Kawasaki
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KAWASAKI TECHNICAL REVIEW

Special Issue on Fields of Focus in Group Vision 2030

TECHNICAL REVIEW

No.183
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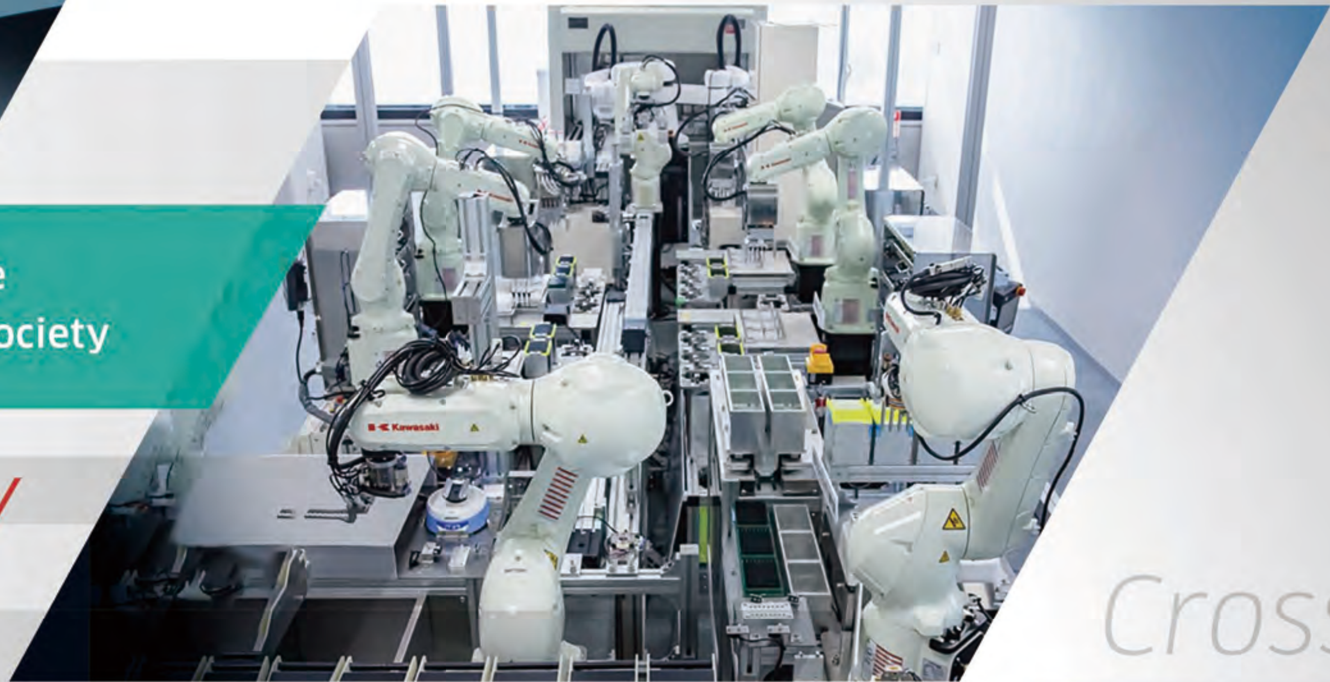
Kawasaki Heavy Industries, Ltd.

New Values

A Safe and Secure
Remotely-Connected Society



Trustworthy Solutions for the Future

Cross Over

Energy and Environmental Solutions

“Near-Future” Mobility

Frontier

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Contents

Technical Description

Interview with the president / CEO Yasuhiko Hashimoto

Striving toward the goals of Group Vision 2030

Yasuhiko Hashimoto
President and Chief Executive Officer

Tell us about Group Vision 2030.

We established Group Vision 2030 as our goal for achieving "Trustworthy Solutions for the Future" by the year 2030. This vision demonstrates our intention to create a brighter future by providing innovative solutions for an ever-changing society in a timely manner, and to continue to grow by expanding our potential through quick action and our ability to face challenges while transcending various boundaries. In order to realize our vision, we've established three fields of focus, and are working on the necessary technological developments to solve social issues.

Tell us about the three fields of focus.

Based on the most advanced technologies available to us, we've contributed to the prosperity and safety of societies around the world by providing a wide range of products that are the first of their kind in the world or in Japan, such as Shinkansen bullet trains, which enable high-speed transportation, and LNG carriers, which support power generation through environmentally-friendly natural gas. Today, as we face a series of rapidly changing social problems such as the coronavirus pandemic, global environmental issues, frequent natural disasters, scarcity of energy resources, and the declining and aging population, we've established three fields for us to focus on: A Safe and Secure Remotely-Connected Society, Near-Future Mobility, and Energy and Environmental Solutions.

Our focus on "A Safe and Secure Remotely-Connected Society" is an effort to achieve social safety and security while exploring new ways of working and living through the use of remote control and robot technology in various fields such as medicine, healthcare, manufacturing, and industrial infrastructure. In addition, we provide solutions for protecting life and property from disasters that have been a common occurrence in recent years. Our focus on "Near-Future Mobility" is part of our goal to help achieve a smart society through new means of transportation and mobility by combining vehicles such as unmanned cargo-carrying helicopters and delivery robots with airplanes, off-road vehicles, and robotics technology. In the field of "Energy and Environmental Solutions," we aim to contribute to achieving a carbon-neutral society by leading the world in building a hydrogen supply chain for the production, transportation, storage, and utilization of hydrogen, as well as the conversion of transportation systems to electric systems.

What are the corporate group's technological strengths?

The three fields of focus established in Group Vision 2030 are all new, groundbreaking fields that are on the frontiers of industry. We believe that hydrogen will especially be a crucial component in achieving a decarbonized society, and is a field that we've been a leader in for the past 10 years. If we can incorporate our hydrogen-related technologies and operational expertise that we've cultivated over the years into a shared global standard, we believe it will put us at a great advantage. This also applies to medical robots and mobility. Through these efforts, and through collaboration with other industry leaders, we strive to lead the market in the future.

Closing comments

We believe that the advanced technological capabilities that we've cultivated through relentless competition have the potential to solve many more social issues. To achieve this, we need a mindset of incorporating market needs into our products in a way that's sensitive to the rapidly changing market. We've also reformed our personnel system so that employees can play a more active role with broader perspectives and incentives to face challenges, and have built a system that helps consolidate the strengths of the corporate group. Through the technological synergy across our group and open innovation in collaboration with other industry leaders, we strive to continue to respond quickly to the social issues of our time that the market demands, and develop the necessary solutions to achieve the goals of Group Vision 2030.

Kawasaki's Solutions in Three Fields of Focus

Takeshi Kaneko
Executive Officer,
General Manager, Corporate Planning Division

Introduction

Since its foundation in 1896, Kawasaki has striven to develop product that are the first of their kind in the world or in Japan to meet the needs of rapidly changing times and has been developing cutting edge advanced technologies in the areas of land, sea and air for over 100 years. In the meantime, global warming and infectious disease problems have developed on a global scale recently and we are facing a major paradigm shift, as can be seen with decarbonization technology and the digital transformation (DX). Our Group Vision 2030 has been presented to serve as a compass as we navigate our way to such a discontinuous and uncertain future.

1 Social issues and our three fields of focus

The novel coronavirus disease (COVID-19) that spread across the entire world in 2020 has completely changed our daily lives. If we are unable to discover remedies for COVID-19 and allow the fighting back and forth between vaccines and variant strains to prolong, not only will the burden be concentrated on healthcare professionals, but the world economy may be more seriously affected, mainly in the transport and restaurant industries, due to the activities of people around the world being brought to a standstill. IT-based remote work has spread only among office workers, and I suspect many people are working while desperately trying to avoid the risk of infections.

In recent years, the advancement of global warming should be obvious to anyone. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) recognized that human activities affected climate change as well as the sea-level rise and expressed its view that the achievement of carbon neutrality by 2050 is essential in limiting the rise in the average global temperature to within 1.5°C of pre-industrial levels. In addition, intensifying natural disasters have become an issue recently, and so the development of infrastructure to ensure disaster prevention and natural disaster reduction is urgently needed.

To solve these social issues, Kawasaki has set out three fields of focus: A Safe and Secure Remotely-Connected Society, Near-Future Mobility, and Energy and Environmental Solutions.

Efforts beyond the boundaries of companies are essential in each of these fields of focus, and we are also working to develop a system for making such efforts. The Presidential Project Management Division, which is under direct control of the president, is aiming for early commercialization of the "Automated Robotic Polymerase Chain Reaction (PCR) Testing System," "Near-Future Mobility," and other projects by leveraging technological synergy in cooperation with internal companies. We have also established the Hydrogen Strategy Division in our head office as an organization that plays a leading role in the realization of a commercial-scale hydrogen energy supply chain.

The following describes the concept of our solutions in each of these fields of focus.

2 A Safe and Secure Remotely-Connected Society

In the field of "A Safe and Secure Remotely-Connected Society," we will utilize our technologies for the purpose of applying remote technologies to workplaces where actual physical work is involved to enable all people to take part in society, protecting lives and properties from disasters, and so on.

(1) Medical and health care

The "hinotori Surgical Robot System" is the first made-in-Japan robotic-assisted surgery system developed by

Medicaroid Corporation, a joint company between Kawasaki and Sysmex Corporation. The system is low cost and small enough to fit in a small operating room, and it is easy to operate. Going forward, we will work to incorporate remote operation via commercial 5G, for the purpose of reducing the burden of surgery on physicians.

The Automated Robotic PCR Testing System, developed as a COVID-19 countermeasure, contributes to further reducing the burden of physicians and other healthcare professionals by fully automating the testing system.

Although vaccination is found to be effective on a global basis, development of a screening test system based on high reliability PCR testing is essential to fully restore the mobility of people around the world due to the successive emergence of new variants. The automated and systematic testing system using our robot can perform high volume, high accuracy testing in a short time without omitting any of the required processes. Driving the development at an unprecedented speed, we are implementing the system into the monitoring test service in cooperation with local governments.

Advancing this project requires us to work to solve various issues in addition to developing technology; that is, to clear some constraints including permits and licenses for installing the Automated Robotic PCR Testing System in a short time as well as to learn hospitality skills that are indispensable for the "service of selling experiences" to the general public. This initiative is a perfect example of open innovation and agile development.

Currently, the system is mainly implemented in the monitoring service for local governments, and a future issue in this initiative is to expand the service to a screening service for various events. In a situation where an overwhelmingly large number of countries require an official negative PCR test result certificate to be submitted as an entry requirement, our automated PCR testing service could play the important role of stimulating passenger traffic on international flights. This testing service, for which we aim to fulfill the requirements for obtaining an international certificate, could also play the important role of eventually returning the private sector airline businesses to a growth trajectory by spreading this service.

(2) Proposal on a new way of working and living

As remote work has spread, more and more people are now balancing work and life, which allows them to effectively use their time. However, the types of occupations that allow workers to work remotely are currently limited. In fact, when a state of emergency was declared for COVID-19, workers engaged in nonclerical work deemed to be essential work could not avoid going to their usual workplace.

If actual physical work at a factory, etc. can be performed remotely, not only can the way people work be changed, but manufacturing equipment in factories overseas, for example, can be operated from anywhere in Japan. In addition, manufacturing hours can be significantly reduced because it would not involve travel, which would drastically change the structure of the manufacturing industry. Technologies that could serve as the keys to such

Fig. 1 Implementation of the automated PCR testing service business

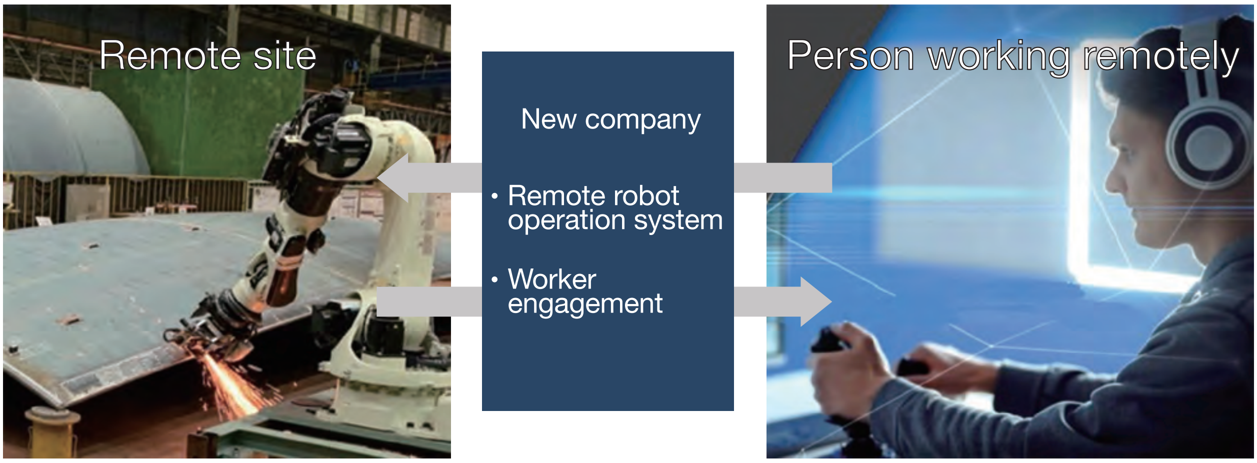

Fig. 2 New value provision based on a platform

a change are remote technologies and robotics.

One such technology is our "Successor," a new robot system featuring remote instruction technology. Remotely operating a robot requires the judgment and senses of a human and introducing a robot in the manufacturing industry, which involves many atypical tasks, is extremely difficult. Our "Successor" is a remote instruction system that reproduces the sensory input of actual physical work and helps the user perform intuitive operations. The user can have the same sensory input in a remote location that they would have doing the actual physical work. The system also enables succession of skills, which was so far impossible with robots, and can be used at a variety of factories because it can be used in combination with a different robot system depending of the purpose of the work.

We are also considering offering a comprehensive service that covers the life cycle of industrial robots, from installation to maintenance of robots, in order to accelerate automation required in many different areas. We are now advancing the development of software functions and the Robot as a Service (RaaS) platform required for that service.

Since remote work that involves actual physical work is needed in the areas of health care and distribution as well as the manufacturing industry, "Successor" is expected to become a solution to the labor shortage.

We are also working to provide new value to our solutions. For the creation of a remote platform that connects people who are willing to work and business operators who need a workforce, we will jointly establish a new company with the Sony Group in fall 2021.

The new company will allow people who had difficulty conducting social activities to take part in society remotely, enabling them to enjoy a new way of working and living regardless of location or time. We will provide new solutions for the "realization of a society that everyone can take part in."

(3) Protecting people from disasters

Realizing a safe and secure society is an indispensable part of dealing with the increasingly intensifying natural disasters in recent years.

In addition to involvement in various infrastructure restoration projects from the Han-Shin Awaji Earthquake disaster in 1995 and the Great East Japan Earthquake disaster in 2011, Kawasaki has been working on products, technologies, and solutions that contribute to disaster prevention and natural disaster reduction.

In the event of a disaster, lifelines such as power and water must be secured first. Installing emergency power generating units is an effective way to ensure a stable supply of electricity. We offer emergency gas turbines, and our Kawasaki PU series includes a total of 21 models covering a wide range of outputs. At the time of the Great East Japan Earthquake disaster, all of our gas turbine units (except one that had not been maintained properly) operated successfully in the wake of the earthquake.

What is needed next is a mode of transportation for transporting goods to damaged areas. With four-wheelers and dirt bikes, medical supplies and other goods can be delivered quickly and stably even if road conditions are poor due to a disaster. The multipurpose vehicle known as the MULE PRO-FX (EPS), which was adopted as a fire engine for the first time in Japan, is well received for its mobility and off-road performance.

The Kawasaki "BK117" helicopter has been adopted by many institutions as a helicopter ambulance to carry patients even if land routes have been disrupted to provide medical care at remote locations. The BK117, jointly developed with Airbus, features a high level of safety and operating performance as a result of improvements over

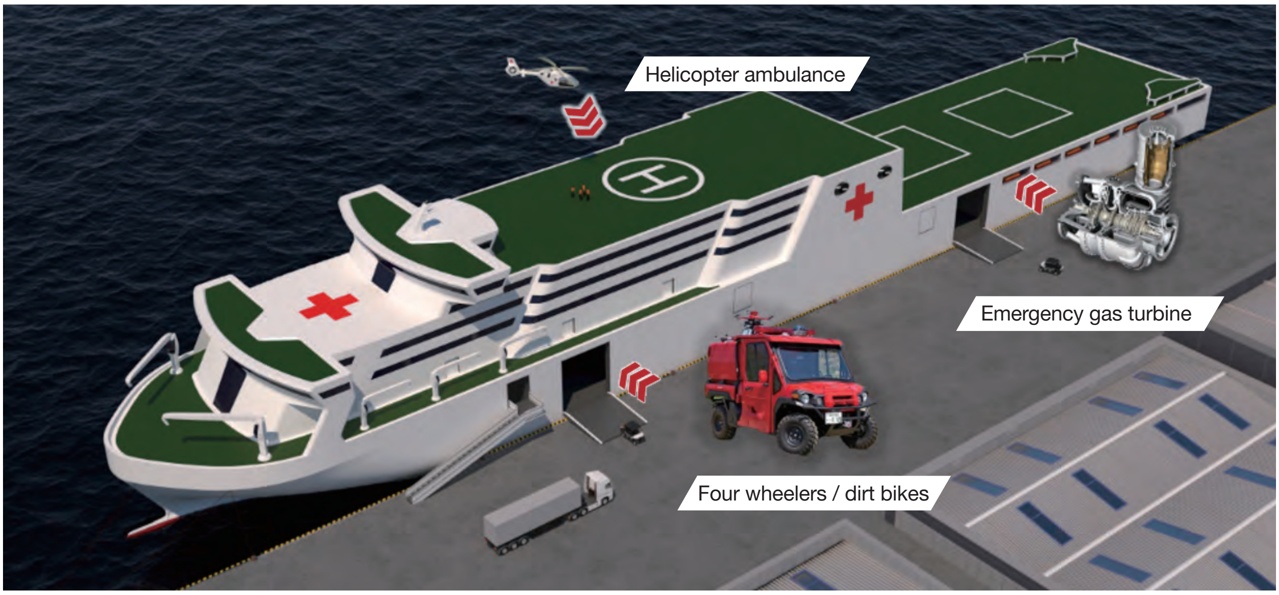

Fig. 3 Rescue hospital ship

many years.

The Japanese government considered the use of a rescue hospital ship in the face of large-scale disasters and the COVID-19 pandemic. Our strength lies in our ability to propose a comprehensive package by combining a remote surgery support robot system and our other products and services.

3 Near-Future Mobility

As a result of changes in people's lifestyles, aside from the progress in CASE (Connected, Automated, Shared, Electric), the environment surrounding mobility is about to make a huge change. At Kawasaki, we have set out "Near-Future Mobility" as one of our fields of focus, aiming at a

Fig. 4 Goods transportation by an unmanned helicopter

society where people and freight can be transported securely, quickly, and efficiently, or while enjoying travel.

Distribution, in particular, is important social infrastructure supporting people's lives. However, the spread of COVID-19 has further accelerated this situation. This momentum has strengthened due to an increase in stay-at-home consumption as a result of people voluntarily refraining from going out and stores and restaurants refraining from operating since 2020, and there is no doubt this situation will become a part of everyday life even in the post-COVID-19 world.

In the meantime, the labor shortage in the distribution industry is becoming serious. The issue of developing a secure and safe environment for delivering goods without being infected with COVID-19 and the issue of securing a distribution network to underpopulated areas must be solved urgently.

With drastic changes such as the development of e-commerce, congestion in cities, and a move towards sharing, in a post-COVID-19 world, changes can also be seen in the movement of people and freight.

Many companies are working to develop autonomous driving technologies to deal with the labor shortage and efficient transport, drones for carrying goods to underpopulated areas and areas isolated by a disaster, other IoT and AI technologies that are necessary for improving efficiency in transport routes and managing goods, and so on.

On the other hand, we provide new solutions combining robotics, mobility, and aviation.

For example, what can be done if we combine the helicopter manufacturing technology that our Aerospace Systems division has cultivated and our lightweight, high output engine cultivated through experience with the "Ninja" Our unmanned compound helicopter, K-RACER, is a realization of such an idea.

The autonomous delivery robot installed on the K-RACER delivers cargo to the entrance of the recipient's home, and the contents of the cargo and the identity of the recipient are confirmed through a conversation between the recipient and AI. Realizing this would bring innovation to the last mile in distribution.

We plan to put it into service in 2022 after going through trial operations at our factory for checking the rotational and running performance as well as the performance of the communication function.

These innovative technologies can be applied to transportation to isolated islands and steel tower work and transport in mountainous areas. We will actively participate in activities in support of deregulation for social implementation of the technologies in regional cities, commercial facilities, hospitals, and so on.

4 Energy and environmental solutions

During the Climate Change Summit hosted by the U.S. held in April 2021, countries around the world announced their greenhouse gas (GHG) reduction targets and goal of achieving carbon neutrality. Japan also declared it will target a 46% cut in greenhouse gas emissions by 2030

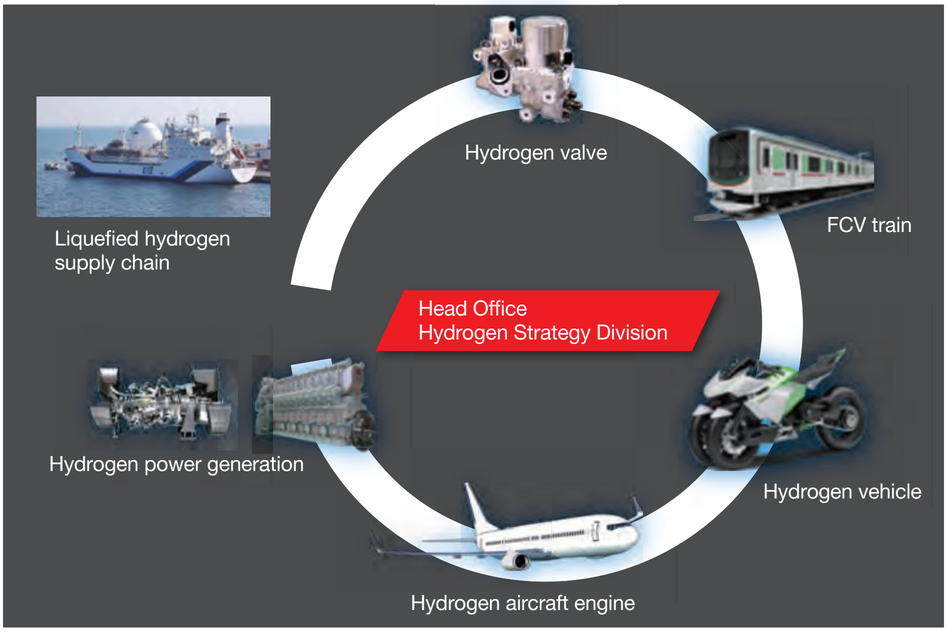

Fig. 5 Further development of hydrogen-related products and businesses

from 2013 levels and achieve carbon neutrality by 2050.

