corporation in a joint investment with Sysmex Corporation, a globally leading company of medical examination equipment and reagent manufacturing in the field of blood and urine tests with its testing and diagnostic technologies, having a wide network in the medical sector. Utilizing the strengths of both companies, Medicaroid develops and provides products in the areas of examination, diagnosis and treatment. Concerning development, Medicaroid uses an open platform method and works with government organizations, hospitals, and medical and healthcare manufacturers for commercialization.

In 2017, Medicaroid released its first product, the "SOT-100 Vercia", an operating table with the ability to move patients around a large area. While hybrid surgery procedures combining catheter-based and surgical techniques to make incisions in the chest and abdomen as small as possible and shorten the overall operation time have been providing good results, this operating table helps make surgeries more efficient using on-board robotics technology to assist with moving patients to positions ideal for surgeons to easily carry out the necessary procedures. The launch of surgery assistant robots is scheduled in 2019 in Japan and the global launch will follow.

Even globally, there is a lot of expectation that the use of robots in healthcare will expand, and it is estimated that by 2030, the market will reach 2 trillion yen.[2] The very first medical robot was the "da Vinci Surgical System" released by American company Intuitive Surgical in 1999. In 2000, the da Vinci was approved by the US Food and Drug Administration (FDA), and it received approval as a medical device in Japan in 2009. About 3,000 systems have been installed worldwide.[3]

The SOT-100 Vercia, a robotic operating table released by Medicaroid Corporation in March 2017.

Birth of the duAro, the Dual-Arm SCARA Robot Designed for Human Collaboration

The Japanese working population is predicted to decrease at a rate of 640,000 people a year. The "New Robot Strategy" announced by the Japanese government in 2015 mentioned the use of collaborative robots as a solution for labor shortage.

A collaborative robot is defined as "a robot designed to directly interact with humans in a specified collaborative workspace" (JIS B 8433-2:2015: Safety requirements for industrial robots). They are robots capable of operating in the same workspace as humans and pose a decreased risk compared to traditional robots. Easing of regulations in Japan in 2013 allowed robots satisfying certain requirements to operate next to humans, giving birth to the market for collaborative robots. Barriers separating humans and robots were required for safety reasons in the past, but no longer is there a need for safety fences under the allowed conditions.

Despite continuous progress being made to prepare ideal conditions for the widespread adoption of collaborative robots, challenges to encourage businesses to implement

Reference: ❶ Ministry of Economy, Trade and Industry; "New Robot Strategy" (2015) ❷ Medicaroid Corporation website
❸ Japan Robotic Surgery Society; "About da Vinci"

robots still remained. Some customers voiced their concerns, saying that even if they wanted to introduce robots, it would be very difficult because the time and costs involved with implementing robots are disproportionate if it takes a few months to go from facility assessment to actual operation in production factories where their product cycle only lasts for a few short months. So to solve this issue, Kawasaki began development on a robot based on the concept that it would “collaborate with humans, require no safety barriers, be portable, easy to install and teach, and be dual-armed”.

The end result of this development was the “duAro”, a dual-arm SCARA robot, completed and launched in 2015. Its “Easy to Use” concept is a reflection of the voices of manufacturers wishing to install robots. A lot of consideration was taken into making it easy to operate even for users unfamiliar with handling robots; it offers the ability for users to manipulate and teach intuitively through the use of tablet devices and by directly moving the robot arm. The launch of the duAro has stretched the range of robotic applications and made robot implementation a much more accessible option, kickstarting the collaboration process between robots and those in small factories, shops and offices—those who previously recognized robots as something unrelatable.

duAro, a dual-arm SCARA robot suitable for multi-product and small-lot productions collaborating with people safely and securely.

In December 2015, Kawasaki released the MG10HL, an ultra-high payload robot with maximum payload capacity of 1 ton. It demonstrated its capabilities by lifting a car body at the International Robot Exhibition 2015.

In this year:
2010s

- 2011 • German government announces “Industrie 4.0” strategy
- 2011 • Japan’s population continues to decrease since this year[4]
- 2015 • Japanese government sets the “New Robot Strategy”[5]

Successor, the New Robot System Learning and Replicating Expert Skills

While it is anticipated that robots will play an important role in solving social problems on a global scale, the introduction of robots has not progressed. Even in the manufacturing industry, there are approximately 300 robots operating per 10,000 employees in Japan, and approximately 600 units in South Korea where robotization is the most advanced in the world.[6] This is because there are certain circumstances making robotization currently difficult. There are many fields where work requires the human senses and the techniques of expert workers, or the costs and time involved with implementing robots is disproportionate. Kawasaki’s proposal and challenge towards such fields came in the form of a new robot system, the “Successor”, which was launched in November 2017. This system, by means of utilizing the remote collaboration technology Kawasaki has fostered over the years and with AI which continues to develop in recent years, allows robots to learn the movements of workers and reproduce them by automatically converting what it learned into a program and then automating the operation, or to elaborately handle the operations changing every time, and traditionally requiring fine adjustment by experienced human workers.

