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

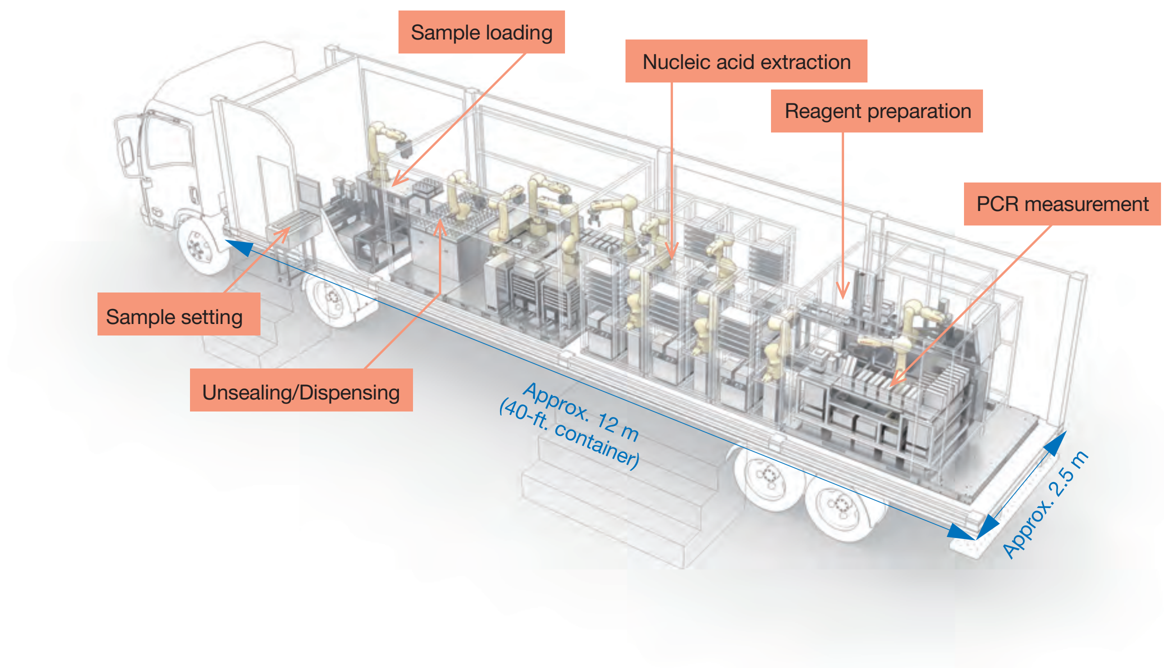

Fig. 1 Container-type automated PCR viral testing robot system

Fig. 2 Example container installation

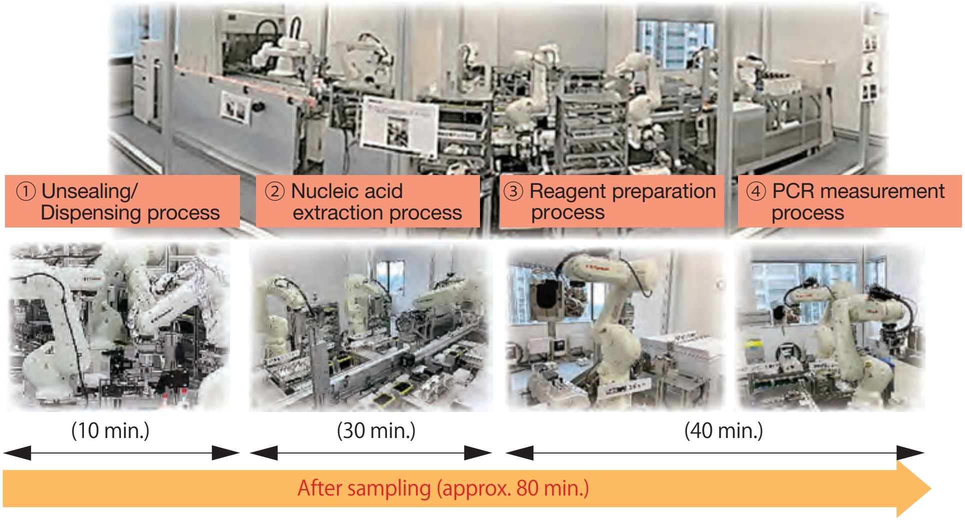