Kawasaki's key solution to the achievement of decarbonization is our hydrogen business that we are working on ahead of others in the world. We have already started demonstration tests, in which mass transportation of blue hydrogen obtained from brown-coal in Australia to Japan is carried out by a liquefied hydrogen carrier. In August 2021, "commercialization demonstration of the liquefied hydrogen energy supply chain" was adopted by the New Energy and Industrial Technology Development Organization (NEDO) Green Innovation Fund Program. In this program, the technologies for large-scale liquefaction and transport of several million tons of hydrogen per year will be established ahead of the world as part of a full-scale initiative to implement a CO_2-free hydrogen energy supply chain in society in anticipation of a hydrogen mass consumption society for achieving carbon neutrality. Then, a demonstration of an international full liquefied hydrogen energy supply chain, including everything from manufacturing, to liquefaction, shipment, marine transportation, and unloading of hydrogen, will be conducted.

We are also undertaking a green hydrogen project, in which hydrogen is manufactured and liquefied from renewable energy and then transported to Japan. In December 2020, we signed a memorandum of understanding (MOU) with Fortescue Metals Group, a major iron ore company, and Iwatani Corporation and are conducting a feasibility study, aiming at demonstration in the mid-2020s.

As a hydrogen utilization project in Japan, we started power generation based on hydrogen mixed combustion at a combined cycle power generation plant for Seibu Oil Company Limited in August 2021.

Although hydrogen is attracting attention as clean energy that does not emit CO_2 during combustion, it emits a lot of nitrogen oxide (NOx). To solve this issue, we have developed a hydrogen dry low NOx combustion gas turbine and succeeded in demonstration testing for the first time in the world. Electricity and thermal energy generated from the hydrogen combustion gas turbine are being supplied to urban areas in Kobe City.

These hydrogen combustion technologies have been implemented in the areas of aircraft, vessels, and motorcycles, and we aim to demonstrate an aircraft engine combustor by 2030.

In the area of international marine transportation, the International Maritime Organization (IMO) has created unified global rules to prevent marine pollution and set out the long-term goal of "aiming to achieve zero GHG emissions as soon as possible within this century." In response, we will lead the world in the development of marine hydrogen engines through collaboration with Yanmar Power Technology Co., Ltd. and Japan Engine Corporation, aiming for a market launch of marine hydrogen engines in 2025.

In addition to such a decarbonization initiative with hydrogen, we are also working on electrification and the use of hybrid technologies while actively applying such technologies to motorcycles and construction equipment including shovels.

Conclusion

Thanks to the efforts of our predecessors who lived through a period of dynamic changes, Kawasaki has accumulated a long history of over 100 years, and by extension, we are now able to live our lives as company employees.

In the face of ongoing global-level historical changes, will we be able to leave Kawasaki Heavy Industries as a vessel for new generations over the next 100 years? We will awaken the DNA we had at the time of our foundation and flexibly improve our internal system so that our corporate culture of continuing to take on the challenge of solving anticipated social issues will be firmly established.

In this way, we will respond to rapidly changing social conditions and issues arising from such conditions with a sense of speed.

hinotori Surgical Robot System, the First Made-in-Japan Robotic-Assisted Surgery System

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In the medical field, where future development is anticipated, medical robots have been increasingly adopted in order to realize a safe and secure remotely-connected society.

Medicaroid Corporation developed the hinotori Surgical Robot System, based on the core concepts of compactness, safety, and high maneuverability. This system became the first robotic-assisted surgery system created in Japan to achieve Japanese regulatory approval in August 2020. The first human surgery with the system was successfully conducted in December 2020.

Introduction

In the medical field, which is expected to expand further in the future as society ages, medical robots have been increasingly adopted as part of efforts to establish a safe and secure remotely-connected society.

1 Background

In Japan, excess imports of medical devices totaled approximately 1.7 trillion yen in 2019. In particular, the da Vinci surgical system from US Intuitive Surgical has dominated the market for robotic-assisted surgery systems, which are large-scale medical devices. On the other hand, many Japanese companies develop, manufacture, and sell world-leading industrial robots, and these companies have been expected to create domestically-made robotic-assisted surgery systems by leveraging their technological capabilities.

The medical robot market is expanding by the year. Robotic-assisted surgery systems are likely to account for a large part of the global medical robot market, which is expected to exceed one trillion yen by 2025 [1]. In addition, as US-based Intuitive Surgical's basic patents on its robotic-assisted surgery system expire, domestic and international companies have accelerated development to gain market share.

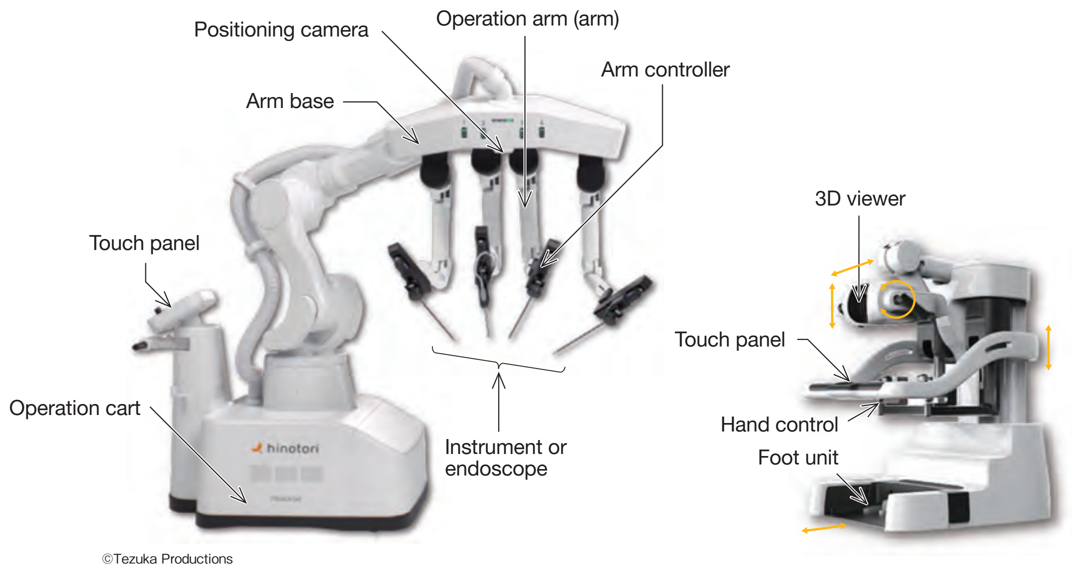
2 Development concept and history

We at Medicaroid developed this system based on the market-in approach. First, we asked domestic and international surgeons renowned for robotic-assisted surgery about current issues, defined the solutions to these issues to be needs, and created a prototype that satisfied such needs. Next, we asked surgeons to evaluate the prototype, after which we further improved the prototype by solving the new issues that were identified as a result of the evaluation. In this project, we executed this process annually for five years before completing the hinotori Surgical Robot System. The first prototype was created in 2015. For the first three years, we executed this process to solidify the concept; for the last two years, we executed the process to refine the product.

3 Concept

This product is a robot system to assist in laparoscopic surgery. As **Fig. 1** shows, surgical instruments (hereafter referred to as the "instruments") and endoscope attached to the operation unit are inserted through multiple ports (diameter: several millimeters) on the patient's abdominal wall, and the operating surgeon sitting at the surgical cockpit operates the hand control while watching a 3D video feed. This system enables the operating surgeon to perform surgical operations as if moving his or her hands within the body cavity and to perform minimally invasive surgery, which minimizes the burden on the patient.

What is important for surgical operations within the patient's body cavity is to minimize interferences among the operation arms while allowing the arms to move within the necessary range. In addition, in a small operating room,



(a) Operation unit

(b) Surgical cockpit

Fig. 1 System configuration

a small occupied volume is desirable to ensure handling and workflow lines. It is also important to reduce interferences with the patient and assistants around the bed and to ensure an ample work area for assistants.

Because this product is directly linked to human life, ensuring the robot is safe is vital. To this end, we decided to proactively adopt the technologies we have accumulated from the development of industrial robots.

In addition, because this system is a manipulated robot, the operator must be able to operate it comfortably in order to complete surgery smoothly and reliably. We must also consider usability by assistants and other staff members as well as the operating surgeon, who operates the system.

As described above, we designed the product by focusing on ① compactness, ② safety, and ③ maneuverability as important concepts during development. Furthermore, we strove to apply new technologies.

4 Details of development

(1) Compactness

(i) Compact arm structure that does not obstruct

For compactness, this product's combination of a motor and deceleration mechanism is designed to be suitable for movement during surgery. The main body of the robot to operate instruments has eight movable axes, each of which requires a different speed and torque. We identified the required speed and torque from simulated surgical operations and determined a motor size and speed reduction ratio that satisfied the conditions.

Also, by maintaining the pivot position through software control to eliminate the mechanism for retaining a tubular device called a trocar sleeve placed on the patient's abdominal wall, we secure a large workspace around assistant surgeon's hands as shown in **Fig. 2**.

(ii) Control to ensure a large working range while reducing arm interferences

Each operation arm is a redundant arm that has eight joints including a linear axis as shown in **Fig. 3 (a)**. Redundant control according to multiple constraints determined based on singular points and required working range reduces interferences among arms while ensuring the working range. The amount of lateral movement of the arm elbow is also constrained as shown in **Fig. 3 (b)** to restrain extension in the width direction in order to provide a large space for the assistants and nurses around the bed.

(2) Safety

(i) Mutual monitoring module to ensure safety

The technology of the functional safety operation monitoring unit Cubic-S [2] that we have accumulated through the development of industrial robots is used to control the actuator and input/output. Safety is enhanced by a mutual monitoring module separate from the controller for motor control.

① Functions involving robot operation are permitted only when an enable switch on each arm or at the operation section at the rear of the operation cart is pressed, or when the operating surgeon looks into the 3D viewer and the Cubic-S redundantly confirms the sensor input. If movement of an arm that is not being operated is detected, such movement is

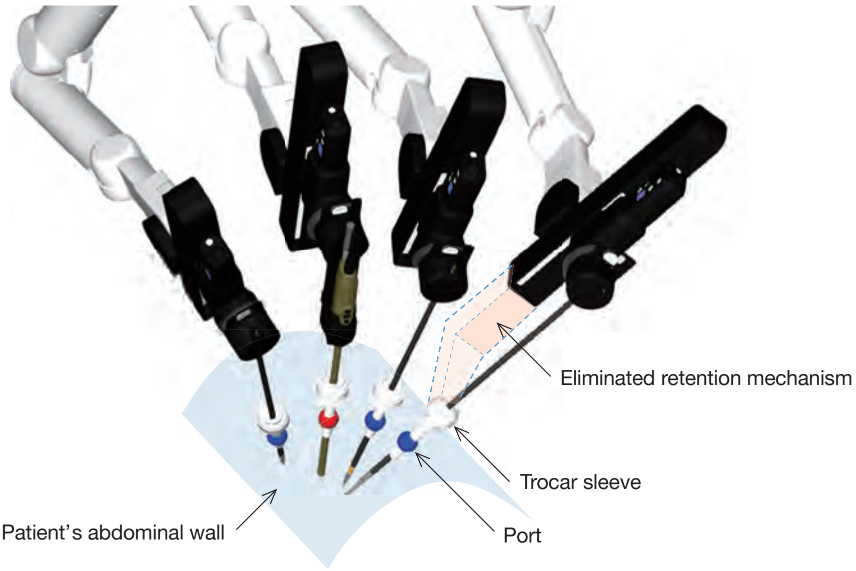
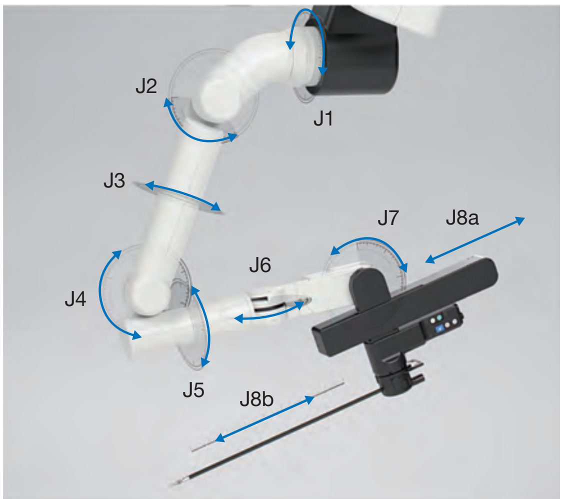
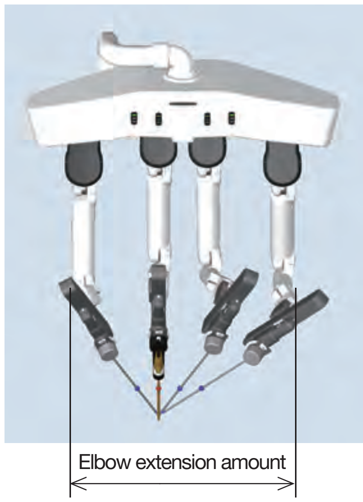


Fig. 2 Elimination of retention mechanism



(a) Placement of axes in the redundant arm



(b) Restraint of elbow extension amount

Fig. 3 Arm structure

immediately judged to be an error

② As described above, maintaining the pivot position through software control leads to ensuring a workspace for assistants. However, if the pivot position shifts, the patient's abdominal wall may be damaged. As shown in **Fig. 4**, when generating the position command, the primary controller confirms that the pivot position has not changed from the set value, and the Cubic-S also monitors and redundantly confirms the pivot position to improve safety.

(ii) Actuator control to reduce the risk of tissue damage

Endoscope vibration causes shaky video and hampers surgery. Instrument vibration may damage delicate body organs. Therefore, the system generates operation specification values that reduce vibration by applying a notch filter and various compensation to the operations inputted by the operating surgeon. In addition, because interferences between arms may generate large vibration at instrument tips and damage tissue, operation is restricted so that instruments do not move in the collision direction.

(3) Maneuverability

(i) Structure and compensated control for comfortable operability

What is important for smooth operations is not to

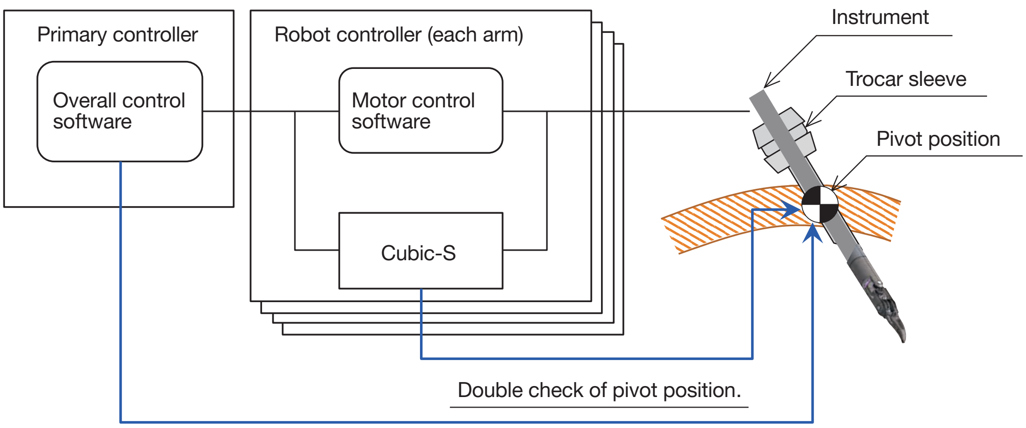


Fig. 4 Pivot position monitoring by Cubic-S

hamper the intended operations inputted. We developed a drive train that combines a high-power motor and a reduction gear that has a low reduction gear ratio with the arm on the operation input side to reduce the friction resulting from the reduction gear. We also designed the system to perform gravity, inertia, and friction compensation. Doing so achieved light, comfortable operability.

(ii) Adjustment mechanism to reduce fatigue

When operating a surgeon cockpit, a surgeon can take a forward leaning posture as if looking into the operative field during laparotomy, or a posture in which the upper body is raised to reduce a burden on the shoulder and neck. Adjustment mechanisms include armrest height adjustment and foot unit depth adjustment performed by touch panel operations, and manually operated 3D viewer position adjustment performed using an electromagnetic clutch equipped with an unlocking mechanism. The surgeon can fine-tune the system according to his or her body shape and preferences.

(iii) Operation input section for simple operations

The arm controller shown in **Fig. 5** is attached to each

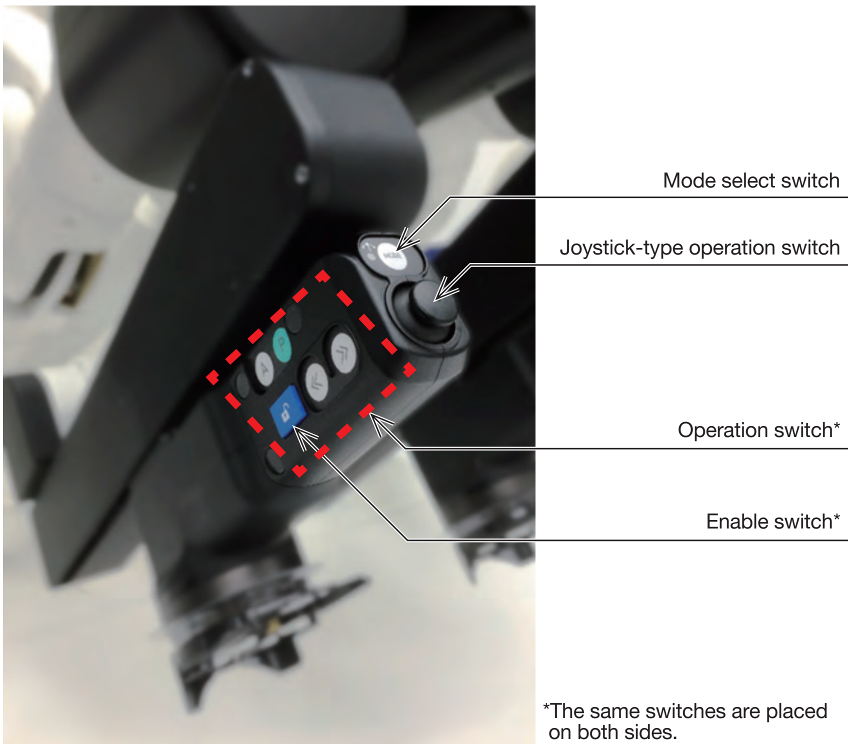


Fig. 5 Arm controller

arm on the patient side so that an assistant by the bed can change the posture when, for example, teaching the pivot position.

The simple joystick-type operation system has a bilaterally symmetric section, and the same switches are placed on both sides so that the system can be easily operated even when the direction to approach the bed is changed for reasons such as surgical site or flow lines.

Moreover, the positioning camera for acquiring an overall view is attached at the center of the arm base so that the relative positional relationship with the bed or patient can be adjusted while watching the video feed on the touch panel of the cart's rear section. This ensures maneuverability when the system approaches the bed.

(4) Striving to apply new technologies

(i) Instrument development

The instruments move inside the patient's body to perform necessary procedures, such as grasping or retraction of tissue, cutting and coagulation using an electrical cautery, and suture ligature using a suture and needle during surgery. Therefore, they require the highest level of functionality and performance for medical devices. Though Kawasaki did not have experience in designing and developing surgical devices, the company has gradually accumulated the required technologies and expertise by repeatedly developing elements.

Figure 6 shows the appearance of an instrument that has been designed with consideration given to the grasping force, tip shape, and ease of cleaning.

① Grasping force: The most important function of the instrument is to grasp and manipulate tissue or a needle. When the hand control grip is tightened to the specified angle, the tip of the jaw closes. When the grip is further tightened, the required grasping force is generated. When the wire in the drive transmission section inside the shaft is twisted as a result of shaft rotation, the wire tension changes, causing the grasping force to fluctuate. This product can maintain a certain amount of grasping force by performing compensation according to the shaft's rotation angle.

② Tip shape: Through repeated evaluation by surgeons, we have improved the instrument's tip shape to optimize it for application. For example, the needle holder, which holds and operates the needle, has been improved by attaching an anti-slip sheet to the grasping surface in order to reduce needle slippage, and by designing the tip round so as not to damage the thread during suturing. Because the grasping forceps adopt a jaw shape (i.e., the forceps are closed from the tip), leaving a gap at the base, they can stably grasp targets from thin membranes to thick tissue.

③ Ease of cleaning and sterilization: The instrument can be used 10 times by cleaning and sterilizing it each time. Therefore, we needed a structure that allows for cleaning and sterilization not only of the tip, where tissue and blood attach during surgery, but also the inside of the shaft and housing. To achieve ease of cleanliness, we analyzed where water accumulates by, for example, simulating the water flow inside the shaft and observing the interior when water passes using a transparent housing cover, and we realized a structure that inhibits contamination. Regarding ease of sterilization, we confirmed that autoclaving using a biological indicator sufficiently sterilizes germs.

(ii) Rulemaking strategies

As part of rulemaking strategies for commercialization, Medicaroid continues to participate in the development of international standards.