When using the Successor, the worker collaborates with a robot through a remote-control device called the Communicator. Movements of expert workers taught to the Successor in advance are reproduced — including any force (replicating impact), touch (replicating vibration) and auditory and visual senses — through the Communicator, guiding the operator. Operators can physically feel the movement of experts. In other words, the Successor can also be viewed as an educator assisting workers with the acquisition of skills. It is Kawasaki’s mission and solution as a robot manufacturer for labor shortage, improving labor productivity and other social issues.

The Communicator of the Successor for assembly applications. Humans and robots collaborate through the use of the Communicator specifically developed for each specific purpose.

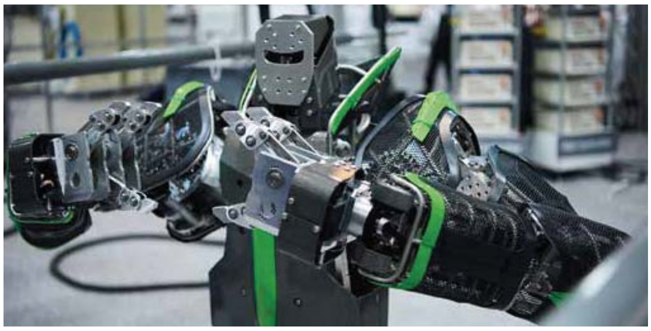
Development of a Humanoid Robot, an Industrial-Academic Collaboration Nurturing Infinite Possibilities

In March 2011, the Great East Japan Earthquake struck setting off a string of nuclear accidents. Mount Ontake had a volcanic eruption in 2014, and occurrences of heavy rain damage due to abnormal weather have been frequent. Such successive natural disasters are also an important issue Japan faces.

For instance, surveying the site of a volcanic eruption involves putting lives at risk if performed by humans, but such a risk can be avoided by having a robot substitute in. Or in the case of disaster relief, a robot can work continuously day and night without the need to sleep or rest. Robots can set foot in extreme environments where humans would not be able to and work on their behalf. When considering that in an emergency, the necessary tools and vehicles would be the same as those used by humans. Therefore, it is ideal that the robot heading to rescue is in the shape of a human in order to use the necessary equipment. Research and development of humanoid robots has been done in the past, but a robot's fragility has always been its Achilles heel, impeding research.

Even in the University of Tokyo's Jouhou System Kougaku Laboratory, where they have been pursuing research on humanoid robots, there were problems surrounding the robustness of robots. As robots get bigger, they break when they fall. So in order to avoid having their robots break down every time an experiment was conducted, researchers dealt with the issue with workarounds such as hanging it from the ceiling with a wire, but the restrictions were huge.

To tackle this problem and put the know-how as a manufacturer of industrial robots to use, Kawasaki teamed up with the University of Tokyo in a co-development effort — the collaboration between industry and academia. Kawasaki has been involved in public-private projects for humanoid robot development since the 1990s, and because the company has been able to build industrial robots where "being indestructible is a given", it is developing a robust body that is practical and durable, and exhibits the same range of motion a person has. A portion of the results were announced at the International Robot Exhibition 2017, along with the unveiling of the Kawasaki Humanoid Robot. The purpose of this project is to



The humanoid robot announced at the International Robot Exhibition 2017 is an endoskeleton-type measuring 175cm tall and weighs 80kg. In a demonstration, it lifted up dumbbells as heavy as the robot itself and showed its ability to get up after falling.

provide researchers with a robot that will serve as a development platform.

In the future, by having a diverse number of researchers develop using our robot as a base, Kawasaki hopes to first create a market, and then speed up the research and development of humanoid robots more than ever before.

The Tokyo Robot Center showroom, "Kawasaki Robostage", opened in August 2016. The aim was to create a place where visitors can see, touch, and experience real Kawasaki Robots, and get more familiar with robots as a whole.

In December 2016, the industry's smallest and lightest small robot controller, the F controller, was launched. At the International Robot Exhibition 2017, the small general-purpose RS007N and RS007L robots demonstrated high speed operations using the F controllers.

An Open Platform for Tomorrow - Innovation Through Alliances with Players of All Kinds

In 2018, Kawasaki is celebrating the 50th anniversary of its robotics business. Gradually moving away from previous "in-house" and "self-sufficient" approaches, Kawasaki is looking ahead with a new theme of "working wide-by-side", promoting alliances with various players in many fields. From manufacturing to medical care, human collaboration and cooperation, and humanoid robots, alliances are not bound by industrial frameworks.

