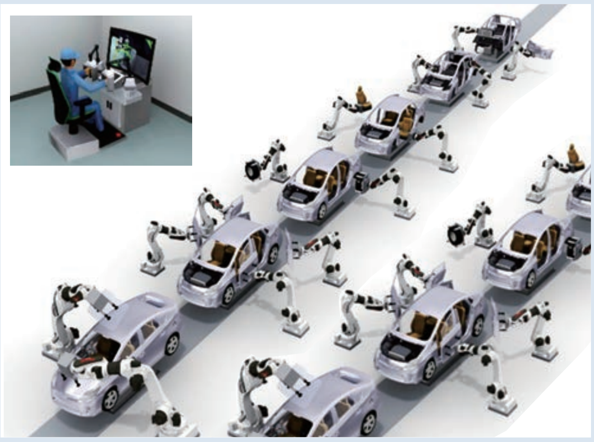
New Robot System Successor, Realizing Remote Production and Working



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

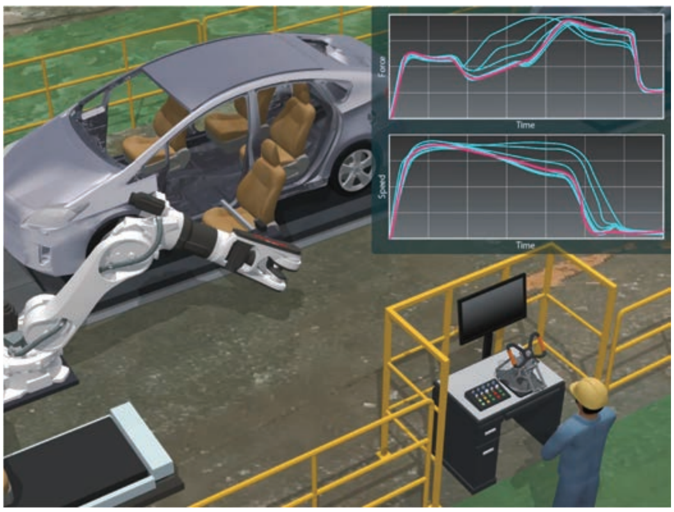
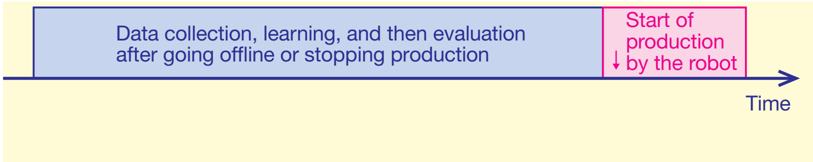
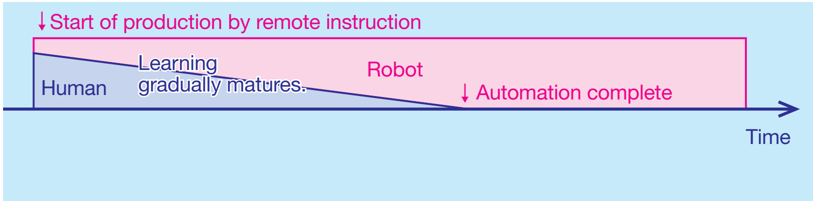


Fig. 2 Automatic control achieved through skill succession



(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

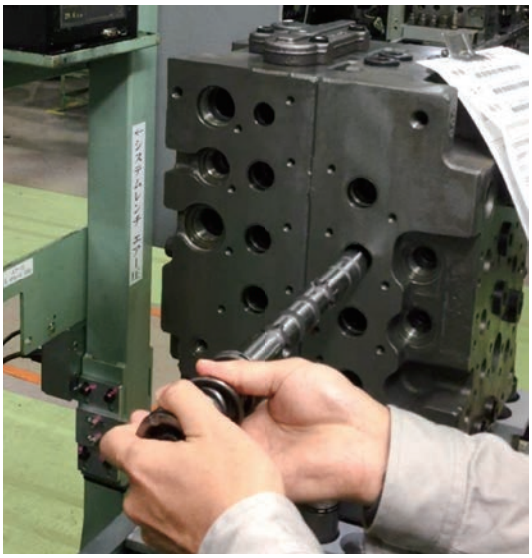


Fig. 6 Inserting a spool manually

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

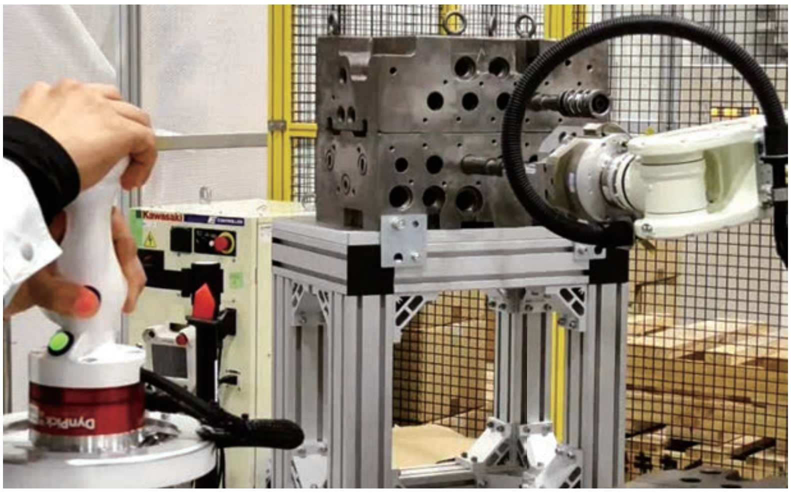


Fig. 7 On the Job Learning

Fig. 8 Image of eRoboWork

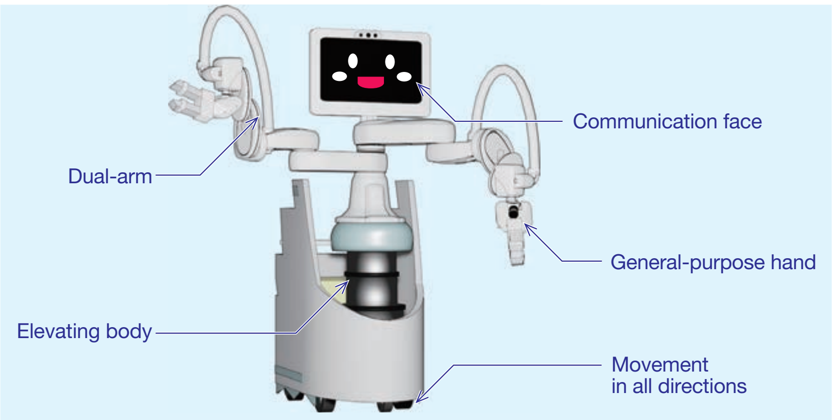


Fig. 9 Platform robot, Nyokkey

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.

Reference

1) World Robotics 2017 (the number of industrial robots used for 10,000 employees in the manufacturing industry), IFR Bureau of Statistics (2017)
2) "A Collaborative Dual-arm SCARA Robot, duAro, Provides a Production System That Allows Human Beings and Robots to Work Together: Development Concept and Applications," Hirata, Suzuki, Murakami, Hibino, Takebayashi, Kanbara, Kawasaki Technical Review No. 178, pp. 9-14 (2017)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