Because the regulatory authorities in each country are very concerned about the safety of medical electrical devices, each country has legislated technical

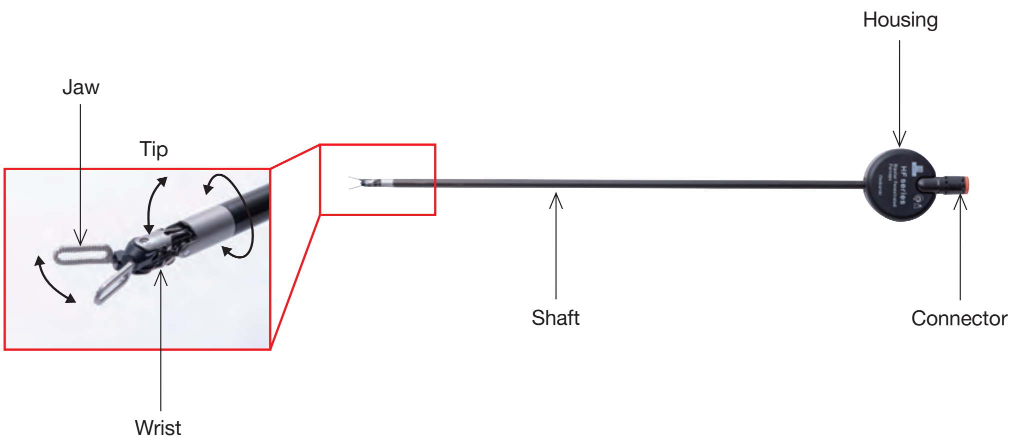


Fig. 6 Example of surgical instrument

requirements for medical electrical devices mainly based on the IEC 60601 series of standards issued by the International Electrotechnical Commission (IEC). However, when Medicaroid started to develop the hinotori Surgical Robot System, there were no safety standards for medical electrical devices using robotics technology.

To address this issue, the IEC has developed a standard that applies only to the robotic-assisted surgery system product group and issued it as IEC 80601-2-77:2019. During the development of this standard, Medicaroid participated in the writing of the standard as a member of the Japanese delegation and encouraged the introduction of safety technologies already in use in industrial robots. Many of the company's proposals were adopted.

Only six months after this standard was issued, Medicaroid completed conformity assessment with the standard and filed an application for pharmaceutical approval using conformity to this new standard as the basis of product safety. This quick application was possible because the technologies of Kawasaki are included in the standard, and some of us participated in the creation of the standard and are familiar with the requirements. We believe that this is one piece of evidence that our rulemaking strategies have borne fruit.

Conclusion

The hinotori Surgical Robot System is a completely new product that we plan to further grow and develop. We will first increase the range of target surgical procedures and expand the market by globally launching the product in the US, Europe, Asia, and other regions. Meanwhile, we plan to adopt many new technologies to make the product more attractive. In particular, by connecting digital information inside and outside the robot to a network and accumulating it in a database, we are focusing on efforts to make the information useful in providing guidance for more efficient surgery, in improving and transferring medical skills, and in providing support for remote robot surgery, in which a surgeon in a remote location supports surgery over a network.

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Robot Systems for Infectious Disease Medical Care That Support Medical Safety and Social Security

Recently, as measures against COVID-19, it is becoming increasingly necessary to enhance PCR testing capacity, ensure safety of healthcare workers, and reduce the burden they are shouldering. Also, economic activity is declining worldwide, and early detection of infections and resumption of economic activity are priority issues.

In these circumstances, Kawasaki is working to develop technologies to perform accurate PCR testing on a large number of samples in a short time and robots that patrol hospitals or take samples by remote control by utilizing its proprietary robot technologies.

Introduction

In early 2020, COVID-19 infections spread worldwide, and in Japan, a state of emergency was declared in April of this year. Given this situation, as measures against COVID-19, it is required to enhance PCR testing capacity, ensure the safety of healthcare workers, and reduce the burden that healthcare workers are shouldering.

1 Background

In Japan, PCR (Polymerase Chain Reaction) testing capacity is insufficient, and most testing is conducted manually by healthcare workers. Today, enhancing PCR testing capacity, ensuring the safety of healthcare workers, and reducing the burden that healthcare workers are shouldering are social issues.

Meanwhile, as a result of strong measures accompanied by travel restrictions in each country, various industries, such as passenger transport businesses (e.g., airlines) and tourism businesses, are on the decline, and early detection of infections and resumption of economic activity are priority issues.

2 Product concept

To address these issues, Kawasaki decided to utilize its proprietary robot technologies to develop an automated PCR viral robot system, monitoring robot system, and nasopharyngeal swabs collecting robot system

(1) Automated PCR viral robot system

PCR testing is a technology to amplify DNA (Deoxyribonucleic Acid). Detecting the COVID-19 virus, which is an RNA (Ribonucleic Acid) virus, requires converting RNA into DNA by a type of manipulation called RT (Reverse Transcription). This system employs a technology called RT-PCR, by which RCR testing is conducted after RT in order to detect the COVID-19 virus.

Conventional PCR testing is conducted manually by healthcare workers, which therefore requires much labor and time. Making the most of the features of robots, which can accurately repeat the same task, Kawasaki aims to develop a system for performing accurate RT-PCR testing on a large number of samples in a short time.

Since it is possible that the samples taken may contain the virus, strict control of the handling of biohazards is required. With this system, samples are taken in an inert solution to inactivate the virus during an early stage of testing, thereby facilitating subsequent handling and ensuring the safety of healthcare workers.

(2) Monitoring robot system

Healthcare workers caring for patients with infectious diseases are continuously exposed to the risk of secondary infection. As the number of patients hospitalized increases, the burden that healthcare workers must shoulder increases. To solve this issue, Kawasaki is developing a monitoring robot system that works in infection isolation areas in the place of healthcare workers so as to reduce the risk of infection and to mitigate workloads.

There are many issues to tackle in order to adapt the robot system to such medical and general environments. The robot system is required to be sufficiently safe so that it does no harm to the people around it. In addition, equipment and facilities, such as serving racks and elevators, are designed for general usage scenarios. Therefore, appropriate sensing and communication interfaces are required to use such equipment and facilities. In tight medical environments, it is unacceptable for robots to malfunction and disturb the work of healthcare workers; therefore, stable operation is required.

(3) Nasopharyngeal sample collection robot system

Saliva and nasal swabs sampled from the nasopharynx are considered to be effective as samples for genetic testing. To take a sample from the nasopharynx, the sampler must insert a medical cotton swab into the examinee's nostril, which exposes the sampler to the risk of secondary infection by the examinee's reflex movement if the examinee sneezes. It is extremely difficult technically for robots to perform sampling work in a fully automated manner mainly according to an examinee's age, physical characteristics, and chronic diseases.

Therefore, Kawasaki is developing a master-slave robot system that enables the sampler to take samples from the nasopharynx by remote control. This isolates the sampler from infection risk and also replicates the sampler's hand movement, thereby achieving reliable sampling while ensuring the examinee's safety.

3 Progress of development

(1) Automated PCR viral robot system

(i) System configuration

As shown in **Fig. 1**, PCR testing is conducted by setting, loading, unsealing, and dispensing samples; extracting nucleic acids; preparing reagents; and measuring PCR.

It is challenging to perform accurate RT-PRC testing on a large number of samples efficiently and quickly by optimizing each process as well as by appropriately arranging and controlling robots compactly in each process.

As shown in **Fig. 2**, the entire robot system is housed in a construction container such that samples are handled only within the container, thereby dramatically enhancing the level of safety for those engaged in testing. Like transport containers, this container can be transported by a trailer truck and can be operated on the chassis of such a trailer truck, thereby providing a mobile testing environment.

As shown in **Fig. 3**, the processes of the container consist of the unsealing/dispensing process, nucleic acid extraction process, reagent preparation process, and PCR measurement process, and robots are arranged in a manner suitable for each process, thus enabling efficient, quick, accurate RT-PCR testing with a large number of samples. In the nucleic acid extraction process, five robots are arranged, thereby achieving optimized throughput. In the PCR measurement process, 16 Sysmex thermal

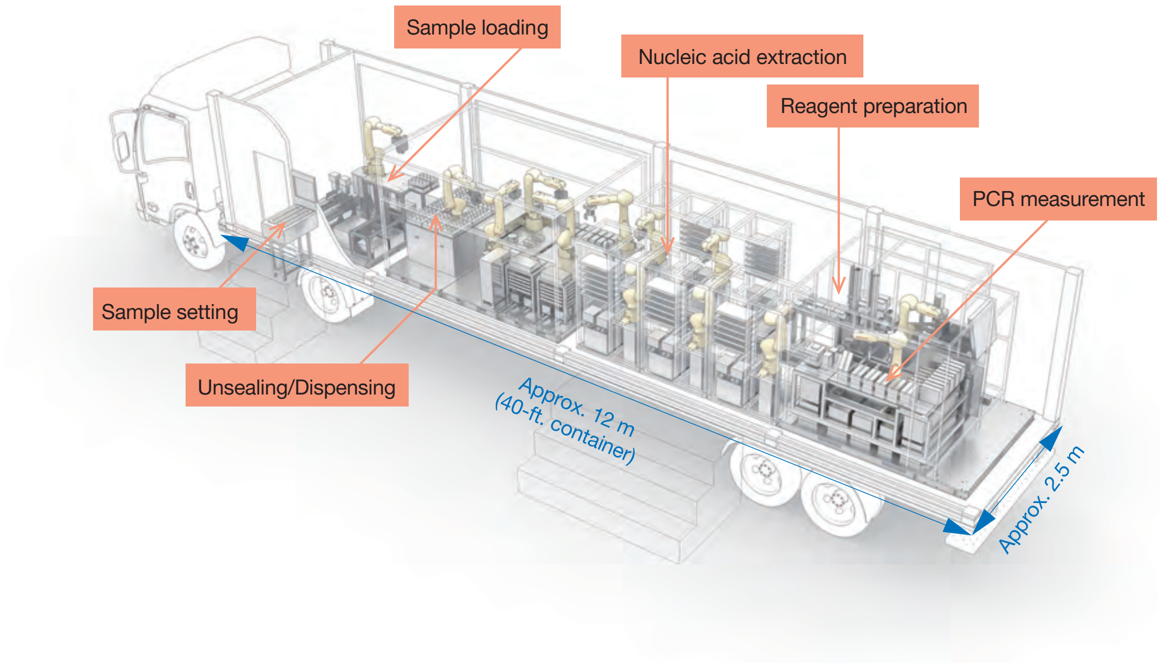

Fig. 1 Container-type automated PCR viral testing robot system

Fig. 2 Example container installation

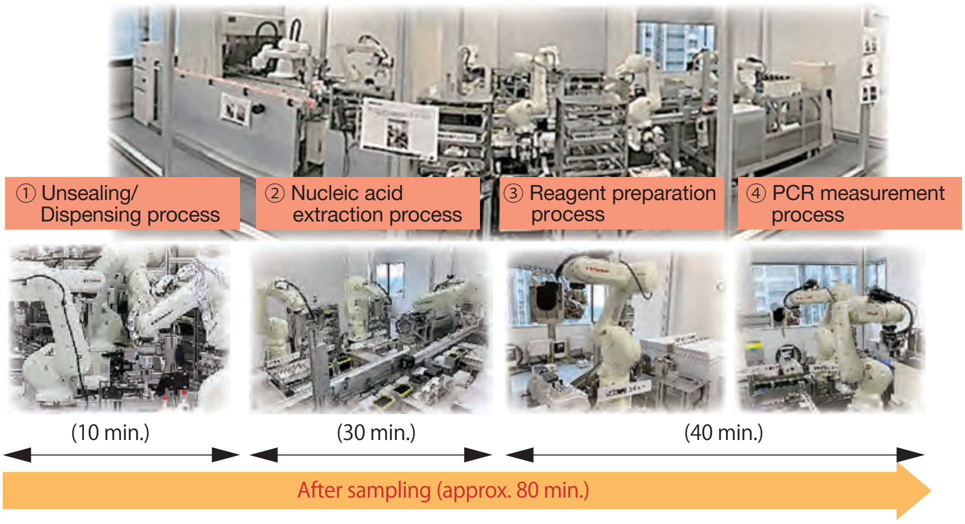

Fig. 3 Configuration of automated PCR viral testing robot system

cyclers are arranged so that PCR measurement results can be obtained for a batch of eight samples at once, which makes it possible to test a total of approximately 2,500 samples when operating the system 16 hours per day.

(ii) Efforts to enhance testing accuracy

This system does not require human intervention after the samples are sealed, and the system minimizes contamination, which causes false positives, through the optimal arrangement of robots in each process and appropriate ventilation achieved by pressure control in each process area.

False negatives can occur depending on how samples are taken. However, the system selects appropriate internal control to obtain a quantitative value so as to obtain an amplification curve as well as the COVID-19 virus, thereby making it possible to determine whether samples have been taken properly.

Regarding accuracy control for single testing, after checking accuracy in each process, the system tests each reagent lot together with the samples for accuracy control and evaluates the test results of the samples for accuracy control.

The progress of PCR testing is controlled by means of a list to enable various types of retrieval. With regard to test results, as shown in **Fig. 4**, the measured amplification curve and Ct (Threshold Cycle) value, which represents the number of cycles where the amplification curve crosses the threshold, are output together with data on the examinees and testing so that the results can be determined to be negative or positive. Systems handling such medical information are developed in accordance with the Guidelines[1, 2] on Safety Management of Medical Information Systems provided by the Ministry of Health, Labour, and Welfare; the Ministry of Internal Affairs and Communications; and the Ministry of Economy, Trade, and Industry.

(iii) Efforts to reduce the burden shouldered by healthcare workers and to ensure healthcare workers' safety

After samples are taken and sealed in containers, healthcare workers can obtain the amplification curve as the RT-PCR test result merely by loading the containers into the automated PCR viral robot system, without

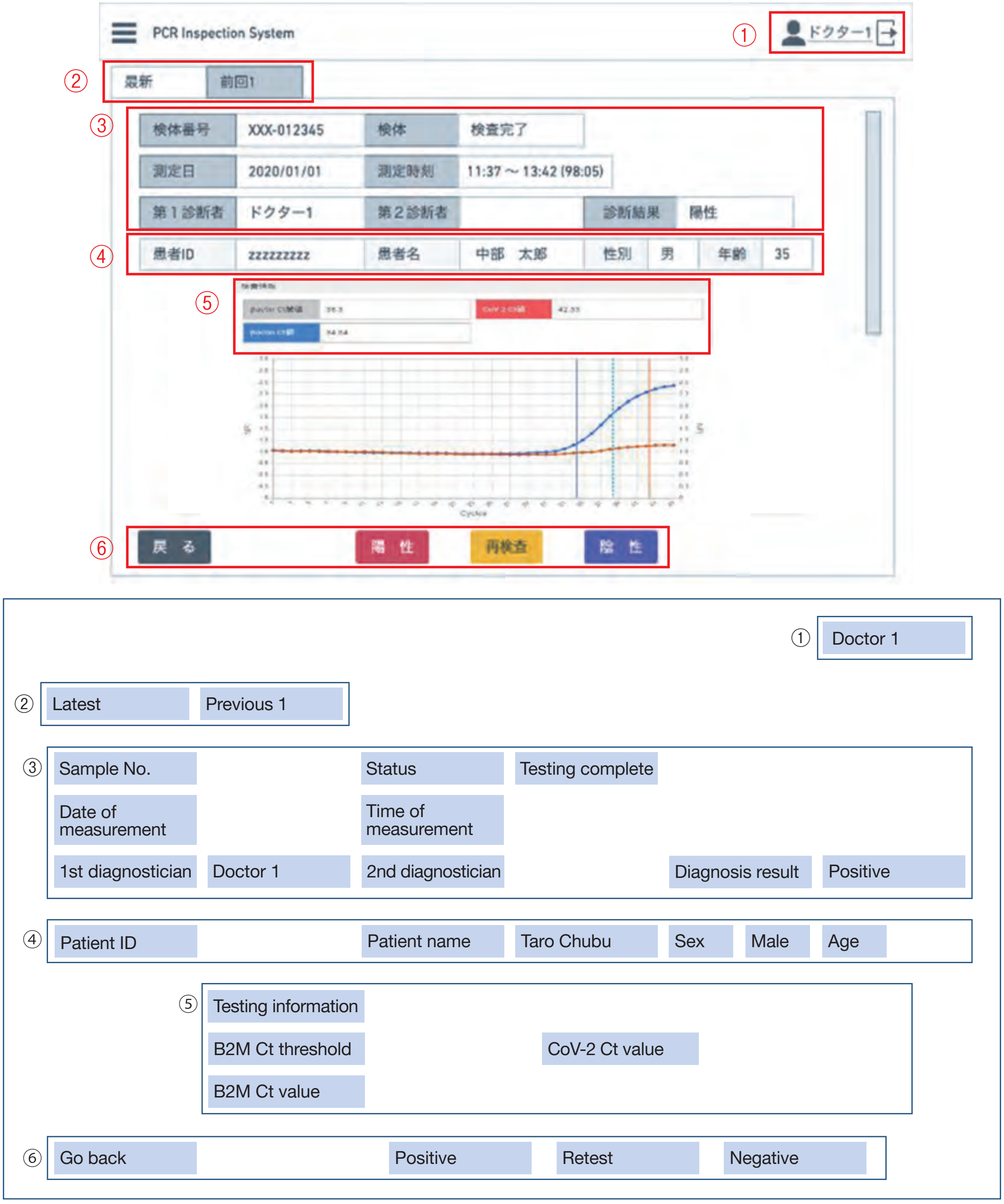

Fig. 4 Example of RT-PCR test results (amplification curve)

touching the samples. Based on the amplification curve, the Ct value is calculated, and the result is automatically determined to be negative or positive. As just described, the system eliminates the excessive burden imposed on healthcare workers and achieves quick, highly safe testing.

(iv) Efforts towards the recovery of economic activity

With regard to economic recovery accompanying the resumption in movement of people, each country is implementing various measures (e.g., vaccinations) while relaxing travel restrictions in a phased manner, and developing and implementing systems to grant permission to travel abroad to those who have undergone PCR testing and obtained a negative certificate immediately before departure. To support this system and to promote overseas travel, Kawasaki is developing a scheme to conduct medical interviews, take samples, and conduct PCR testing at airports on the day of departure, and to issue many negative certificates quickly in time for departure.

(v) Efforts for large-scale monitoring

The national and local governments are accelerating the move toward conducting monitoring surveys with periodic, large-scale PCR testing in cities, including conducting PCR testing for nursing homes and essential workers, so as to monitor the spread of COVID-19 infection.

To support this move and to offer a PCR testing environment in a prompt, timely manner wherever testing is required, Kawasaki has packaged the automated PCR viral robot system in a container, thereby facilitating road

Fig. 5 Monitoring robot system configuration

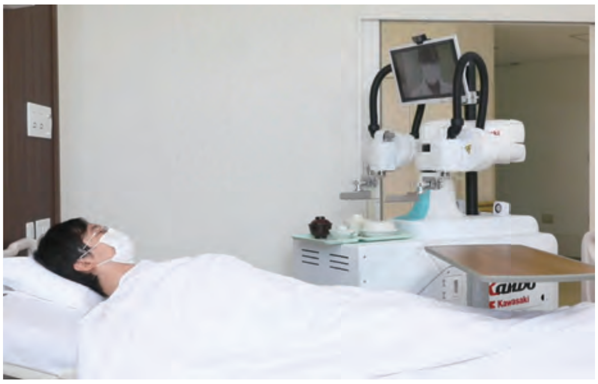

Fig. 6 Communication with infected patients

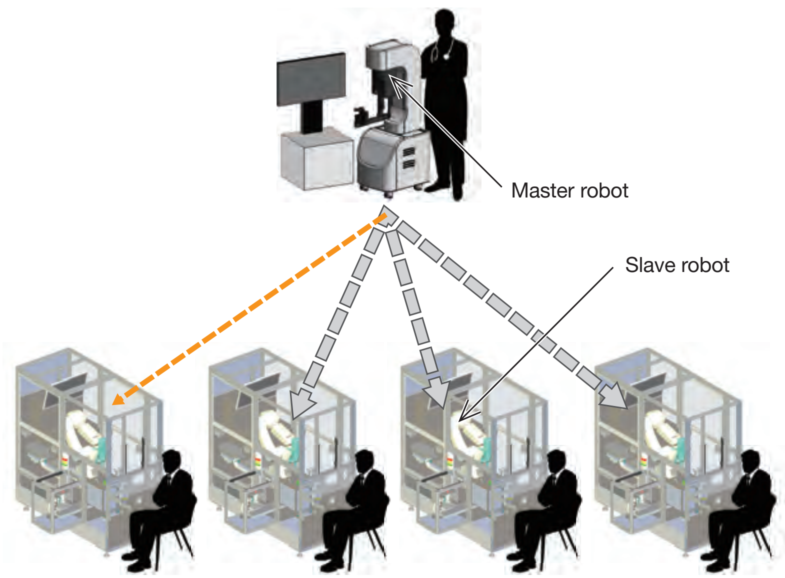

Fig. 7 Switching the connection among four slave robots

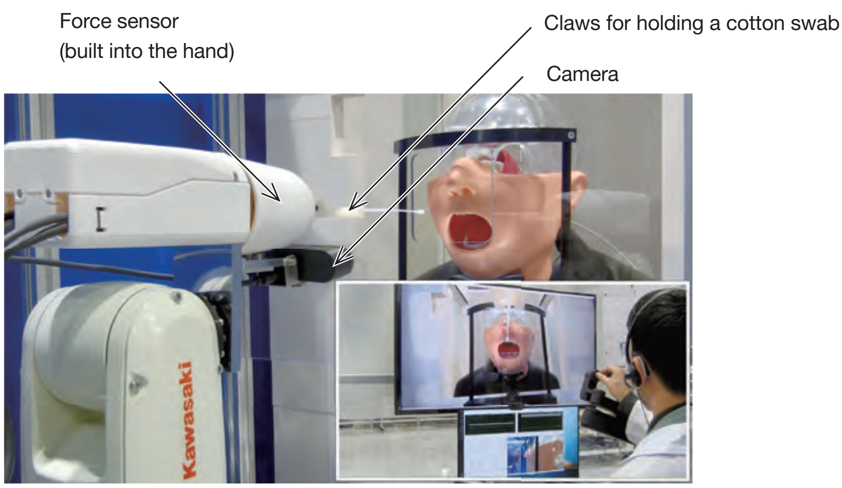

Fig. 8 Nasopharyngeal sample collection by remote control

and sea transport of the system.

Also, Kawasaki is developing systems for use before and after testing to allow examines to book PCR testing appointments, to accept examinees at testing sites, to link examinees with their samples, to match examinees and their samples with the test results in the testing system, and to notify examinees of their test results. These systems will be set up in cloud and mobile systems, and combined with mobile containers, thereby enabling larger-scale PCR testing with greater mobility than before.