Already in 2017, Kawasaki had agreed to collaborate with leading Switzerland-based robot manufacturer ABB in the field of collaborative robots, or cobots. Its purpose is to establish industry standards on robot safety and to unify approaches for robot operations. By doing so, the companies aim to further improve usability and safety for robot users, and set up an environment to further promote robot applications.

Press conference held in November 2017 on the cooperation between ABB and Kawasaki in the collaborative robot field.

Today, in 2018, Kawasaki celebrates the 50th year since the founding of our robotics business in 1968, and we are entering a new phase.

We are reshaping ourselves from an industrial to a fully-integrated robot manufacturer. With the mission as a robotics solution provider, we will continue on our quest to give back to society all we have learned and experienced and design a bright, new future promising the world where humans and robots can co-exist side by side.

Reference: ❹ Ministry of Internal Affairs and Communications, "Statistics on the Elderly Population" (2017) ❺ Ministry of Economy, Trade and Industry, "New Robot Strategy" (2015) ❻ International Federation of Robotics (IFR), "World Robotics 2017"

As a robot solution provider for the next generation

We continue on in our quest to create robots to help people realize their dreams and solve problems in society.

Our robotics business, which started with the production of the first industrial robot in Japan, marks its 50th anniversary in 2018. Thanks to the support and efforts of our longtime customers, business partners, our many predecessors and employees who have helped establish the groundwork on which we stand today, we have been able to keep developing the business for half a century. Here I would like to express my deep gratitude.

Our robot business began in 1968 when the "Office for Promoting Domestic Production of Industrial Robots (IR)" was first established. In the following year, we successfully produced the first industrial robot in Japan, and ever since, we, together with companies quick to note the potential of industrial robots, have continued to pursue new approaches to the utilization of robots.

Practical use of industrial robots began in the early 1970s with their implementation into the manufacturing process of the automotive industry. In the latter half of the 1990s, we began development of cleanroom robots for use during the production of semiconductors. Our central philosophy of responding to the needs and demands of society has guided us to gradually expand the playing field for industrial robots.

During the period of Japan's rapid economic growth, we grew our business by developing and implementing industrial robots hand in hand with our customers and partners. Our effort served as one of the biggest driving forces in accelerating the automation of manufacturing processes in the time of accelerating motorization and growth of the semiconductor industry. I am greatly honored to be able to contribute to the history of manufacturing in Japan.

With the rapid aging of society and the diminishing workforce becoming critical social issues, expectations for robots are higher than ever. To satisfy such social demands, we have been proactively developing robots that can collaborate with humans.

For instance, in pursuit of expanding the fields for robot applications, we have developed robots which can safely co-exist and work beside humans, reducing implementation time and costs in our pursuit to expand the fields for robot application. Also, our innovative robot system, which learns and replicates the operations of skilled engineers through a combination of remote collaboration features and artificial intelligence (AI) technology, is our collaborative robots to pass down the skills of experienced engineers to new workers. Skill transfer for the tasks requiring human senses and experiences — a feat once thought difficult for robot application — can now be achieved with the use of robots as well.

As future where AI and the Internet of Things (IoT) integrate with society comes near, robots are entering a completely new phase. The future often illustrated in comic books or science fiction films where robots work for us not only within factories, but also in our daily lives is just around the corner.

One way we are working to make that a reality is active development of medical robots. By employing cutting-edge technology and creating safer, more reliable robots for healthcare applications, we are working toward a society where the burden placed on medical staff, patients and their families can be alleviated through the collaboration between humans and robots.

We are also participating in a joint development project tying industry and academia together to develop humanoid robots with structurally robust bodies and the ability to flexibly adapt to their surroundings. We aim to speed up development and promote the global utilization of robots in everyday life by incorporating open platform/open innovation models and by collaborating with people from all fields who share our vision.

This year marks our 50th anniversary. At this big turning point, we set new goals for the next phase building upon the rich skills and experiences gained from our customers and society.

Regardless of when, there is always someone somewhere out there waiting for robots. We will listen to the voices of such people and devote every effort to develop robots that positively contribute to people and the greater society.

We are transforming ourselves from an industrial to a fully integrated robot manufacturer, with the aim of creating robots to help people realize their dreams and solve problems in society. As a robot solution provider, we continue on in our quest to develop robots which realize the needs of people and society by working along with people.

Your continued support would be highly appreciated.

June 2018

Yasuhiko Hashimoto
Director, Managing Executive Officer of
Kawasaki Heavy Industries, Ltd.
President of Precision Machinery
& Robot Company


Kawasaki
duAro
Kawasaki

50th ANNIVERSARY
Kawasaki Robotics

We deeply thank you for all of those who supported the creation of this brochure.

The references are at the bottom of each page. The ones from our internal sources are omitted.
The original sources are in Japanese and the references do not reflect official titles in English.

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