Fig. 3 Configuration of automated PCR viral testing robot system

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

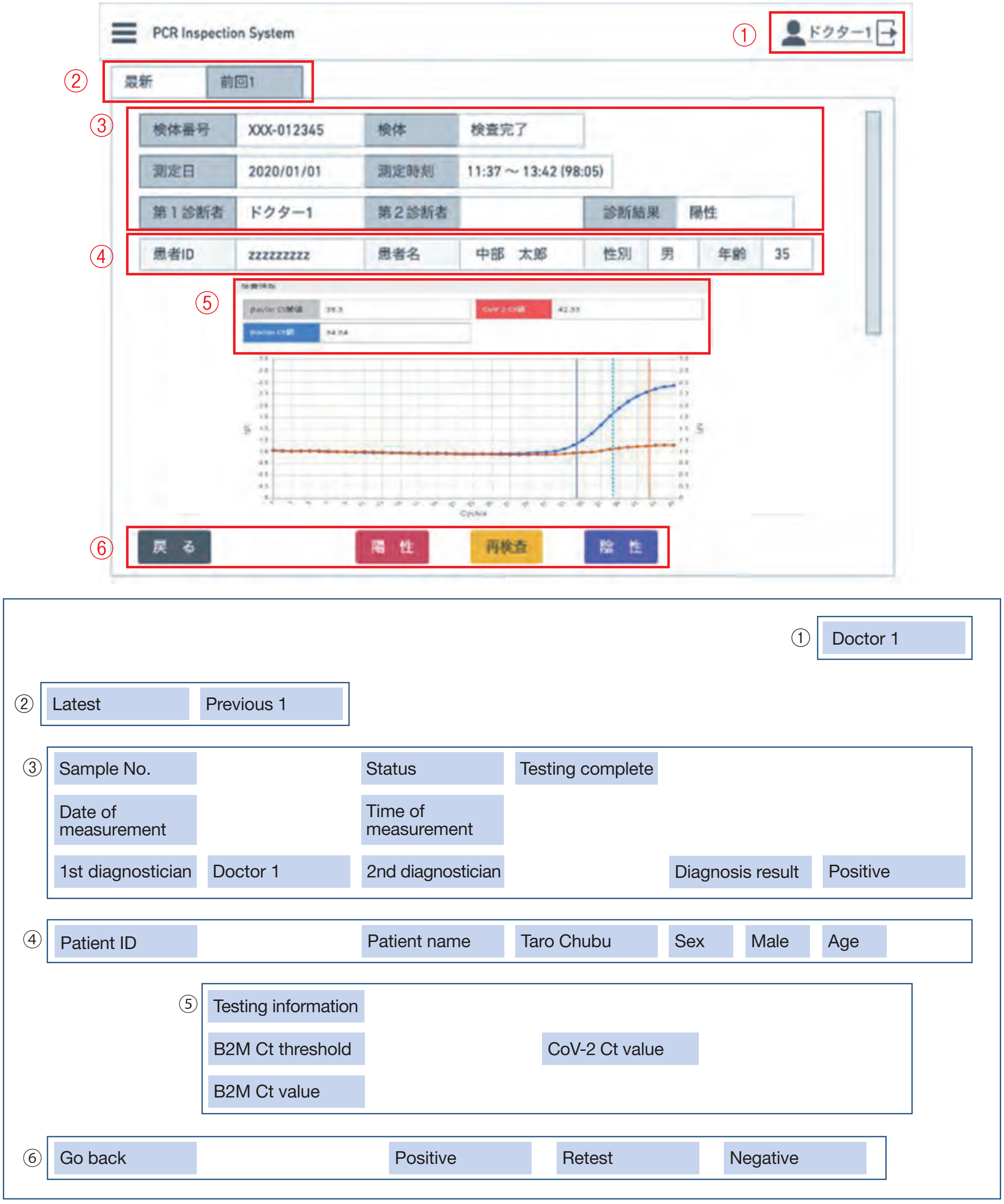

Fig. 4 Example of RT-PCR test results (amplification curve)