(vi) Efforts to further enhance testing capacity (pooled testing)

With the RT-PCR testing system, Kawasaki is developing a system that supports pooled testing with the aim of testing a larger number of samples at once. Pooled testing is considered to be effective for dramatically increasing the number of samples tested per unit time for groups of people, most of whom are presumed to be negative for infection.

Specifically, Kawasaki is developing a process to dispense five samples into one container with a robot according to the guidelines provided by the Ministry of Health, Labour, and Welfare. Pooled testing enhances testing capacity while potentially reducing the testing cost per sample.

(2) Monitoring robot system

The monitoring robot system consists of Kawasaki's dual-arm collaborative robot duAro2 and video and audio equipment, such as monitor cameras and speakers, mounted onto an autonomous vehicle as shown in **Fig. 5**. With this configuration, the monitoring robot system can move autonomously to the specified patient room according to instructions issued by healthcare workers, open and close the room door, and offer amenities such as meals and linens.

In addition, as shown in **Fig. 6**, healthcare workers can communicate with their patients remotely from a safe location. Furthermore, the autonomous vehicle is equipped with LiDAR sensors, which detect humans and obstacles, and the vehicle incorporates safety design so that it decelerates and stops before a collision occurs.

(3) Nasopharyngeal sample collection robot system

The nasopharyngeal sample collection robot system consists of a master robot, which is operated by the sampler, and slave robots, which move in response to the master robot. As shown in **Fig. 7**, up to four slave robots can be connected. The sampler selects which slave robot to communicate with and allows them to take samples in turn. This enhances sampling cycle time.

Also, as shown in **Fig. 8**, each slave robot is outfitted with claws for holding medical cotton swabs, cameras, and force sensors built into their hands. These devices allow the sampler to take samples safely while monitoring the examinee's nasal condition and the reaction force generated on the hand when a cotton swab is inserted into the nostril.

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Conclusion

Amidst the unprecedented COVID-19 pandemic, it is required to ensure the safety of healthcare workers and to reduce the burden that healthcare workers are shouldering. Another challenge is to contribute to secure lives for people all over the world and the recovery of economic activity. To achieve these aims, Kawasaki has developed an automated PCR viral robot system, monitoring robot system, and nasopharyngeal sample collection robot system. Kawasaki will continue to work to restore society's safety and security as well as contribute to economic recovery.

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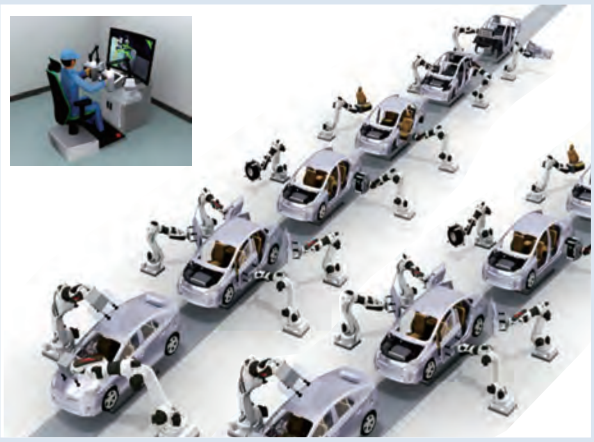
New Robot System Successor, Realizing Remote Production and Working



Labor shortages due to declining birth rates and population aging have become a social problem. In this situation, utilizing robots and increasing the rate of their introduction are necessary for economic development.

A new robot system, Successor, provides a solution that makes it possible to robotize operations for which it was previously difficult to deploy robotics, achieving manpower-saving and early automation based on its "remote instruction" and "skill succession" core technologies. Successor has been applied to painting, grinding, and assembling operations, producing good results.

Introduction

One of the social challenges Japan faces is to address the nation's workforce reduction. In addition, recent "work style reform" and prevention of COVID-19 infection have become social issues. In this context, the role of robots in society is expected to change.

1 Background

Regardless of workforce reduction, further use of robots is essential to aim for global-level economic development. However, the prevalence of robots compared to the size of the workforce reduction has largely fallen behind the target value [1)].

In fact, this trend is not limited to Japan. Robots are not sufficiently prevalent in any developed country. In other words, only a limited number of tasks have been robotized in daily living and manufacturing processes.

An increase in the types of tasks that can be robotized leads to higher prevalence of robots. Therefore, we have been developing a new robot system to robotize more tasks.

2 Concept

As primary tasks that are difficult to robotize, we focused on tasks related to small-scale production (e.g., one-off production and small-lot production) as well as tasks that require full use of human senses and skills. Successor is a strategic system that we developed to apply robotics to such tasks.

Successor consists of two core technologies, remote instruction and skill succession.

(1) Remote instruction

Conventional industrial robots are operated in two phases: teaching to teach operations, and repeating to repeat them. For robots used on mass production lines, spending time on the teaching phase is worthwhile because the repeating phase is long. However, in the case of the aforementioned tasks for small-scale production (e.g., one-off production and small-lot production), the repeating phase is short. For tasks that require full use of human senses and skills, the teaching phase is enormous. Because the ratio of the repeating period to the teaching period is small in both cases, companies have been reluctant to introduce robots for these tasks. A new manner of using robots for such tasks is remote instruction, which does not separate the teaching phase from the repeating phase.

During remote instruction, a worker in a location remote from the robot controls the robot to perform tasks by leveraging his or her skills while feeling as if he or she is on site. When operating a large robot at high speed, which is difficult with conventional coexistence collaboration robots, remote instruction makes it possible to ensure intrinsic safety, to prevent production efficiency from decreasing, and to enable the worker to work with multiple robots as shown in **Fig. 1**. This results in manpower savings.

Fig. 1 Multiple robots remotely controlled by one worker

(2) Skill succession

Though remote instruction saves manpower by, for example, freeing workers from “3D” (dirty, dangerous, and demeaning) environments, the technology cannot fully automate jobs. Another feature of Successor, skill succession, enables unmanned jobs.

Skill succession, which is shown in **Fig. 2**, is achieved through the following processes.

① Accumulate sensing data passed to the worker, and accumulate robot control data obtained through remote instruction.

② Have the robot learn the accumulated data, have the robot repeatedly carry out trials of autonomous robot operation, and have the worker perform correction operations.

③ Achieve autonomous operation by the robot alone.

Although many instances of AIs can be seen in the manufacturing industry, such AIs have learned in advance from a large amount of prepared experimental data. This means that a long preparation period is required until such an AI can be introduced on site. In addition, even after introducing the AI on site, if a failure occurs, the line must be stopped and the learning process must be repeated.

By contrast, Successor is a new type of AI robot system that performs OJL (on-the-job learning). OJL refers to repeatedly learning and carrying out actual tasks. Successor gradually increases the automation rate by supporting tasks that require human senses and skills through remote instruction, introducing the robot on site at an early stage, and learning the obtained data as shown in **Fig. 3**. Even if learning is insufficient, problems such as line shutdown can be prevented because people can assist the robot through remote instruction.

3 Usage applications

We announced Successor at International Robot Exhibition 2017, and we have subsequently developed a variety of element technologies, peripheral devices, and

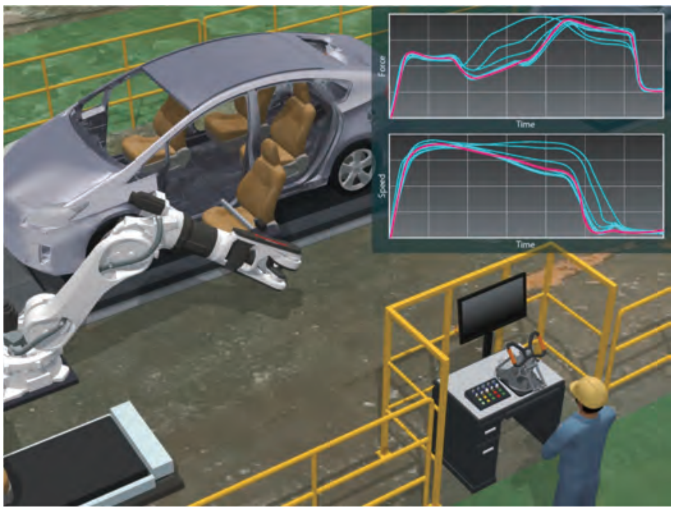
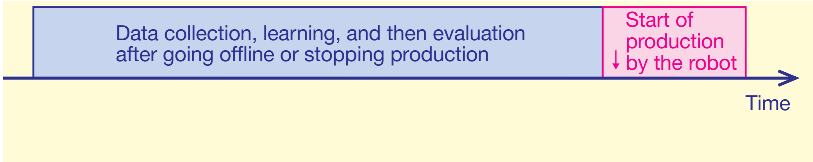
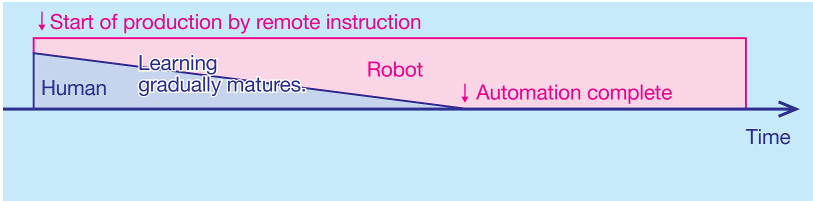


Fig. 2 Automatic control achieved through skill succession



(a) Conventional AI robot



(b) Successor

Fig. 3 Differences between conventional AI robots and Successor

application systems inside and outside the company.

(1) Painting task based on the intuitions of full body motion

Successor was put to practical use for the first time at an internal painting site. The painting task requires skills. The worker must use his or her entire body, including not only the arms but also the knees, lower back, and legs while making the most of the visual sense. In addition, this task is conducted in a typical adverse environment in which the worker must wear a protective suit that covers the entire body, suffering from bad odor and mist due to hot and humid conditions.

We introduced Successor for painting the casting and sheet-metal parts in our industrial robot mother factory. This system allows a worker outside the painting booth to comfortably complete the task, while visually checking the workpiece type and spraying conditions as shown in **Fig. 4**.

We developed Wizard, which uses VR equipment, as the controller (communicator) so as not to obstruct the intuitions of the worker, who uses his or her entire body. When the same workpiece is in process again, the worker can switch to repeated operation.

(2) Grinding task using force sense control technology

For tasks associated with contact with workpieces (e.g., assembly and machining), the force sense as well as the visual sense must be conveyed to enable the remote worker to perceive the task. In particular, although grinding is performed in an adverse environment with powder dust, vibration, noise, and hard tasks, automation has been difficult because work quality largely depends on

Fig. 4 Painting operation using Successor adapted for coating

sensations felt by the hands. Therefore, we developed Successor-G for grinding as shown in **Fig. 5**.

Successor-G is equipped with a grinding tool. This large robot also has a force sensor at the end, which conveys the force sense during the task to the remote controller so that he or she can control the robot in order to complete the task. We are also attempting to leverage 5G communication to control this system across remotely located factories.

(3) Assembly task using the AI control technology

We have been attempting to introduce Successor's skill succession technology into the assembly of multi-control valves for hydraulic equipment at our precision machine factory.

During this assembly task, "spools," which are stick-shaped parts with different lengths and shapes, are inserted into clearance holes (diameter: several micrometers) on the casing. The worker cannot visually check the contact state and must insert the spools while checking how they are inserted by the force sense in his or her hands. Such assembly requires mastery because the clearances are also small. The skill succession function achieved work performance equivalent to when a skilled worker controls the robot as shown in **Fig. 6**.

To realize autonomous operation with the skill succession function, we first performed the assembly task with work performance equivalent to that of a human by using the remote instruction function, and we had the robot learn the task from control data obtained by

Fig. 5 Grinding operation using Successor-G

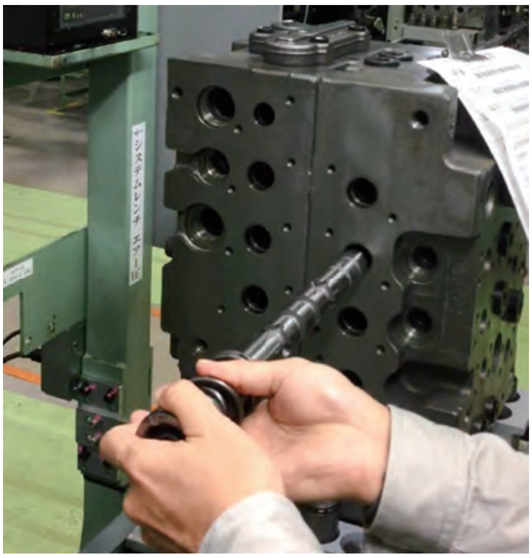


Fig. 6 Inserting a spool manually

performing several tasks. The resulting autonomous operation achieved a success rate of over 90% for insertion. If the spool is not inserted after a certain amount of time due to an unexpected incident, another worker who performs a different task switches to remote instruction mode and continues the task. Through OJL using the skill succession function shown in **Fig. 7**, the system additionally learned to take action to respond to unexpected incidents from data on the tasks that the worker took over to perform, thus improving the task

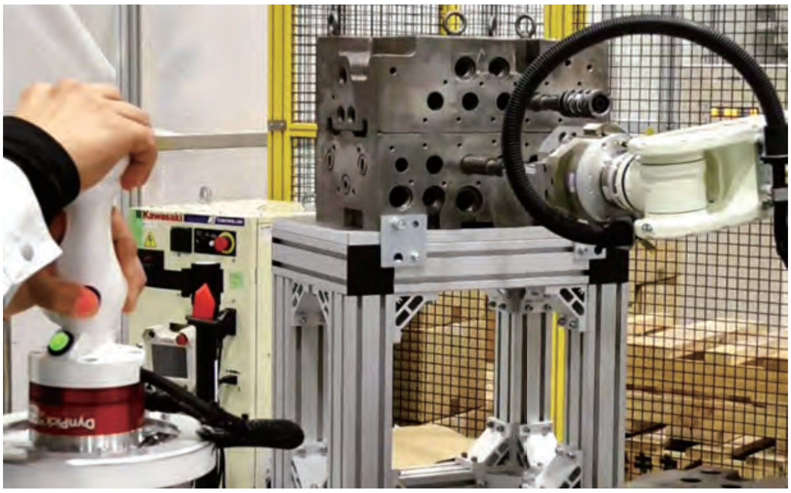


Fig. 7 On the Job Learning

Fig. 8 Image of eRoboWork

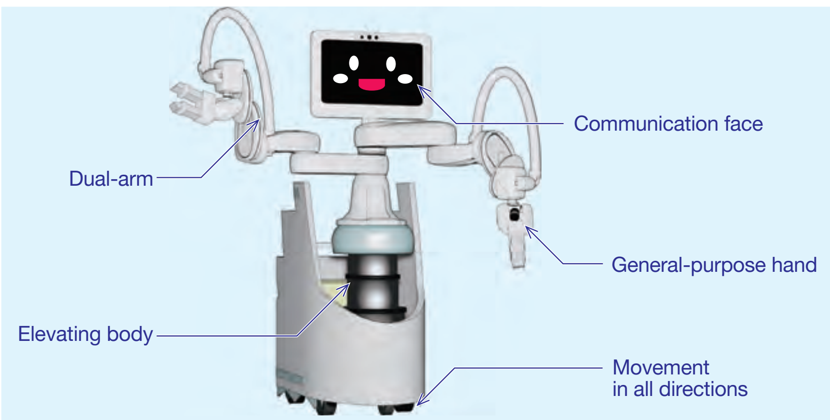


Fig. 9 Platform robot, Nyokkey

success rate to 99%.

4 Next steps for a safe and secure network society

The decrease in the working population is a serious social problem. The number of workers has continued to decrease and caused a shortage of successors, particularly for work in dangerous workplaces. The recent COVID-19 pandemic has led to broader use of remote work among office workers. Meanwhile, people who can only work on site, such as essential workers and skilled workers in manufacturing, still cannot work remotely.

We have been working to propose a new way of working by which every worker can work remotely with the remote robot technology called eRoboWork shown in **Fig. 8**. We also founded a new company with Sony Group in order to provide a platform service for this remote robot operation system. We plan to accelerate promotion of work style reform by leveraging the two parent companies' technologies. We developed Nyokkey shown in **Fig. 9** as a general-purpose robot platform to realize this eRoboWork. Nyokkey brings together: ① the technology to coexist with people from our industrial Dual-arm SCARA Robot duAro [2], ② a communication system that employs the remote control technology and AI of Successor, ③ the elevating body of life-size humanoid robot Kaleido, ④ our proprietary general-purpose hand, and ⑤ the vehicle technology of our motorcycle Ninja and off-road four-wheeler TERYX. As the control software, we have adopted unique software that is friendly to academia and startup engineers based on ROS, which is a software platform for robots, rather than industrial robot software for professionals.

Conclusion

As the working population decreases, in addition to changes in usage of robots, people's ways of working are diversifying, which requires new work styles.

Meanwhile, industrial robots have freed people from adverse environments and simple repeated tasks under limited conditions—namely, mass production in the manufacturing industry. In the future, people will be freed from conventional work styles as robot systems that enable remote work provide job opportunities to people regardless of work conditions, such as their physical abilities and places of residence.

The new era requires a social system in which people assist and train robots as well as coexist and prosper with such robots. Successor and eRoboWork enable you to achieve these goals.

We will realize these systems and put them into practical use to achieve a safe and secure network society for people around the world.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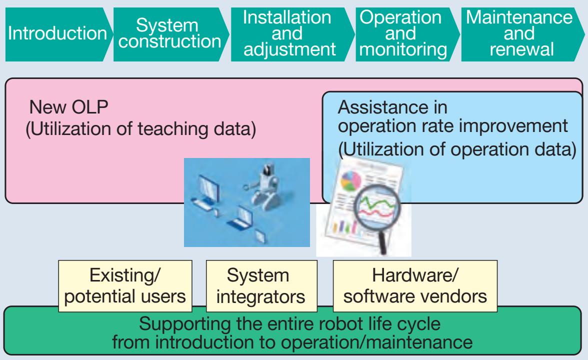
New Comprehensive Services That Cover the Life Cycle of Industrial Robots



Market demands for automation in various fields are emerging due to the shortage of workers derived from the declining birth rate and rapidly aging population. However, the implementation of automation in society cannot be realized as soon as is being expected. This is because experts in operating machinery such as robots cannot be allocated as required. Therefore, Kawasaki focuses on developing a service platform that comprehensively supports the various phases of the robot life cycle.

Introduction

As the shortage of workers becomes a social problem caused by the declining birth rate and rapidly aging population, there is a growing need to utilize robots as a solution to this problem.

1 Background

The scope of usage of industrial robots has been expanded from conventional areas of operation such as welding, coating and transportation to assembly and inspection. On top of that, they have been introduced in small and mid-sized firms—as opposed to just leading companies—and there has been an increasing number of situations where robot engineers' support is required. As a solution to such circumstances, services that support robots' utilization from examination of feasibility to maintenance are required [1].

2 Concept of services

The following describes challenges we face and services we propose for the examination of the feasibility of introducing robots and for robot operation.

(1) Service to support the examination of the feasibility of introducing robots

(i) Current situation and challenges

To automate production processes, many different things need to be examined not the least of which is the analysis of manual operations to figure out how to replace such work with robots, how to arrange peripheral equipment, and whether the operation can be completed in a reasonable amount of time, and these examinations are carried out by system integrators (SIs) in many cases. However, the number of companies that offer these services is small compared with the needs of automation these days, so it is difficult to accelerate the spread of automation with robots.

One of the tools that SIs use when examining the feasibility of using robots is Off-Line Programming (OLP). This is a tool to create a robot operation program in a virtual space using 3-dimensional data. It makes it possible to verify the robot layout and cycle time and programs can be uploaded for use in actual robots. However, OLP often cannot verify synchronization with peripheral equipment. In addition, it can only be used for the initial rough examination as various changes are made at the stage of fabrication of actual robots. It takes time to create a robot operation program and examine the motion path, and its performance varies depending on the person's skill level. Functions for sensing, force sense control and other skills need to be incorporated into OLP, especially when seeking to execute a complicated operation such as assembly with a robot, so it takes longer to design and create an operation program in such cases.

(ii) Overview

We will provide the following service for OLP to help examine the feasibility of the introduction of robots in an efficient manner:

- Function to synchronize with peripheral equipment by using and sharing data with software made by a third party.

- Library of operation programs for sensing, force sense control and other skills using arms and other existing peripheral equipment
- Function to automatically create an optimal motion path
- Environment where data is shared in different locations such as at an office and a site where an information system is introduced or between an SI and user

The service is provided on a cloud server on which contents are continuously added/improved and are always up-to-date. The cloud server is accessed by members of our marketing and engineering-related departments as well as SIs so that a variety of support will be provided in an efficient manner. When a lot of data is accumulated on the cloud, users can share know-how and the introduction of robots will become easier. It may also be possible to develop more useful new functions by analyzing the accumulated data. Furthermore, we are considering partial replacement of know-how on the introduction of robots with AI.

These functions will not be developed only by Kawasaki. We will provide a platform for Robot as a Service, in which functions developed by third parties can also be introduced as content as shown in **Fig. 1**, so that the platform will become a marketplace in which various stakeholders can participate.

(2) Service to support robot operation

(i) Current situation and challenges

As part of our service after the introduction of robots, we monitor the data of robots in operation and predict when failures might occur to prevent unexpected system stops.

Even if the robots do not fail, there are some cases in which robots' operational efficiency cannot be maintained due to the occurrence of operational conditions that are different from those covered in prior verifications, but it is just as big a problem for users as a failure. The lowering of robots' operational efficiency is caused by the timing of synchronization with peripheral equipment, variations in workpieces, incorrect supply of workpieces and various other factors, and it is not something that can be solved by the user alone in many cases. However, it would be too inefficient for an SI to conduct an analysis on-site every time a problem occurs, yet without a solution users will not be able to introduce or operate a robot system without any worries.

(ii) Overview

We will provide the service shown in **Fig. 2** to support the efficient operation of robots:

- Tool to acquire data from peripheral equipment as well as robots to visualize operating conditions
- Tool to analyze acquired data remotely to identify factors causing low operation rates and provide

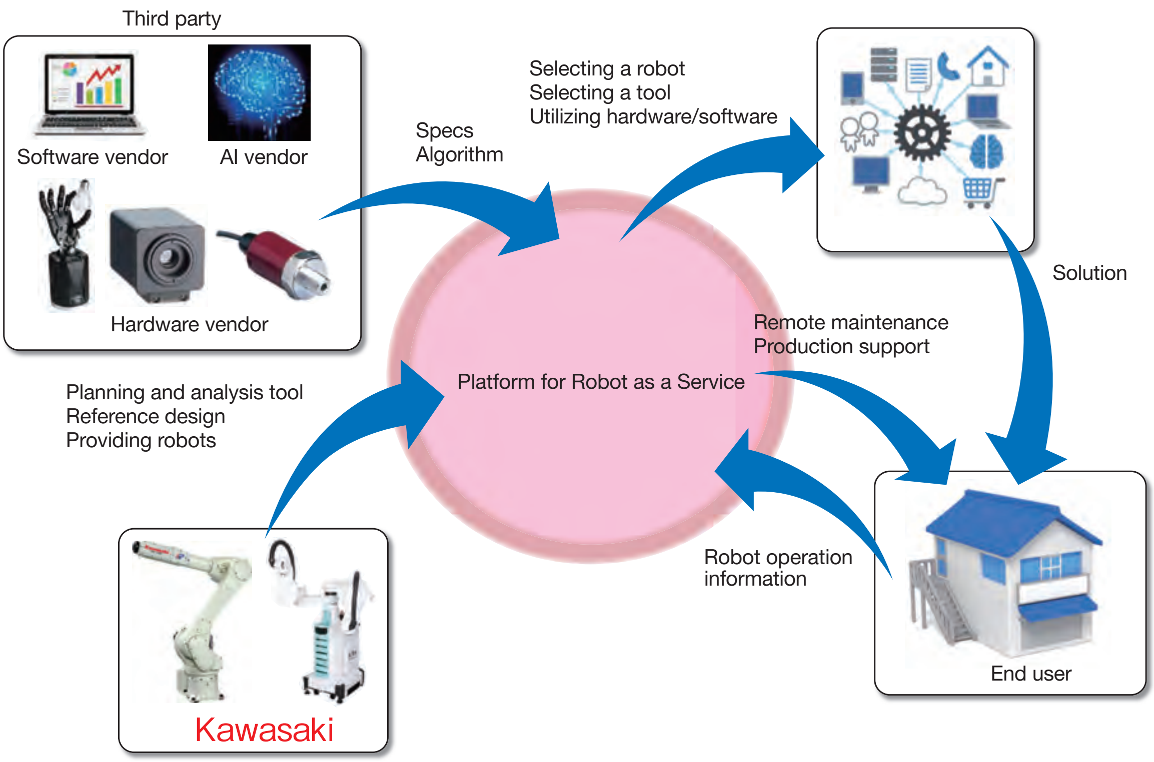


Fig. 1 Concept of the platform for Robot as a Service

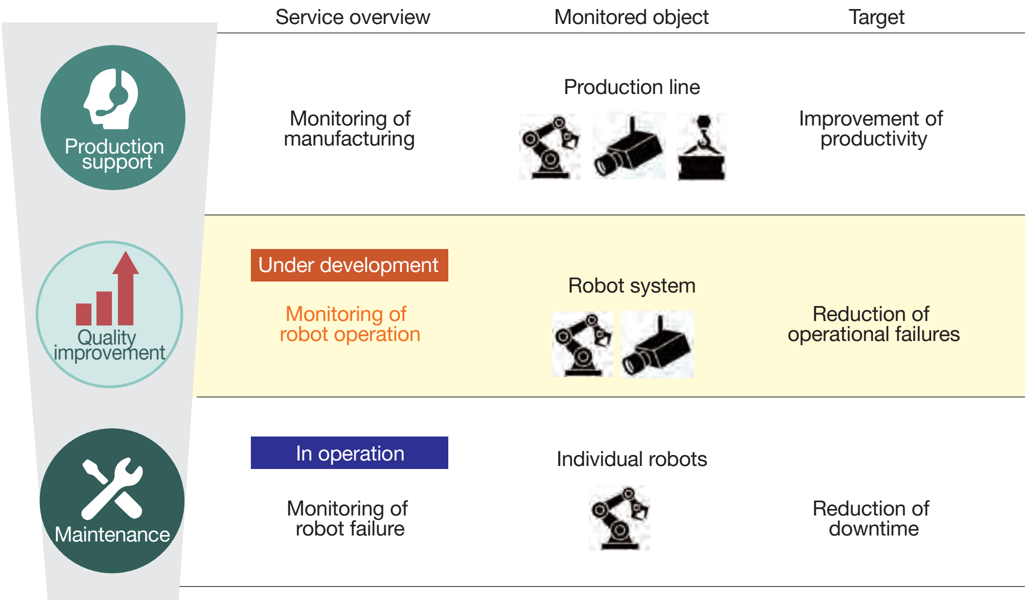


Fig. 2 Support layers for robot operation

information to improve operation

- Environment where operating conditions are identified remotely by sharing OLP data and data acquired on-site to introduce improvement programs remotely

The analysis of acquired data will be performed manually at first, then learned by AI and ultimately automated as a goal for the future. The acquired data will be synchronized with monitoring of operations throughout a factory, and various other functions will be added according to the user's wishes. Just like the aforementioned OLP, we will provide a platform for Robot as a Service, in which acquired data is accumulated, and functions developed by a third party can also be introduced as content as shown in **Fig. 1**, to create an environment where continuous progress can be made.

3 Technical challenges

We are facing the technical challenges described below when executing the services described in section 2.

① Ensuring information security

Data containing a lot of know-how that can be assessed and utilized by SIs and vendors will make it possible to accelerate the development of functions and expand the scope of robot usage. However, the platform requires a system to ensure security without giving up usability because the data may include confidential customer information and technical information.

② Synchronization of robots with a virtual environment

The robots in a production site must always be synchronized with the virtual environment in OLP so that OLP can be utilized for the examination of the feasibility of introducing robots and remote monitoring. Therefore, it is necessary to develop functions such as those for creating 3-dimensional data easily, for environmental sensing and for importing the information of peripheral equipment.

③ Improvement of OLP's operability

While OLP will be more and more useful as various functions are added, operation will become difficult due to the complicated functions. Therefore, operability must be improved in line with the improvement of functions.

④ Using both cloud and edge computing

The variety of data and functional content accumulated on a cloud server may generate new value. On the other hand, it is necessary to consider that server capacity affects service costs and that communication speed affects usability. Instead of storing all the content on a cloud server, data processing must also be performed on edge computers to create a balanced system configuration.

⑤ Data selection and analysis

In order to provide services that are really useful to users, it is necessary to select the data to be acquired and examine a data analysis method. In addition, information needs to be provided in an appropriate manner.

4 Activities

(1) OLP development

Functions that support teaching are required, including a function to perform high-speed and high-precision simulation for larger 3-dimensional environmental data and one to automatically create a program for the complicated shape of a workpiece to respond to the needs of automation in various kinds of fields.

Kawasaki has K-ROSET, a robot simulator that can simulate robot motion with high precision. K-ROSET has functions that are equivalent to those of robot controllers and it is used in prior verifications to check the motion and cycle time of a robot program. We also have KCONG, a teaching support tool that uses CAD geometry information. KCONG makes it possible to create a teaching point along a ridge line based on the shape of a workpiece. It also has a function to automatically create an operation program that covers the database of operating conditions [2].

By utilizing these types of software, Kawasaki is developing next-generation OLP which integrates K-ROSET and KCONG as shown in **Fig. 3**. In order to realize the concept described in section 2 based on the software, we will develop a new function using a cloud server and another function to solve the challenges of ① to ③ described in section 3.

We are also verifying the service using a cloud service in parallel with the development of the next-generation OLP software. Specifically, we are verifying whether the various services proposed in section 2 can actually be provided in collaboration with several SIs. This will lead to the early provision of services by identifying not only technical issues, but also operational challenges in data sharing such as the handling of intellectual properties.

(2) Development of a system for data acquisition and analysis

For the verification of solutions for the challenges in ④ and ⑤ of section 3 and for the small start of internal productivity improvement, Kawasaki is acquiring and analyzing operational data to improve the rate of operational success and visualizing the operational quality.

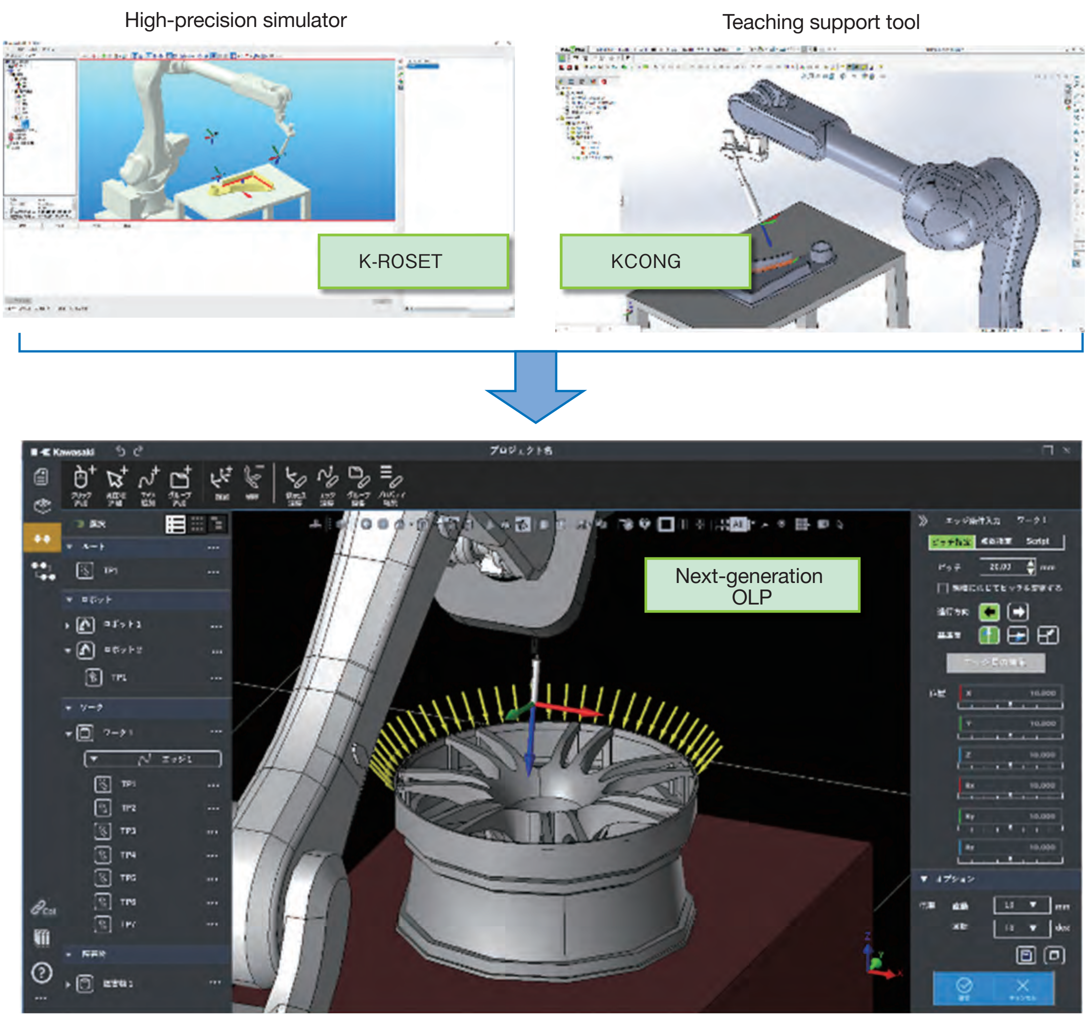


Fig. 3 Image of the next-generation OLP software under development

(i) Overview of the system

As shown in **Fig. 4**, the data acquisition and analysis system consists of edge computers which acquire data and perform primary processing on-site, the cloud which accumulates and analyzes data, and the data communication network which connects edge and cloud computing platforms.

In the edge computers, primary processing is performed for robot operation data, camera images and other peripheral equipment data such as the extraction of operational information and image processing to create data to be transferred to the cloud.

The data transferred to the cloud is stored in a chronological database which is accessed by an analysis application on the cloud to perform analysis of factors that caused operational failures and other processing. The analysis results and operational information are displayed on a mobile device such as a tablet as a dashboard as shown in **Fig. 5**. These sorts of information will enable production sites to take concrete steps to enhance robot operation for the maintenance and improvement of productivity.

(ii) Analysis of acquired data

The analysis application is the killer content of this system as the performance of data analysis has a significant impact on the robot user's productivity.

We are now focusing on the development of an analysis application to visualize the causes of robots' operational failures, which is directly related to the user's productivity, while the content will be increased one piece

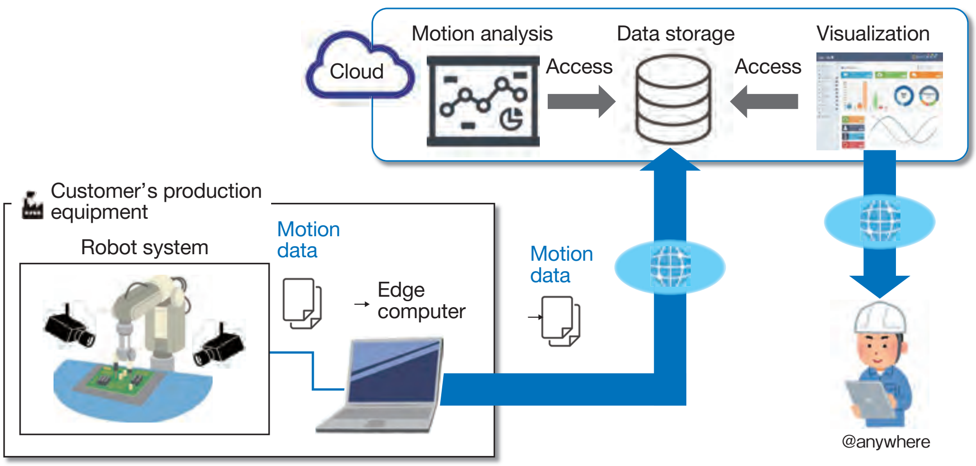


Fig. 4 System overview for data acquisition and analysis

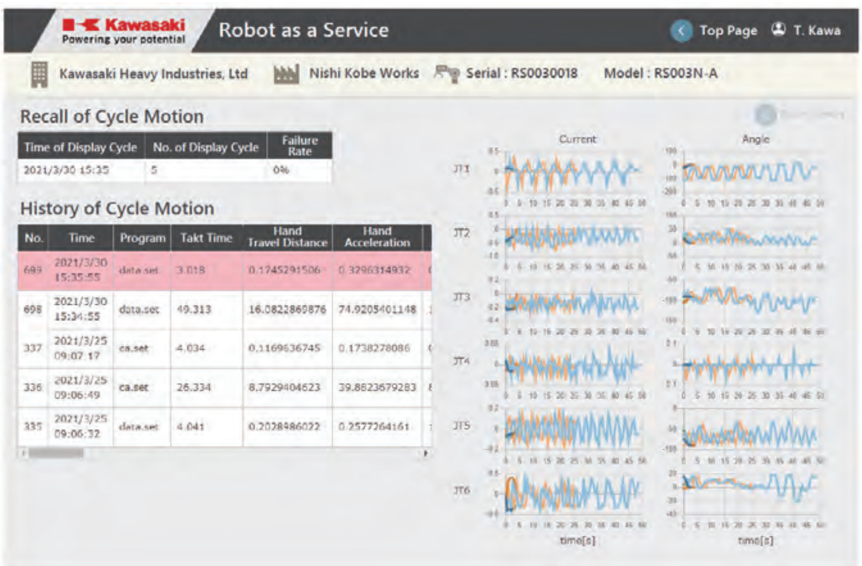


Fig. 5 Example of monitoring system

after another.

Failures in robot operation are often caused by a combination of various factors. This makes it difficult to identify the causes of robots' operational failures because individual monitoring of robots, tools and workpieces identifies no problems in many cases. Therefore, we will apply multimodal analysis [3, 4] in which several types of information are analyzed in order to judge abnormalities with high precision.

Kawasaki is now working on correlation analysis to extract combinations of changes in data that occur when a robot fails. The analysis results will enable us to identify data to be used in multimodal analysis for the development of an analysis application to identify factors causing operational failure.

Conclusion

Kawasaki is working on services to support the use of robots as a solution to the shortage of workers.

After providing such services, it is important to continuously improve functions by strengthening contact with users and collect more data. We will also analyze collected data to understand market needs, for technological development and the development of robots. Furthermore, OLP will be used as a tool to collaborate with other companies to accelerate open innovation.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Autonomous Off-road Vehicles Enable Automation and Labor-savings of Human and Material Transportation

As an effort to solve social issues, such as a decreasing labor force due to an aging society and natural disasters, we are developing autonomous vehicles with the aim of achieving automation and reducing labor.

We have demonstrated element technologies that allow such vehicles to drive autonomously, not only on paved roads, but also on uneven surfaces in mountains and other areas. Also, we have developed a unique optimal autonomous driving logic that takes into account road surface roughness, turning radius and other such conditions and verified its advantages with actual vehicles.

Introduction

In order to cope with the decreasing labor force due to an aging society and natural disasters, autonomous vehicles are needed with the aim of realizing automation and reducing labor.

1 Background

Although autonomous vehicles have been researched and developed targeting paved roads, automation and labor-saving may come to be in demand in the near future to transport people and goods on unpaved roads and uneven surfaces in mountains and other areas.

We are selling the multipurpose off-road vehicle MULE series, which are mainly used on large farms and factories in North America for travel and transportation. They are popular because of the excellent running performance that makes it possible for the vehicles to travel on unpaved roads and mountains, and also the strength of the vehicles themselves. Currently, the movement of people is restricted due to natural disasters and the pandemics, and efforts to realize autonomous operations have been accelerated mainly in the distribution sector.

2 Autonomous off-road vehicles

Despite the impact of the COVID-19 disaster, the multipurpose off-road vehicle market has been expanding and various manufacturers have been introducing new features, bringing about intense competition in the market. In addition, there are new demands for automation and labor-saving of operations to be performed using multipurpose off-road vehicles like the MULE from the viewpoint of cost reduction.

Therefore, we determined to develop autonomous vehicles with the simplest system configuration possible that can automate simple operations and transportation and that can reduce the labor required for such tasks. Specifically, using MULE PRO-FX [1)] as the base, we started developing an autonomous driving technology specific to driving on unpaved roads while drawing on the excellent running performance, strength, and load capacity of the MULE PRO-FX.

3 Development policy

(1) Product concept

Market research on MULE users has revealed that, as shown in **Fig. 1**, they are used for wide variety of applications mainly on farms and ranches, the main use being repetitive routine work such as material transportation and patrols.

Based on this finding, we added a new autonomous driving function to the mass-produced model to allow users to select autonomous driving, remote control, and

(a) For farms and ranches

(b) Transportation of workers

(c) For leisure

(d) For hunting

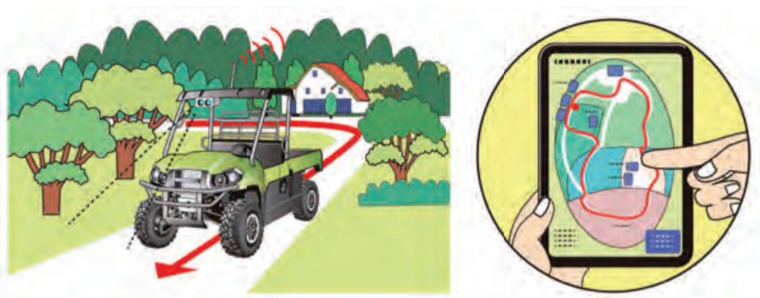
Fig. 1 Overview of market research (MULE users)

manual control depending on the situation. We will allow customers to experience the autonomous driving function based on the mass-produced model and will improve the vehicle with the feedback received from them.

We also aim to provide vehicle platforms specific to unattended operation through communications with users while retaining the excellent running performance, strength, and load capacity of the MULE.

(2) Use cases

For labor saving and automation of routine work carried out at farms and ranches, we came up with use cases based on actual operations. Examples of use cases are shown in **Fig. 2**. A user uses a tablet or other device to enter the driving route and the vehicle automatically travels at low speed along the specified route, or a user records the route by manually driving the vehicle at the start of



(a) Driving along the route specified using a tablet

(b) Driving based on changes in the road surface environment

(c) Detection and avoidance of obstacles

Fig. 2 Examples of use cases

work and the route is used as the specified driving route.

Because the MULE is used on unpaved roads, the vehicle speed needs to be controlled based on changes in the road surface and obstacles need to be detected and avoided in autonomous driving as well.

4 Technical tasks

This section shows technical tasks to be achieved to allow vehicles to travel safely on unpaved roads along specified routes.

(1) Autonomous driving under rough road conditions

In an autonomous driving system of a vehicle that travels on a general paved road, as shown in **Fig. 3**, based on the output from a camera, radar, and LiDAR sensor, the system recognizes the track conditions including the road structure and traffic participants, such as pedestrians and vehicles. The system also uses a self-localization function to recognize the position of the vehicle itself on the map using the Global Navigation Satellite System (GNSS), map data, and camera. The risk forecasting function uses the recognized information to forecast the behavior of the traffic participants in the future, their intentions, and possible risks. Based on the information that these higher-level functions have recognized or forecasted, the behavior planning function determines the driving path and speed so as to realize safe and smooth driving. Then the vehicle control function determines the driving force (power train), braking force (brake), and steering input (steering).

On the other hand, when driving in an off-road environment, environment recognition sensors, such as LiDAR and camera, may not work properly due to mud spattering on them or vibration during driving. Therefore, a vehicle control method that does not rely on environment recognition sensors is required, which is also necessary in order to have a redundant autonomous driving system.

(2) Route tracking for an actual vehicle

In the assumed use cases, the roads are uneven and the road surface environments also change successively. The load conditions of vehicles also vary. There is a risk of the loaded goods falling or the vehicle toppling during autonomous driving. Accordingly, under the aforementioned road conditions, whether a vehicle can travel with the conventional GNSS-based route tracking function needs to be examined in driving simulation and driving tests using an actual vehicle.

5 Development of elemental technologies

For the task of autonomous driving under rough road conditions described in “Technical tasks,” we constructed logic to estimate rough road conditions based on vehicle behavior. Speed planning logic that does not rely on environment recognition sensors and that enables safe and efficient driving on rough roads was constructed as follows.