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

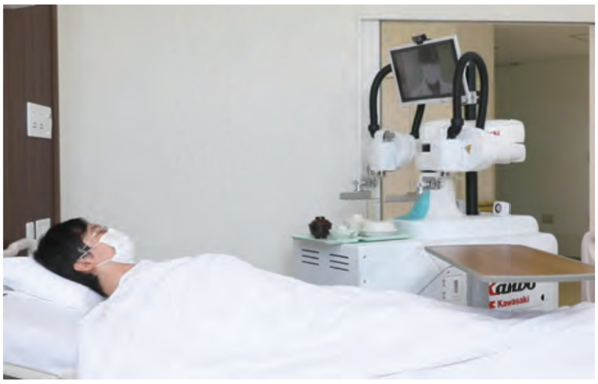

Fig. 6 Communication with infected patients

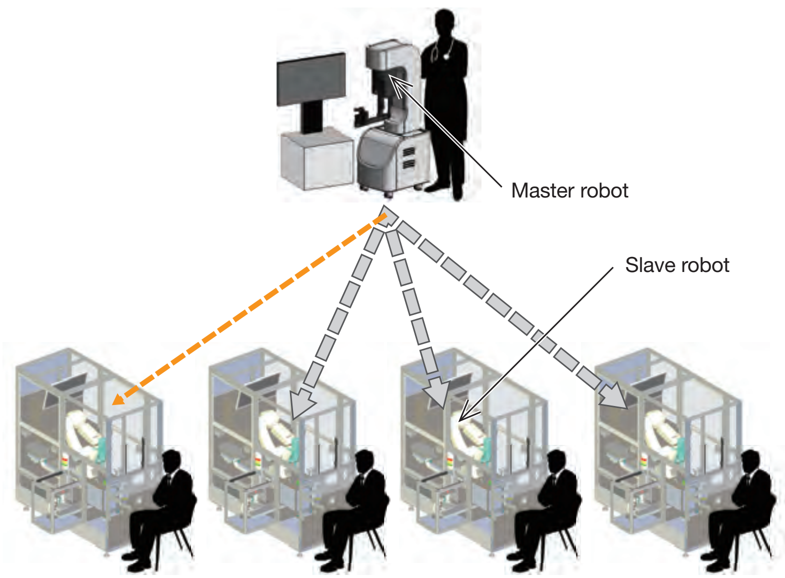

Fig. 7 Switching the connection among four slave robots

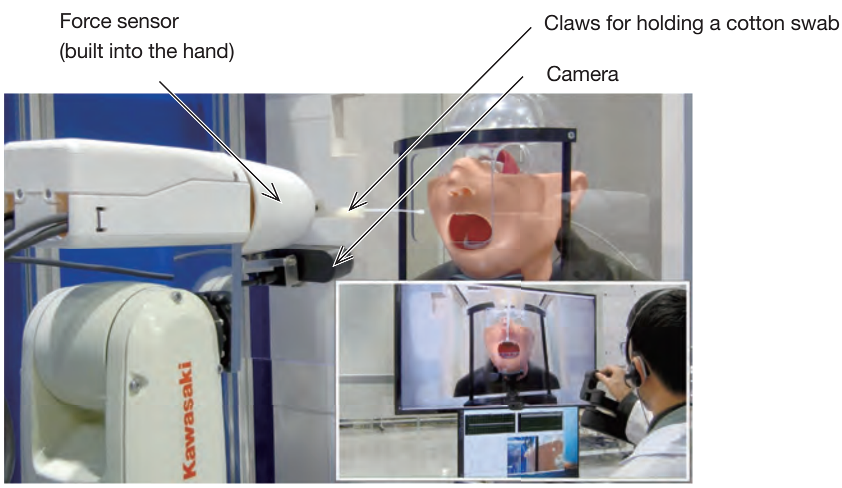

Fig. 8 Nasopharyngeal sample collection by remote control

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.

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.

References

1) Guidelines on Safety Management of Medical Information Systems Ver. 5.1, Ministry of Health, Labour, and Welfare (2021)
2) Guidelines on Safety Management in Providers of Information Systems and Services Handling Medical Information, Ministry of Internal Affairs and Communications and Ministry of Economy, Trade, and Industry (2020)

Tetsuro Koma
System Development Department,
PCR Supervisory Department,
Presidential Project Management Division

Doctor of Engineering
Tetsuya Kubota
PCR Supervisory Department,
Presidential Project Management Division

Hiroki Kokushi
Medical Robot System Department,
Medical Robot Group, Robot Business Division,
Precision Machinery & Robot Company