- Estimate the roughness of the road surface of the route based on the vehicle behavior during the first drive.
- Determine the speed limit based on the roughness of the road surface and turning radius.
- Maximize the acceleration and deceleration within the friction circle of the tire force.

(1) Estimation of the roughness of road surfaces

In order to estimate the roughness of a road surface from vehicle behavior during driving, measurement items that are strongly correlated with the roughness of a road surface, such as acceleration of the vehicle body, vehicle speed, and suspension stroke, need to be used.

We decided to use vehicle speed and acceleration of the vehicle body for estimation as they are easy to measure. In actual service conditions, the loading conditions change each trip and such changes affect the

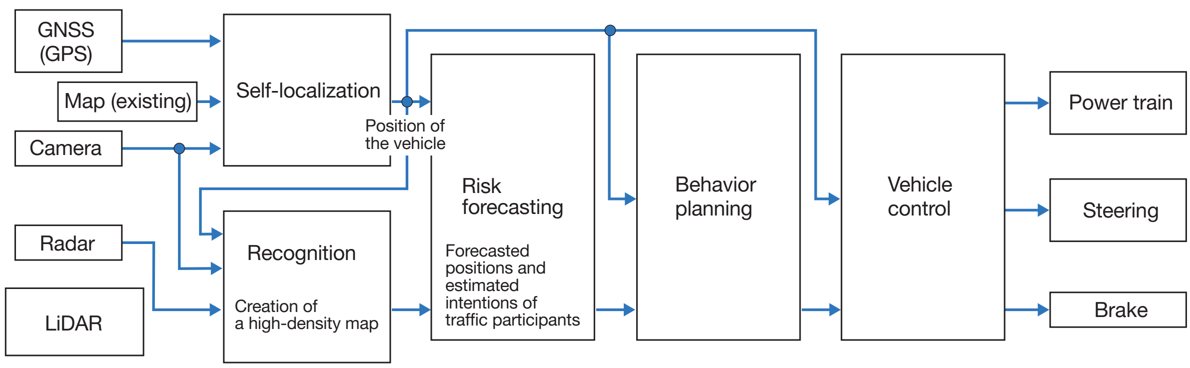


Fig. 3 Concept of autonomous driving system

acceleration of the vehicle body. Therefore, the influence from varied live loads also needs to be considered.

In order to examine whether the roughness of a road surface can be estimated when the vehicle speed, acceleration, and loading conditions are known, we used the three road surfaces each with a different roughness shown in **Fig. 4** to simulate driving at a supposed vehicle speed. As a general method to understand the degree of projections and depressions on a road surface and frequency components, power spectral density (PSD) is used. Therefore, the roughness of each road surface was organized with PSD. **Figure 5** shows the relationship between the vehicle speed and the acceleration of the vehicle body for each road surface obtained in the simulation. When the vehicle speed, spring vertical acceleration RMS, and loading conditions are known, the roughness of the road surface can be estimated.

(2) Vehicle speed control considering the roughness of road surfaces and turning radii

Based on the information on the roughness of road surfaces acquired in the aforementioned examination and set route information, we determined a speed limit that served as an indicator of vehicle speed control under rough road conditions. We assumed that the speed limit was inversely proportional to the roughness of a road surface, and so the estimated value when a vehicle traveled at 10 km/h was used for calculation as a typical value of the roughness of road surfaces. In addition, when a vehicle goes around a curve with a small radius of curvature, lateral acceleration is generated to prevent the loaded goods from falling. The speed limit was determined such that the lateral acceleration would not go above a preset value.

(3) Acceleration and deceleration considering the friction circle of tire force

Due to the characteristics of tires, a tire can produce force only within the friction circle. That is to say, when a vehicle is traveling on a rough road and thereby the friction circle itself is small or a transverse force is generated during turning, the longitudinal force that can be generated

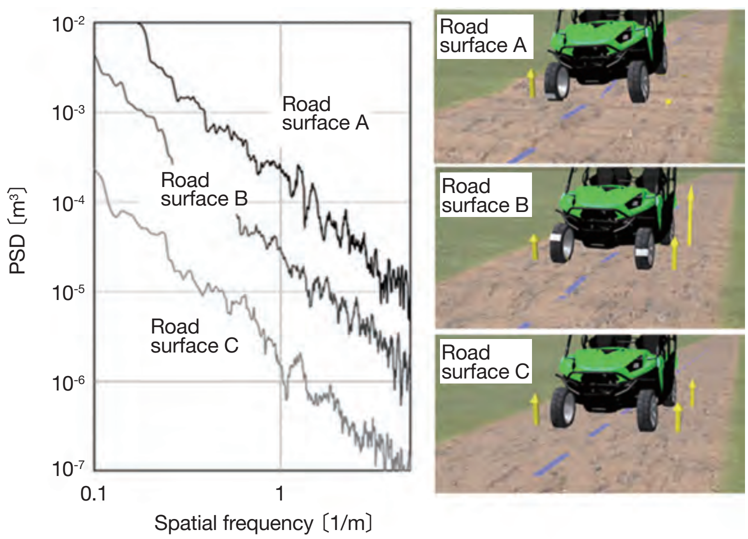


Fig. 4 Roughness of the road surfaces used for simulation

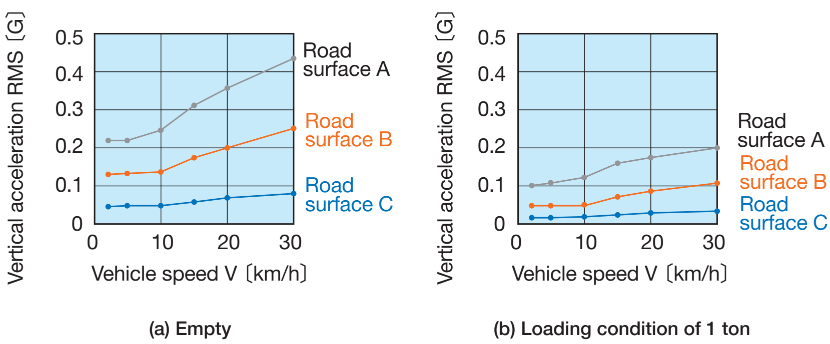


Fig. 5 Relationship between vehicle speed and vertical acceleration

is smaller. We considered this fact to determine the speed limit such that the longitudinal acceleration would be less than or equal to the upper limit.

6 Driving tests

To examine the route tracking of an actual-size vehicle as described in "Technical tasks," we modified the MULE PRO-FX (base) to develop a prototype vehicle and used the vehicle to test driving under flat and uneven rough road conditions [2].

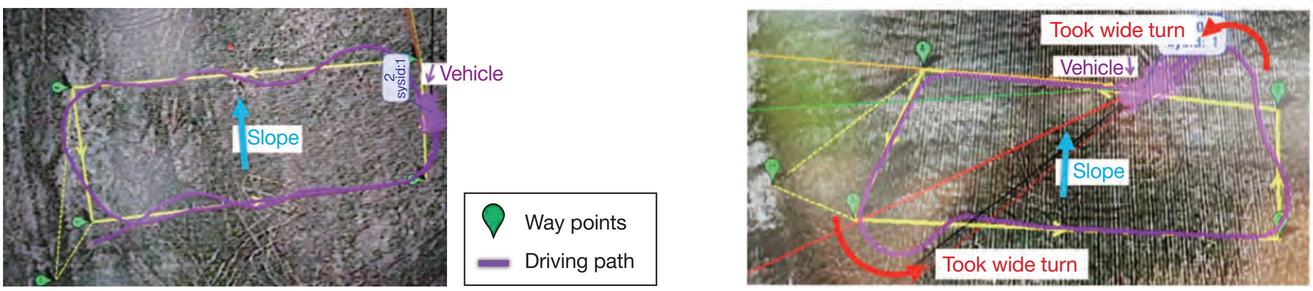
(1) Driving test on a flat road

In order to adjust the autonomous driving parameters for an actual-size vehicle, a driving test was performed on a flat road. As shown in **Fig. 6**, way points were provided and the maximum speed was 10 km/h. The test showed that the vehicle can travel a square track and figure-eight track with good accuracy. In addition, assuming a use case involving remote control, driving by radio control operation was also checked.

(a) Driving situation

(b) Driving route

Fig. 6 Self-driving test on a flat road



(a) Maximum speed 10 km/h

(b) Maximum speed 15 km/h

(c) Slope

Fig. 7 Self-driving test on an uneven surface

(2) Driving test under uneven rough road conditions

The results of the driving test on an uneven road surface are shown below. In the test shown in **Fig. 7**, way points were provided in advance in a figure-eight track and a route tracking driving test using GNSS was performed.

Figure 7 (a) shows the driving path in the square circuit track when the maximum speed was 10 km/h and **Fig. 7 (b)** shows it when the maximum speed was 15 km/h. The test has confirmed that at a maximum speed of 10 km/h, the vehicle can travel with good accuracy. On the other hand, the test with the higher maximum speed shows that the vehicle took a wide turn at corners and thereby the accuracy of the route tracking decreased. As described above, the test revealed a problem with the route tracking during turning due to the influence of the inertia of the vehicle although such a problem was not observed in the test on the flat road. In the future, it is necessary to take measures in terms of hardware such as vehicle control, throttle, and brakes.

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Conclusion

As an effort to overcome social issues such as a decreasing labor force and natural disasters we are developing autonomous vehicles with the aim of achieving automation and reducing labor.

The basic technologies have been developed and we will start demonstration experiments as the next stage in cooperation with local governments in Japan. Specifically, autonomous vehicles will be used on farms and forest roads to perform actual operations in demonstration experiments to check the performance and convenience. We will construct an optimum system and aim at putting the new product onto the market promptly through communications with the market including local users.

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Unmanned Logistics System Using New Mobility Technologies

To solve social challenges such as labor shortages and the increasing number of parcels handled by the logistics industry, Kawasaki is working on new unmanned logistics solutions that combine air and land transport equipment with robotics technologies. To achieve it, Kawasaki is developing delivery robots, multi-purpose unmanned ground vehicles (UGV), and unmanned vertical take-off and landing (VTOL) aircraft.

Introduction

In the logistics industry, social challenges such as labor shortages, traffic congestion in urban areas, transport to rural areas, and an increasing number of parcels due to the rapid growth of electronic commerce have been becoming increasingly obvious recently. If logistics, which is essential as social infrastructure, does not function well, our lives become less convenient, and moreover, economic activity stagnates.

1 Background

A serious labor shortage presents a fundamental social challenge for the logistics industry. To address this, the government has suggested logistics DX and logistics standardization in its "Comprehensive Logistics Policy Outline for the 2020s [1]."

Logistics DX refers to the act of updating the conventional form of logistics through mechanization and digitalization. Mechanization refers to the act of automating human-intensive transport and warehousing work with machinery (automation or labor savings). Digitalization includes computerization of procedures and streamlining of operations through the use of matching systems and AI. Standardization of logistics is as important an effort as logistics DX.

To contribute to solving the logistics challenges that society faces, Kawasaki is developing technologies that offer new solutions with the primary aim of contributing to automation and autonomy in logistics DX.

2 Solution concept

To solve the logistics challenges that society faces, Kawasaki aims to offer unmanned cargo transport and transshipping without human intervention, by combining its robotics, mobility, and aviation technologies shown in **Fig. 1**, and seamless, unmanned logistics solutions as shown in **Fig. 2**.

Long-term, Kawasaki aims to achieve carbon-neutral transport by combining its energy and environmental solutions, looking ahead to solving not only logistics challenges but also the decarbonization challenges that society faces.

At present, as means of transport and of delivery in seamless logistics solutions, Kawasaki is developing delivery robots (shown in **Fig. 3 (a)**) as well as multi-purpose unmanned ground vehicles (UGVs) and unmanned vertical take-off and landing (VTOL) aircraft (shown in **Fig. 3 (b)**).

(1) Delivery robots

Kawasaki is developing robots that can not only deliver packages but also hand over and receive packages as well as perform light-duty work. This development combines the size and weight reduction technologies and suspension systems offering high running-through performance that Kawasaki has developed for motorcycles as well as the arm control and surrounding environment recognition technologies that Kawasaki has developed for robots. In addition to the logistics field, the company aims to apply these robots to other fields such as the manufacturing field as well as the medical and nursing care fields.

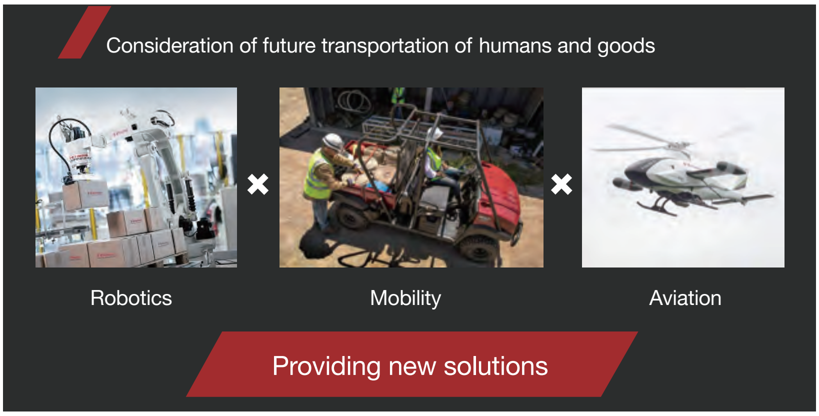


Fig. 1 Combination of Kawasaki’s technologies that transform transportation of humans and goods

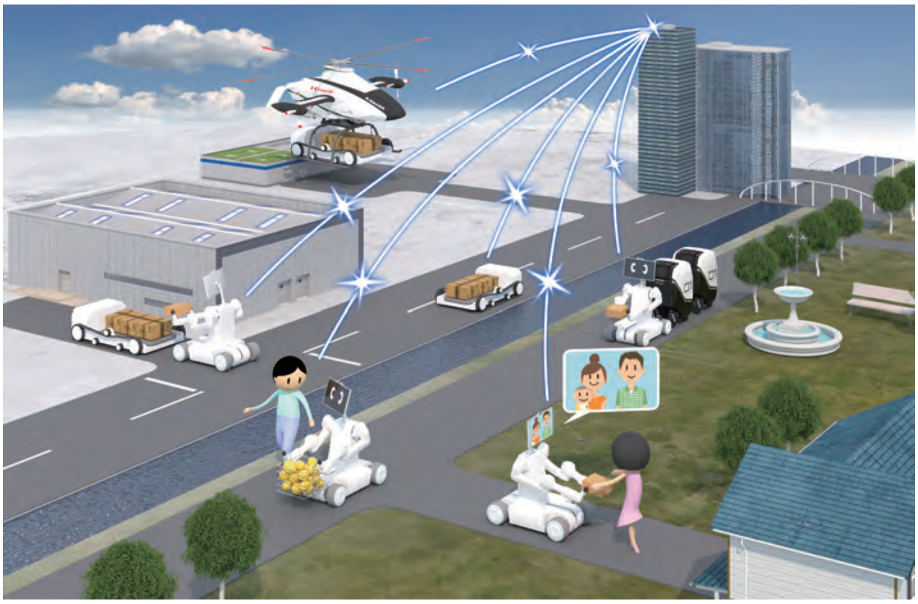
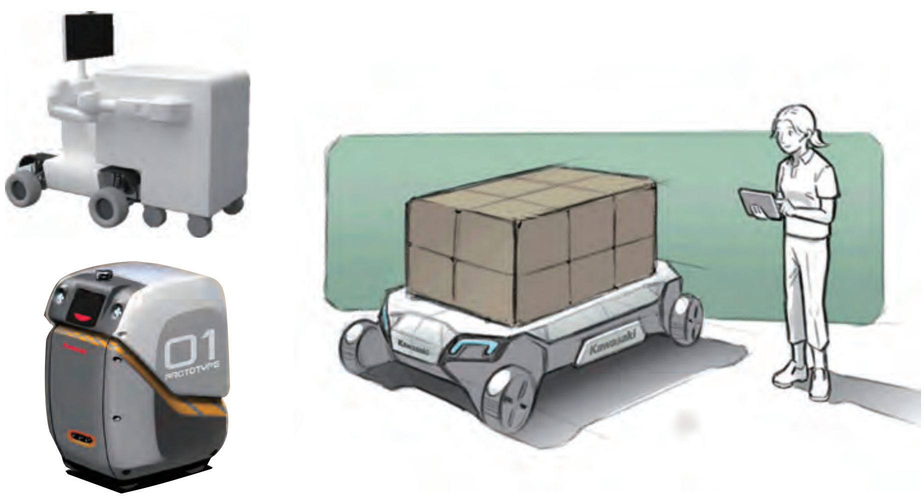


Fig. 2 Concept of a seamless logistics solution



(a) Delivery robot

(b) Multi-purpose UGV

Fig. 3 Delivery robot and multi-purpose UGV

Fig. 4 Demonstration test on a factory road of the first prototype on a factory road

As of June 2021, Kawasaki has conducted autonomous driving tests as a technological demonstration, with the first prototype (shown in **Fig. 4**) driving along the factory roads at its Akashi Works, and the company has obtained satisfactory results. Also, Kawasaki plans to conduct technological demonstrations on public roads with its partner companies in late 2021.

(2) Multi-purpose UGVs

Kawasaki is developing UGVs for logistics based on its technologies for off-road four-wheelers. These UGVs are differentiated by their high running-through performance, which is based on Kawasaki's off-road technologies, and in addition to somewhat uneven roads, the UGVs can also run on the rough roads seen, for example, at construction sites. The running-through performance can be adjusted according to the application. Looking ahead to decarbonization in the future, Kawasaki is also working to electrify these vehicles.

(3) Unmanned VTOL aircraft

Kawasaki has developed helicopter technologies and high-power small engine technologies for motorcycles. By combining these technologies, Kawasaki is developing unmanned VTOL aircraft with the aim of achieving a 200-kg payload, which cannot be achieved with common unmanned aircraft (e.g., drones). In the future, the VTOL aircraft will also be equipped with carbon-neutral power units.

The following describes the development of the unmanned VTOL aircraft.

3 Unmanned VTOL aircraft

(1) Development policy

Assuming transport in mountainous areas as the first target market, we will conduct technological demonstrations in a phased manner, aiming for the production models to transport a 200-kg payload at an altitude of 3,000 m.

First, we will develop transport demonstrator K-RACER-X1 by adding a 100 kg payload at sea level to the existing aircraft, and we will conduct a technological demonstration for the purpose of quickly incorporating customer feedback.

Next, we will develop K-RACER-X2, a model that can carry a 100-kg payload at an altitude of 3,000 m by applying technologies and know-how obtained from our existing models and K-RACER-X1, and we will conduct a technological demonstration of transport in mountainous areas.

After these technological demonstrations, based on the results, we will develop production models.

(2) Efforts made so far (existing models)

As Kawasaki's development project-based internal research, we started the development of prototype unmanned aircraft for research on compound helicopters in fiscal 2015 under a five-year scheme. The purpose of this research is to develop unmanned compound helicopters and to acquire the technologies required for both speeding-up and realizing unmanned operation through testing.

Typical examples of compound helicopters that have another propulsion force in addition to the main rotor are Airbus Helicopters' Eurocopter X^3 [2] and Sikorsky Aircraft's X2 [3]. Boeing Bell's tiltrotor [4] also has this configuration. In this research, we set the basic concept based on the configuration of Eurocopter X^3, which is the most similar to that of the conventional helicopters that Kawasaki has developed thus far, and then launched development.

For step-by-step development, based on the small electric unmanned helicopters on the market for industrial use, we first made the compound helicopter (main rotor diameter: approx. 2m) together with a flight control system for it, and we verified flight control laws developed by KHI for the compound helicopter. During this stage, we demonstrated that the compound helicopter could fly automatically through predetermined waypoints.

While developing the small compound helicopter, we designed and produced a large compound helicopter (main rotor diameter: approx. 4m). The large compound helicopter required high horsepower to fly at the target speed of 200 kt. No high-power engines for unmanned helicopters of this class were available; therefore, for this helicopter, we decided to use the engine mounted on Kawasaki's motorcycle Ninja H2R.

With the large compound helicopter K-RACER-IV, we conducted ground functional tests and ground resonance test at the ground test site of Kawasaki's Gifu Works between December 2018 and March 2019. In addition, as shown in **Fig. 5**, the first flight was made at the Gifu Works athletic field in April 2019. After solving the problems identified during the first flight, a second flight test was conducted at the Gifu Works athletic field in November and December 2019 in order to verify feasibility as an aircraft.

After that, as the final test under the five-year scheme, the flight test shown in **Fig. 6** was conducted at Taiki Multi-Purpose Aerospace Park in Hokkaido in July 2020 in order to demonstrate stable flight conforming to Kawasaki's compound helicopter flight control laws. Also, the automatic return flight to the take-off point was verified with a view to BVLOS (Beyond Visual Line Of Sight) automatic flight .

(3) Development of transport demonstrators

The aforementioned K-RACER-IV has been designed for high-speed flight; therefore, it has a light payload. For K-RACER-X1, the main rotor specifications were modified and the skid was expanded in order to enable carrying of a 100-kg payload with minimal modifications from K-RACER-IV.

To achieve the goal of seamless, unmanned/labor-saving logistics, it was decided to equip K-RACER-X1 with an automatic take-off and landing abilities. Also, since the

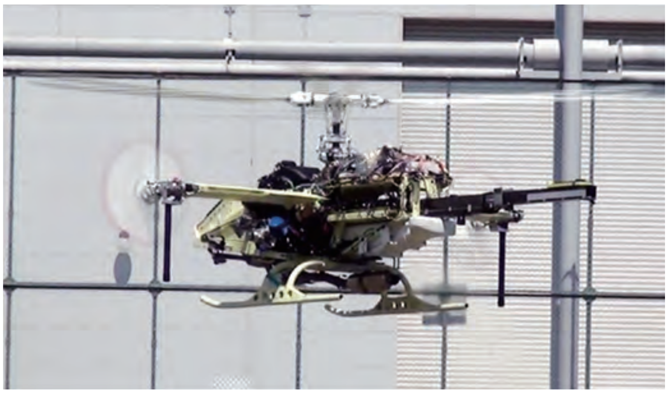


Fig. 5 First flight of K-RACER-IV (April 5, 2019)

Fig. 6 Flight test of K-RACER-IV at Taiki Multi-Purpose Aerospace Park (July 2020)

first target market for the production model is transport in mountainous areas, the function was added to fly automatically with external load operation With K-RACER-X1, we conducted an internal flight test and to verify the automatic flight sequence, including automatic take-off and landing, in autumn 2021. We will continue the development of automatic flight with external load and conduct an internal test in spring 2022.

Simultaneously with the development of K-RACER-X1, we are developing K-RACER-X2, which is intended for transport in mountainous areas. As for K-RACER-X2, we are in the basic design stage and making the most of the knowledge we acquired during the development of K-RACER-X1. We are designing the specifications of K-RACER-X2 with a view to mass production, and we will start prototype production of K-RACER-X2 in series. The development, including internal flight tests, is scheduled to be completed around September 2022.

(4) Demonstration tests

We plan to conduct demonstration tests to incorporate customer feedback into the production models and to demonstrate the usability and safety of unmanned VTOL aircraft.

(i) K-RACER-X1

For K-RACER-X1, we conducted demonstration tests mainly at low-altitude test sites, such as airfields or test airfields for unmanned aircraft, on transport with a 100-kg payload and on seamless, unmanned logistics with delivery robots as shown in **Fig. 7** (autumn 2021) and we plan to conduct automatic flight with external load (after spring 2022).

(ii) K-RACER-X2

For K-RACER-X2, we plan to conduct a demonstration in which a payload is transported to a mountain lodge in order to demonstrate transport in mountainous areas with a view to operation of the production model. Conducting these demonstration tests requires collaboration with local communities that provide test sites as well as collaboration with telecommunication companies and coordination with relevant ministries and agencies for unmanned BVLOS automatic flight. We are presently coordinating with the parties concerned. We plan to start demonstration tests after autumn 2022.

(5) Plan to bring the unmanned VTOL aircraft to market and challenges in commercial production

As the basic policy for commercialization, we plan to begin with transport in uninhabited areas (mountainous areas), which has certain market needs with a low safety risk on the ground, and then gradually expand the operation area. For the production model, customer requests and safety technologies obtained through the demonstration test in mountainous areas will be incorporated into the aircraft specifications, which are based on those of the K-RACER-X2. The production model will be categorized as a remotely piloted aircraft, and operation of such aircraft, like that of conventional manned aircraft, requires type certification and airworthiness certification. However, there are currently no specific design standards in place for remotely piloted aircraft (airworthiness classification and airworthiness examination procedure), and no remotely piloted aircraft have been granted type certification and put into service as unmanned transport aircraft so far.

Therefore, in order to put K-RACER into service for cargo transport as a production model, certification standards must be developed for remotely piloted aircraft before type certification. Certification standards for remotely piloted aircraft differ greatly from those for manned aircraft in that remotely piloted aircraft carry no crew and that remotely piloted aircraft can be operated remotely from the ground by an operator. With respect to these points, all requirements for the aircraft (and the

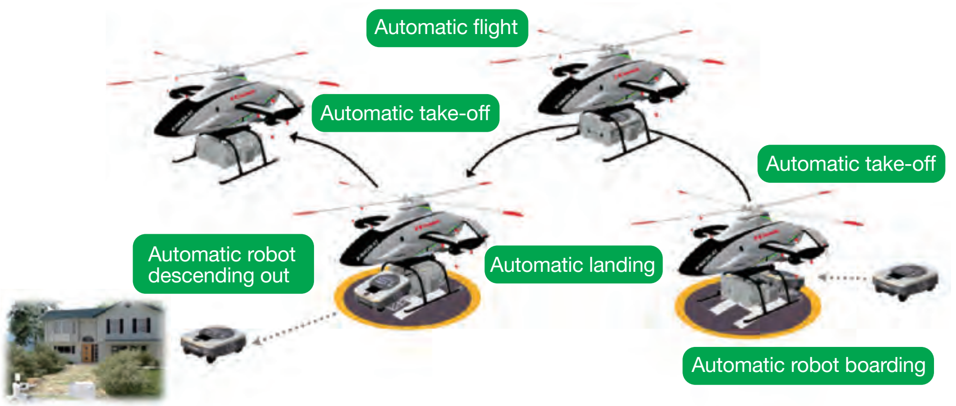


Fig. 7 Demonstration plan for seamless and unmanned logistics using K-RACER-X1 and delivery robots

entire system), including the communication method and flight traffic control, must be established in advance. We are now consulting with the Japan Civil Aviation Bureau to formulate certification standards.

Commercialization requires that aircraft development costs and product costs be minimized. Therefore, operation of unmanned aircraft in uninhabited areas (mountainous areas) must be appropriately assessed in terms of air and ground risks, and the required level of reliability and safety with adequate quality must be ensured while aiming to realize a reasonable aircraft without an excessive quality. To do so, it is important to formulate appropriate certification standards for individual applications (use cases) in order to realize new mobility.

Conclusion

Kawasaki will first bring its delivery robot and multi-purpose UGV to market as quickly as possible and offer a seamless ground logistics solution in combination with its palletizing and depalletizing robots. It will then bring an unmanned VTOL aircraft to market to offer seamless ground and air logistics, thereby contributing to solving the logistics challenges that society faces. In the future, Kawasaki will expand this business into passenger transportation services, bringing about innovation in passenger and cargo transportation by means of automation and remote control.

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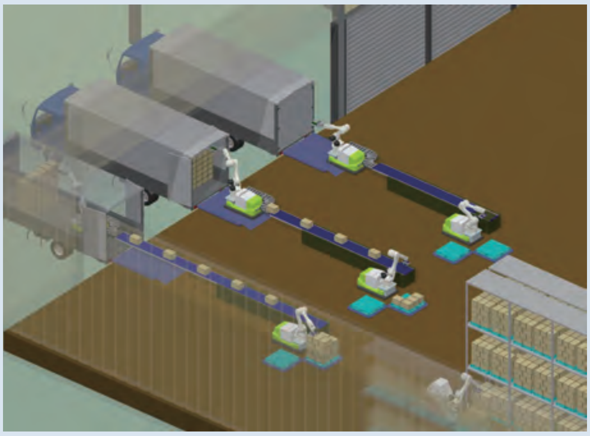
Automating Logistics Centers by Using Robots



Society as a whole is experiencing a labor shortage, and the logistics industry is experiencing a similarly severe shortage. Meanwhile, due to the current problem of the infectious COVID-19 disease, the electronic commerce (EC) business has been growing rapidly. In these situations, the entire logistics industry is extremely interested in automation and there is a strong demand to use automation for devanning, picking bulk workpieces, palletizing and depalletizing. Focusing on these processes first, we are working on automating logistics operations by using 3D vision and other sensing technologies.

Introduction

Society as a whole is experiencing a labor shortage, and the logistics industry is experiencing a similarly severe shortage. Meanwhile, the demand for EC is growing all the more due to the current problem of the infectious COVID-19 disease. In these situations, the entire logistics industry is more interested in automation than ever before.

1 Background

At a logistics center, received packages are sorted by destination and shipped out. While packages are shipped out directly without being stored at delivery terminals, at logistics centers goods are also unpacked, stored on a shelf and sorted by type.

The operations performed at a logistic center can be

Fig. 1 Processes in a logistics center

roughly divided into receiving and shipping as shown in **Fig. 1**. In these processes, the majority of work is carried out manually although part of it has been automated. An interview on the ratio of employees by process at logistics centers and the need for automation in material handling manufacturers and users found that the demand for the reduction of labor costs and the prevention of human errors is high. Taking these matters into consideration, of all processes, automation is most required in picking followed by allocation, devanning, inspection and vanning.

So far, most automation equipment has been equipped with single-function solutions, which made it difficult to apply automation to all processes. However, all processes can be automated by mixing functions such as an automatic guided vehicle and palletized/depalletized robot and a palletized/depalletized robot and image recognition.

Our ultimate goal is to expand automation to all the processes in logistics centers and delivery terminals. We chose vanning/devanning, palletizing/depalletizing and picking as the processes in which automation has been introduced because automation is feasible in these processes by applying our robot technology and image recognition technology and due to the large market size and urgent need for automation.

2 Vanning/devanning

Loading and unloading cases from a container is dangerous because the work may be carried out at places higher than 2 m and workers may handle heavy items. On top of that, the working area is often outdoors and it is physically intense work. That is why there is such strong demand for automated devanning all over Japan.

(1) Technical challenges

As containers are only accessed from the doors in back, the cases' image recognition, holding and transportation can only be carried out from the back. In addition, the cases inside a container are not necessarily piled up in order. It is often the case that containers can only be at a logistics center for up to two hours, an additional fee being required if they are there longer than that. It is also important to transport cases without damaging them.

The technical challenge to meet these requirements is to transport unstable cases that can only be accessed from one direction within the given amount of time without damaging them.

(2) Activities conducted so far

Ideally we would use vision recognition for cases piled up in a container, but it would be too difficult to obtain information on how they are loaded by viewing them from several directions due to the walls getting in the way and cycle time constraints. Therefore, we adopted K-VStereo, which is software that corrects the position of the cases with a robot using a 3D camera installed in a robot arm by measuring their 3-dimensional position. The system has a simple configuration consisting of a 3D camera, vision computer and robot controller shown in **Fig. 2**. We started by developing a system to recognize one type of case.

The cases' 3-dimensional inclination is measured by calculating the rotation angles of X, Y and Z-axis from a 3-dimensional point cloud of the measured surface, and the robot performs corrective actions according to the rotation angles. The system also has a function to avoid colliding with the walls, and the robot stops when an inclination larger than a set values is detected. In such cases, the workers remove or arrange the cases to continue the automatic operation.

The devanning hand has a servo motor which is the robot's external joint to drive the vacuum unit through a belt as shown in **Fig. 3**. The belt also serves as a conveyor belt on which the suctioned cases are placed, and the cases are gently pulled onto the hand. The vacuum unit's lifting function temporarily lifts cases on the floor, which

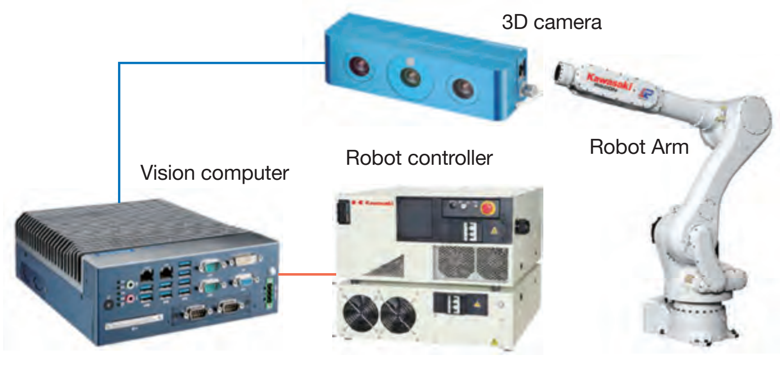


Fig. 2 Configuration of the K-VStereo system for devanning

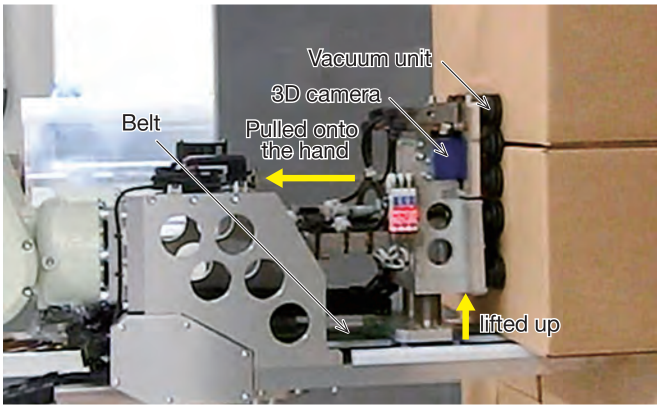


Fig. 3 Devanning hand

are then pulled up onto the hand. The 3D camera is installed inside the vacuum unit.

As a specific example, we set up the system to process a container with 1,000 cases within two hours. This would require the robot to work at a pace of 7.2 sec per case, but it operated at 12.5 sec per case on average, so we considered the simultaneous transportation of a stack of two cases placed side by side to reduce cycle time. When the system recognizes that the cases of both layers are placed horizontally, it judges that the devanning hand can pick up two cases. The system also has a function to automatically pick up one case by setting a threshold for the deviation if the hand cannot pick up two cases because of their orientation. The robot achieved an average of 6.25 sec per case when picking up two cases at the same time.

The travel of the arm shown in **Fig. 4** is the product of a collaboration project with Nakanishi Metal Works Co., Ltd., which planned to install a robot in an automatic guided vehicle for automatic devanning. We adopted the RS080N, a robot with an operating range that makes it usable in several different types of containers with different ceiling heights. Meanwhile, we define devanning in the most basic sense as the round trip of travel between the working area and the area where containers are. This robot does not require a battery as it can be plugged in to a power source in this case. This enabled us to make the automatic guided vehicle smaller.

(3) Activities for the future

We conducted a test using a container in an actual logistics center and performed a demonstration as shown in **Fig. 5**. In addition, this system has been sold as a base machine for testing without a hand or vision.

It provided us with more opportunities to hear a lot of opinions, and we were reminded that the demand for handling several types of models and accelerating the transportation speed is high. Kawasaki will carry out further development to realize faster devanning of several different models via the onboard AI.

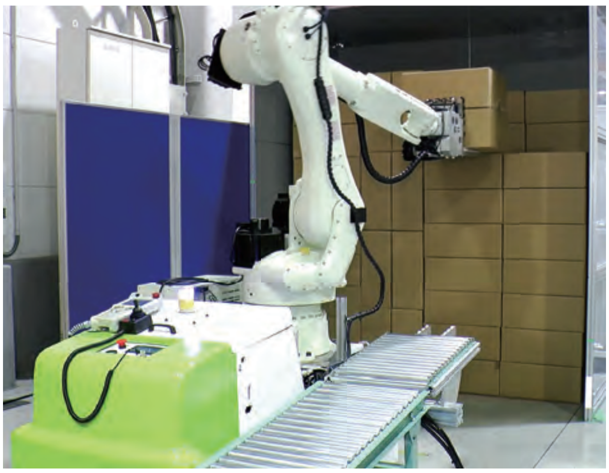


Fig. 4 Traveling arm

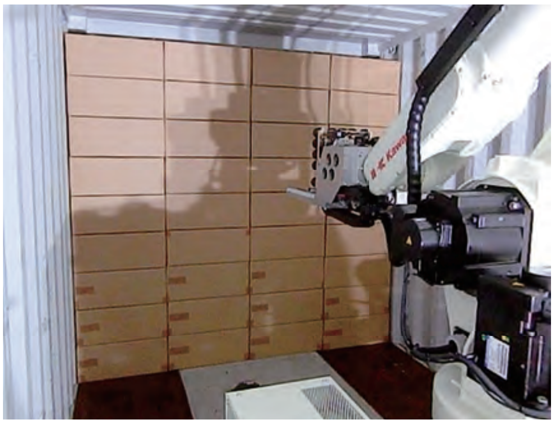


Fig. 5 Verification using actual containers

3 Picking

Picking is the process of picking up and collecting pieces (minimum product unit) to be shipped out based on an invoice or instruction sheet. It requires a huge amount of manual labor in logistics warehouses.

(1) Technical challenges

Automation of the picking process is extremely difficult from a technical perspective. One of the reasons is the irregularity in the supply of pieces in this process. Specifically, pieces are not always well arranged in a folding container or a cardboard box, but may have fallen over or have been piled up at random in the first place. In such cases, the robot must pick up pieces while avoiding collisions with the container as well as with surrounding items. It is nearly impossible, even for experts, to create a robot program to make a robot move in a way that covers all situations as it would take a huge amount of time and work. Reducing the amount of work to create a robot program is essential to automating the picking process. In addition, the robots' picking operation is slow compared to manual operation, so making it work faster is another challenge we have to overcome.

(2) Activities conducted so far

In order to reduce the workload for creating a robot program for picking, we developed a system to automatically create a robot's motion path based on the information from a 3-dimensional visual sensor as shown in **Fig. 6**. The system makes it possible to identify the picking point of a piece in a container using 2- and 3-dimensional images obtained from the visual sensor, and automatically create the robot's motion path with the identified position as an end point.

When creating a motion path, the system searches for

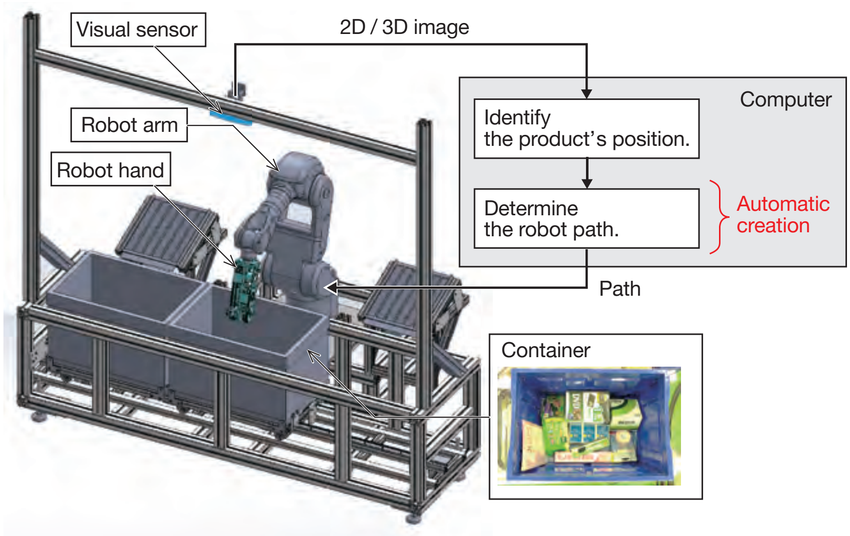


Fig. 6 Configuration of the picking system

a path that avoids collision by reproducing the relative positions of the robot and the surrounding area in 3-dimensions in a simulator. The 3-dimensional information of the robot and other known objects in the simulator is provided as a 3D model in advance, and the relative positions of pieces that change when they fall down is obtained from the visual sensor.

We are also developing technology to pick up several pieces consecutively to increase the throughput when using a robot for picking. This is to pick up several pieces and place them at one time to streamline the operation.

This system works with a robot hand equipped with several movable parts for holding a piece and the technology to create a path with the hand's motion is taken into consideration, as shown in **Fig. 7**. This leads to the creation of a motion path in which the hand does not collide with surrounding objects when picking a piece with movable part B while recognizing the piece held by movable part A. The movable parts enable the robot hand to pick up a piece in the corner of a container. It is expected that the system will reduce the manual labor of organizing items as workers do not need to arrange pieces properly on the supply side.

(3) Activities for the future

Another challenge to picking is how to handle different types of pieces at the same time. At present, the types of pieces have been limited to those of small boxes that are suctioned with vacuum pressure. We will improve the technology used for the visual sensors and robot hands to

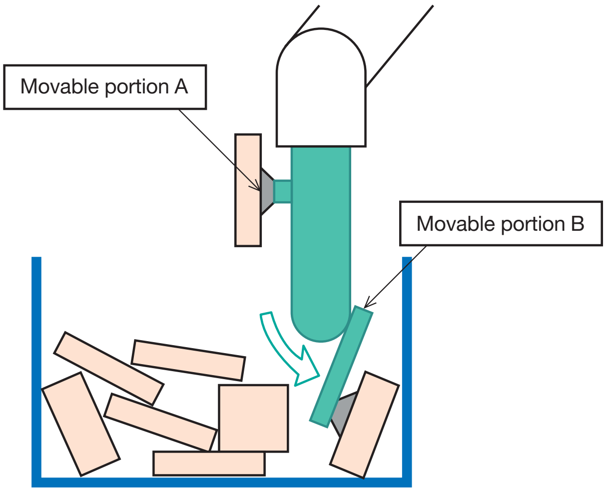


Fig. 7 Picking a piece placed in a corner

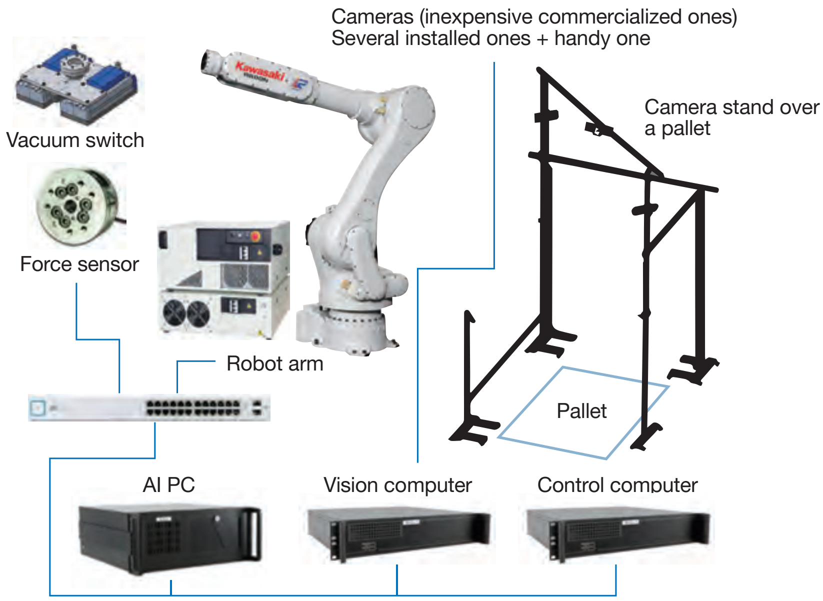


Fig. 8 Configuration of the AI robot vision system for palletizing

expand the scope of the system.

4 Palletizing/depalletizing

(1) Technical challenges

The development of holding and transportation tools is extremely difficult as is that of recognition technology because there are a variety of undetermined objects such as boxes with different sizes and bags in the working area. In addition, as planning a loading strategy is important when palletizing, it is technically very difficult to palletize different types of items with no prior information.

(2) Activities conducted so far

In order to launch a system for palletizing different types of items (which other companies are also developing) as early as possible, Kawasaki decided to commercialize the system early in collaboration with a startup company through a project in which the core technology related to the arm's motion was developed by Kawasaki and the recognition technology was created by the startup. Kawasaki executed a joint development agreement with Dextelity, our startup partner which excels in AI technology for image processing, in 2019, and since then, we have carried out development starting with application to the combination of pallets and cases.

Once a case's size is identified with a 3D camera, it is transported by a robot. Several 3D cameras are installed over the pallet to determine the optimal location to place them based on the loading information. There is no information on the order of transported cases, and they are loaded on a pallet in real time. The system does not require prior learning for cases with a general shape as it automatically creates position to hold and suction them.

As shown in **Fig. 8**, the system consists of a control computer to determine the movements, an AI computer equipped with AI for palletizing different types of items and a vision computer for image processing. The system achieves both appropriate functions and low cost by using several inexpensive 3D cameras.

A system for palletizing/depalletizing different types of items was jointly displayed at the iREX2019, International Robot Exhibition. We have gathered a lot of attention from the Japanese logistics industry since then.

(3) Activities for the future

We will improve the capability of the system by expanding the scope of usage such as the use of a roll-tox pallet and the transportation of items other than boxes.

Conclusion

Kawasaki is working on the automation of logistics centers as part of a solution to the shortage of workers. The challenges common to each process include how to deal with situations with different types of items and how to go faster. We will introduce the developed systems in logistics centers while solving these challenges.

We would like to express our appreciation to the cooperating companies involved in the verification.

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Development of Electric and Hybrid Motorcycles Aimed at Achieving Both High Riding and Environmental Performance

CO_2-free and carbon-neutral are required to prevent global warming. In the automotive industry as well as other industries, efforts are being made to achieve CO_2-free and carbon-neutral.

Given this social situation, Kawasaki is developing batteries and motors that are suitable to be packaged into motorcycles (with reduced size and increased power) in order to develop electric and hybrid motorcycles and offer them as near-future mobility that has both high riding and environmental performance.

Introduction

CO_2-free and carbon neutral are required to prevent global warning. The Ministry of Economy, Trade, and Industry has formulated the "Green Growth Strategy Through Achieving Carbon Neutrality in 2050" in collaboration with the relevant ministries and agencies. This includes the electrification of new cars by the mid-2030s. In response, the automotive industry has declared that it will make every effort to achieve carbon neutrality.

1 Background

As a solution to environmental issues, low-emission zones have been established in urban areas in some regions; these zones mandate that entering vehicles have an environmental sticker, and entry of motorcycles that do not satisfy environmental standards is restricted. Though few countries have legislated restrictions on the sale of new gasoline or diesel vehicles, many countries are planning to do so. Movement toward electrification is accelerating. Given the social push that is demanding efforts to spread electric vehicles be accelerated, as a new solution, Kawasaki is working hard to develop hybrid motorcycles with the aim of offering such motorcycles as near-future mobility.

2 Development overview

To realize a new product concept that achieves both high riding performance and environmental performance, we are developing core technologies for electrification, such as batteries, motors, and systems suitable to be packaged into motorcycles.

(1) Concept of electric motorcycles

We have defined quietness, zero emissions, and "fun to ride" (the joy of riding and the fun of maneuvering) as characteristics that electric motorcycles should have.

We aim to achieve "fun to ride" as a characteristic that conventional motorcycles lack while achieving low noise and zero emissions.

(2) Concept of hybrid motorcycles

We have defined riding performance and convenience equal to or better than those of conventional motorcycles, high quietness and high controllability during low-speed operation, and low emissions as characteristics that hybrid motorcycles should have.

We aim to achieve high comfort during riding in suburbs and at high speeds as with conventional motorcycles, while simultaneously achieving high quietness and high controllability in addition to reducing emissions by enabling electric riding in urban areas as shown in **Fig. 1**.

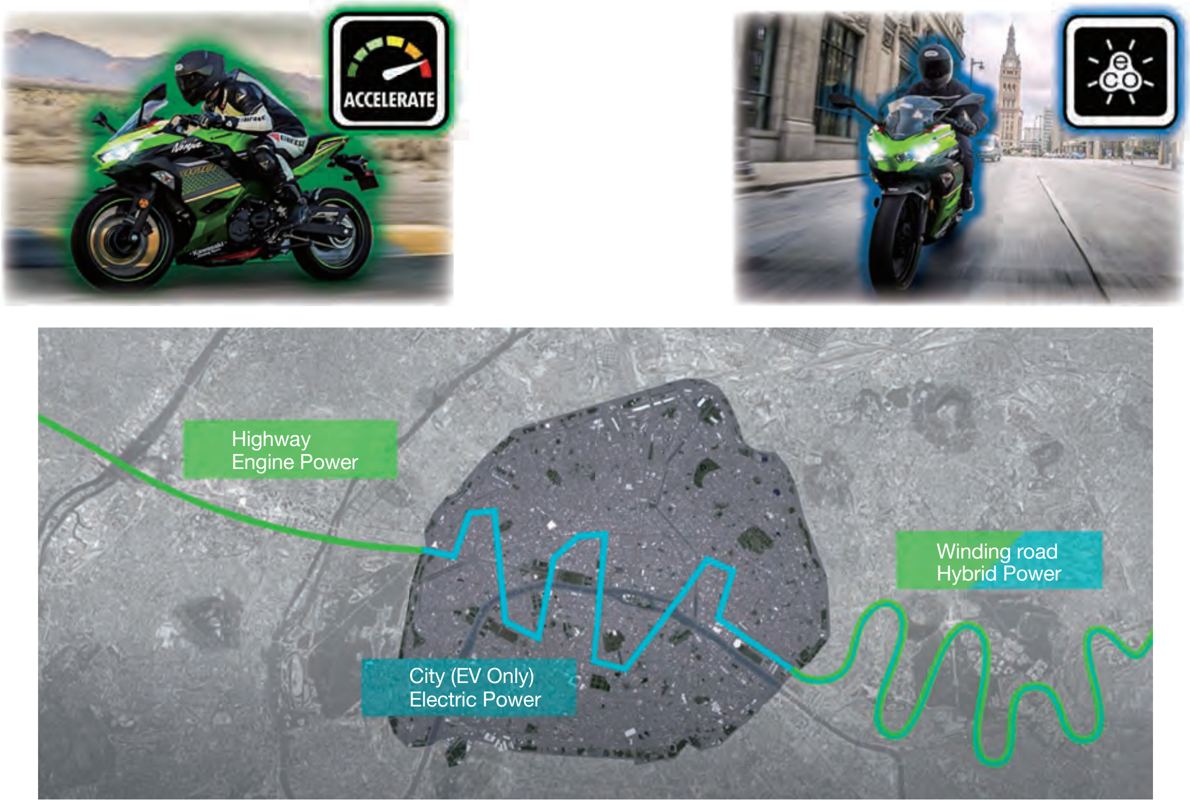


Fig. 1 Product concept

(3) Technical challenges

The following are the key technical challenges in the development of electric and hybrid motorcycles.

① Reduced battery size and increased battery output (for both electric and hybrid motorcycles)

Batteries that provide comfortable acceleration, that withstand repeated acceleration and deceleration, and that are sufficiently compact and inexpensive to be mounted onto motorcycles need to be developed.

② Reduced motor size and increased motor output (for both electric and hybrid systems)

Motors that have high efficiency in the high frequency operation region, that are sufficiently compact to be mounted onto motorcycles, and that have high environmental resistance (cooling and vibration resistance).

③ Efficient layout of electric motorcycle components and creation of fun (electric systems)

Components that engine motorcycles do not have, such as traction batteries and motors, need to be arranged efficiently, and as with engine motorcycles, vehicles that make riding fun need to be developed.

④ Cooperative control of the motor and engine (for hybrid systems)

There is a need to improve the torque characteristics and fuel economy by making the most of the respective strengths of motors and engines.

3 Development of elemental technologies

(1) Reduced battery size and increased battery output

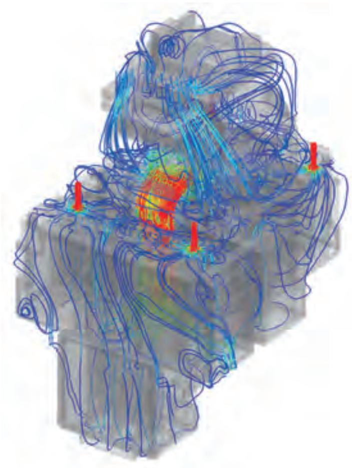
There are many types of batteries, including lead acid batteries, nickel-metal hydride batteries, and lithium-ion batteries. To achieve a reduced size and increased output, we selected lithium-ion batteries, which have high output and high energy density while being relatively inexpensive.

Lithium-ion batteries require efficient cooling because they get hot and deteriorate if charged and discharged frequently and repeatedly [1]. To address this problem, we conducted the analyses, including CFD, and the tests shown in **Fig. 2** over and over again for optimization.

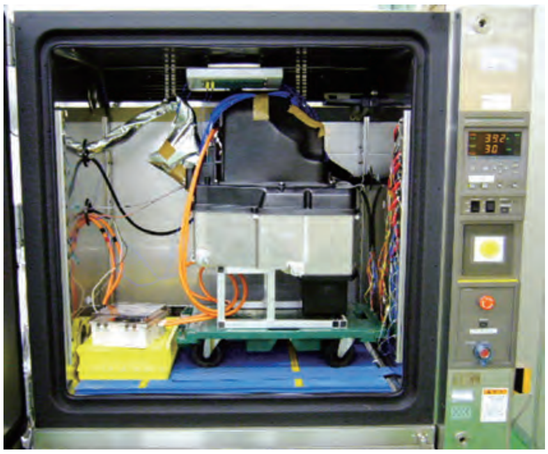
Cell output performance is known to greatly depend on the cell's condition. Therefore, we are developing technologies to detect the pack condition, such as the temperature, charge state, and deterioration state, to estimate the output performance based on the detection results; and to reflect the detection results in vehicle control as shown in **Fig. 3**.

(2) Reduced motor size and increased motor output

Traction motors are required to have high torque characteristics in the low rpm range, which is a weak point



(a) Analysis



(b) Test

Fig. 2 Optimization of battery pack cooling

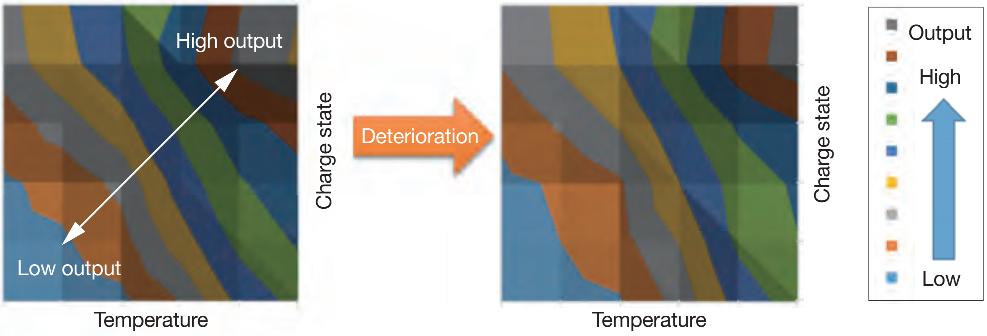


Fig. 3 Detection of battery pack condition

of engines; to have high rpm characteristics at maximum rpm; and to have high efficiency in the high frequency operation region. In addition, the traction motors must be mounted within a limited space; therefore, both electric motorcycles and hybrid motorcycles are required to have smaller, lighter motors, which also leads to cost reduction [2].

Focusing on regions where motorcycles are operated frequently, we are attempting to design motors that have the highest efficiency in such regions as shown in **Fig. 4**. Hybrid motorcycles run while switching between the engine and motor; therefore, we are developing motors that have high efficiency at a low rpm, which is a weak point of engines.

To increase the output and to reduce the size, more heat must be cooled with a smaller radiation area; therefore, we have adopted an oil cooling system with high

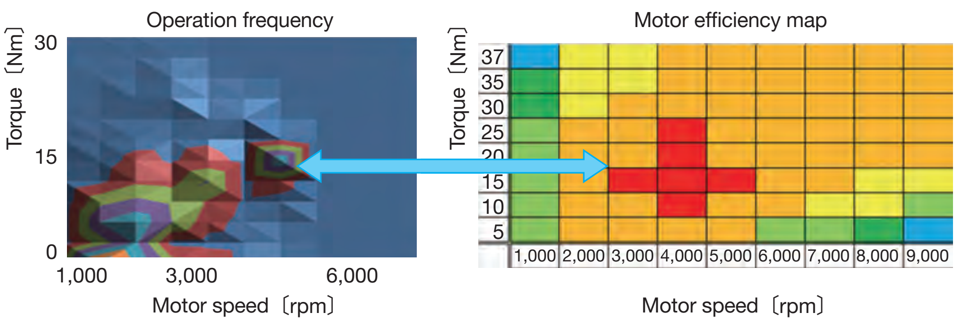


Fig. 4 Optimization of the high efficiency region of the traction motor

heat removal capacity. Oil can be given electrically insulating properties, and high cooling effects can be obtained by allowing the oil to flow through the motor to directly cool the heat sources, such as the coil, core, and magnet. We are conducting analysis to identify a flow channel that enables effective cooling and are developing the cooling structure shown in **Fig. 5**.

(3) Efficient layout of electric motorcycle components and creation of fun

For electric vehicles, there is a need to consider the layout of components that engine motorcycles do not have, such as batteries and motors. For batteries in particular, special requirements must be considered—for example, the center of gravity, the power cable length, measures against electric shock, and protection in the case of falling.

Figure 6 shows a typical component layout for an electric vehicle. This vehicle requires a high drive voltage; therefore, almost all the high-voltage parts are housed in the battery pack, which is placed inside the frame. This protects the high-voltage parts and reduces the cable length. Also, the quick charge CHAdeMO connector is positioned near the battery pack, facilitating easy handling during maintenance and at other times.

Electric vehicles generally run at fixed speeds, but this vehicle is equipped with a stepped manual transmission. This enables the rider to feel the motor characteristic of greater torque in the low speed range.

Also, this vehicle is equipped with a lever operated to adjust the amount of motor regenerative braking as shown in **Fig. 7**, empowering the rider to feel the fun of

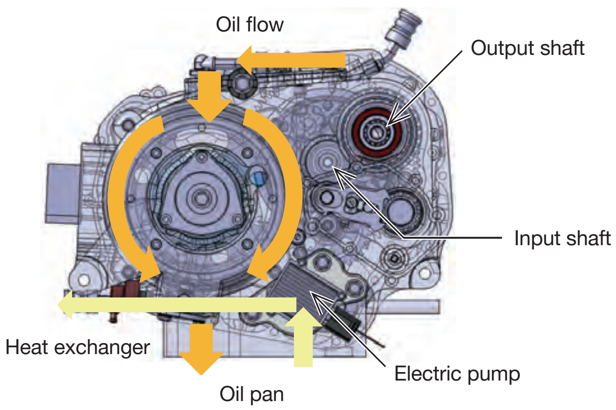


Fig. 5 Oil cooling structure of the traction motor

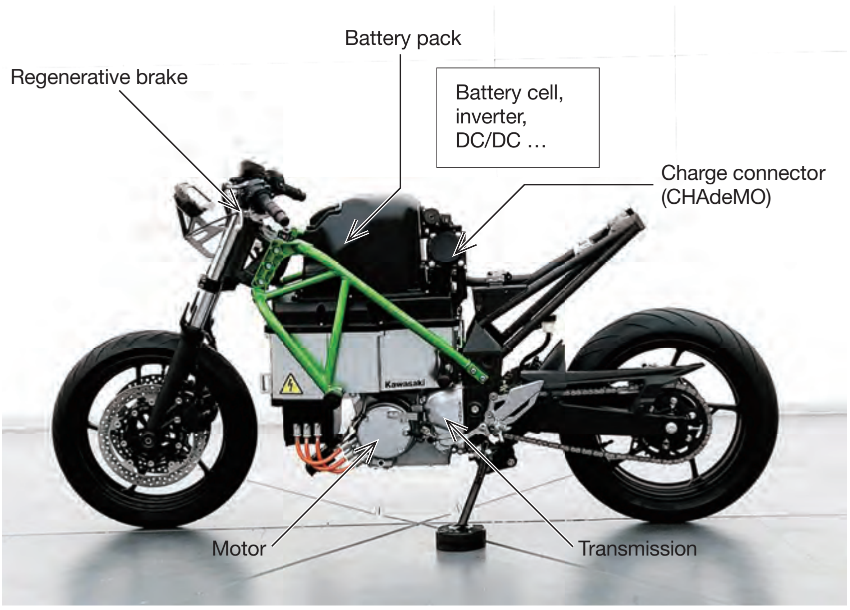


Fig. 6 Electric vehicle components

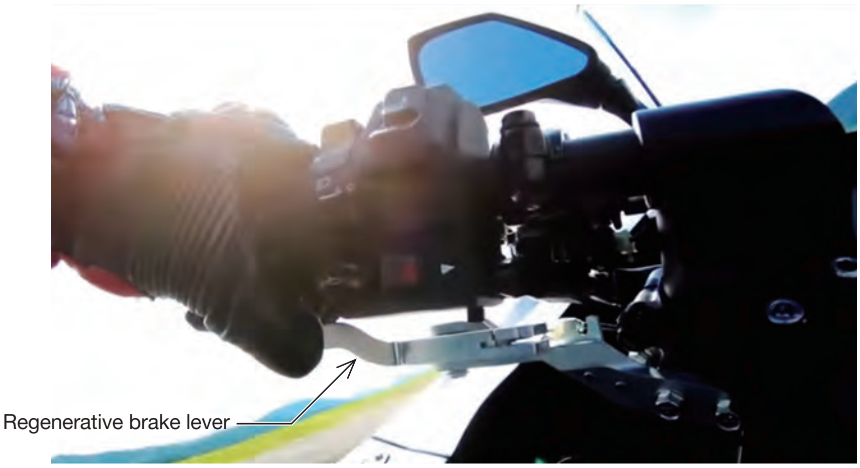


Fig. 7 Regenerative brake operation

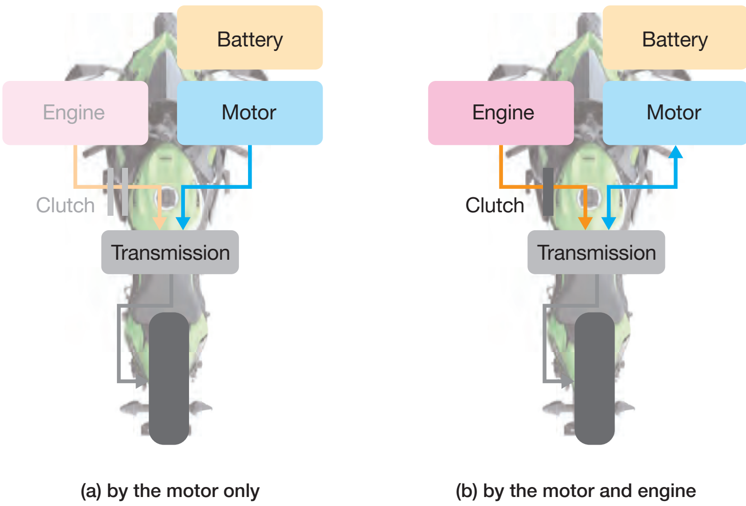


Fig. 8 Hybrid system configuration

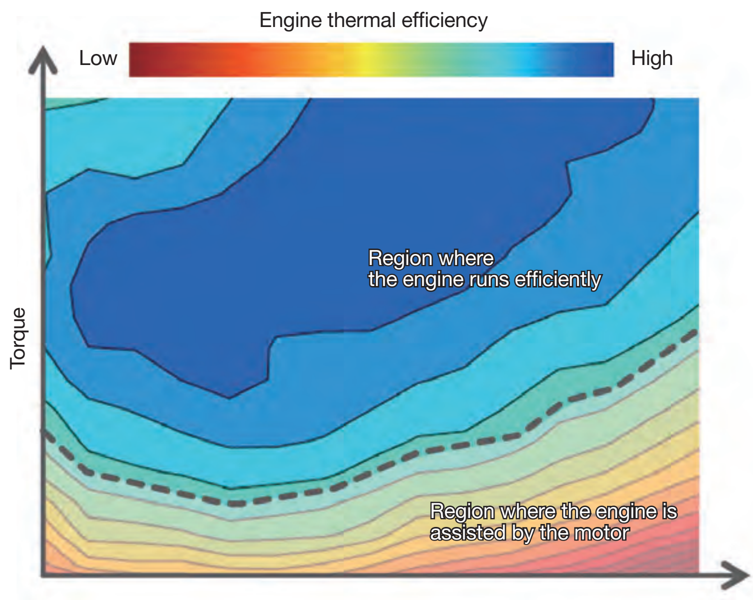


Fig. 9 Thermal efficiency characteristics of the engine

maneuvering[3].

(4) Cooperative control of the motor and engine

The developed hybrid system is a parallel hybrid system in which the motor and engine are connected in parallel via the clutch as shown in **Fig. 8**. The vehicle can be run by the motor only **(a)** or by the motor and engine **(b)**, which can be selected by clutch operation. This enables the rider to select the riding mode and power distribution according to the situation, thereby achieving a good balance between environmental performance and riding performance[4, 5].

Generally, engines have lower thermal efficiency in a lower torque range as shown in **Fig. 9**. Therefore, engine vehicles have lower fuel economy in low torque ranges, such as when starting or running at low speeds.

Hybrid systems use the torque from the motor to assist the engine in the low torque range, which is a weak point of engines. Hybrid systems also reduce fluctuations in thermal efficiency across the entire system, thereby improving fuel economy. In addition, during running, the motor is operated as a generator to shift the engine's activation point toward the high efficiency side by the power generation load, which secures power distribution that can recover the electricity consumed to assist the engine while simultaneously enhancing the fuel economy during normal running.

Conclusion

With regard to small motorcycles, commercialization of electric vehicles is proceeding gradually around the world. This is because thanks to the technological evolution of batteries and motors, performance and cost can be better balanced than before in this class of vehicles.

However, as for medium- and large-sized motorcycles, many challenges remain to be solved, as the required performance of these motorcycles is quite different from that of small motorcycles. We will continue this development, aiming for the early establishment of core technologies for commercialization.

Towards carbon neutrality in the future, we are planning mobility development using hydrogen fuel, which is a source of clean energy.

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Main Products and Production Bases by Business Segment

Business Segment	Main Products	Main Production Bases
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	• Aircraft engines • Aircraft gear boxes	Akashi Works (Akashi, Hyogo Prefecture) Seishin Works (Kobe, Hyogo Prefecture)
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