Feature Articles

Application of Robots to the Construction Sites

Summary

The current Japanese construction industry faces the challenges of an aging population and a shortage of new workers. We expect that productivity improvement through robot technology and computer technology, which have been developing in recent years, will be a countermeasure against this labor shortage. From the 1980s to the 2000s, general contractors, including our company, had developed more than 160 types of robots. However, they were never used continuously. In developing the robot, the authors examined these past cases, clarified the reason why they were not used, and set three new policies. (1) Identification of users and true needs, (2) Examination of pinpoint and simple solutions, (3) Collaboration with service providers. This paper introduces five types of robots and one type of remote control system developed for use at construction sites in recent years based on these policies. Specifically, (1) transport robot "Kamon" (2) transport robot "crawler TO" (3) scraping type cleaning robot "TO gather" (4) suction type cleaning robot "AX Kyuiin" (5) self-propelled marking robot (6) tower crane Remote control system "Tawa Remo". In the future, we will collaborate with rental companies, etc. to promote the spread and development of these technology groups. Furthermore, we will develop lower-cost and easier-to-use robots that can be applied to work that is expected to have a high robot introduction effect.

Keywords: construction robot, transport robot, cleaning robot, floor marking robot, tower crane remote control system

1 Introduction

Mikita Miyaguchi*1

The labor shortage in the future is becoming a serious concern in the construction industry.

Improvement of productivity is another critical issue to be addressed. As shown in Fig. 2, the manufacturing industry has shown an upward trend consistently for the past 20 years, whereas the construction industry has remained at a low level of value-added productivity. Although information technology (IT) has progressed in the construction industry, such as the widespread use of portable terminals, resulting in increased productivity in recent years, construction sites (the forefront of production) still depend on individual skills, analog communications, and many labor-intensive tasks. Hence, further productivity improvement remains a concern.

Under such circumstances, in April 2024, the upper limit of working hours will be enforced in the construction industry, and workstyle reform is becoming an urgent issue. Therefore, all measures must be taken to improve the industry's attractiveness to improve productivity and secure new employees.

Robot-based work automation and support can be one of the solutions to these problems. The Takenaka Research and Development Institute has been involved in analyzing past construction robot development cases and current construction site

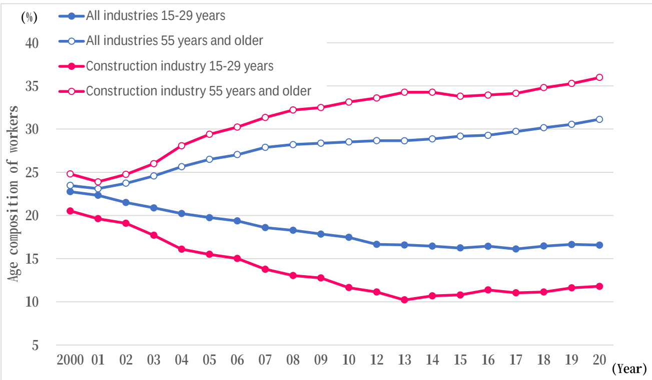


Fig.1 Progress of aging in the construction industry [1)]

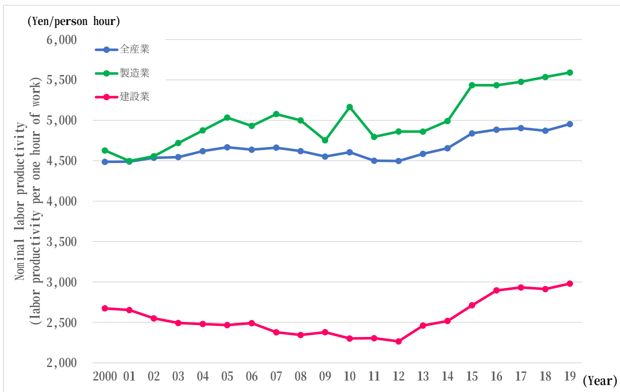


Fig.2 Changes in value-added labor productivity in the construction industry

*1 Chief Researcher, Research & Development Institute

issues. The institute focuses on genuine requirements for the robots for their use at the site and formulation of development policies. In this study, we have reported on the status of robot development in recent years.

2 Past Robot Development

Mikita Miyaguchi*1

The authors have investigated the construction robots previously developed and discussed the reasons for their low popularity. It has been identified from the literature that, from 1980 to 2000, there were over 20 and 160 types of robots developed at our Takenaka and in the construction industry, respectively [3], as shown in Fig. 3. However, all of these were limited to trials at construction sites, and there were hardly any that became truly widespread. The authors believe that the main reasons why these robots did not become widespread were as follows:

- Automating a series of construction works to replace skilled workers led to the robots becoming large and heavy, requiring more effort to transport and install.
- As battery and communication technology was immature, cables for power supply and control to drive a giant robot for long periods were required, and installation at the construction site was complicated.
- Since control and computer technology were still immature, complex operations were necessary, and a dedicated operator was required.
- Since these robots were equipped with complex and diverse functions, the cost of manufacturing and operating them was large.

Considering these, we have identified that thorough research should be conducted in this area, and robots should be developed in the field while making full use of the advanced technologies.

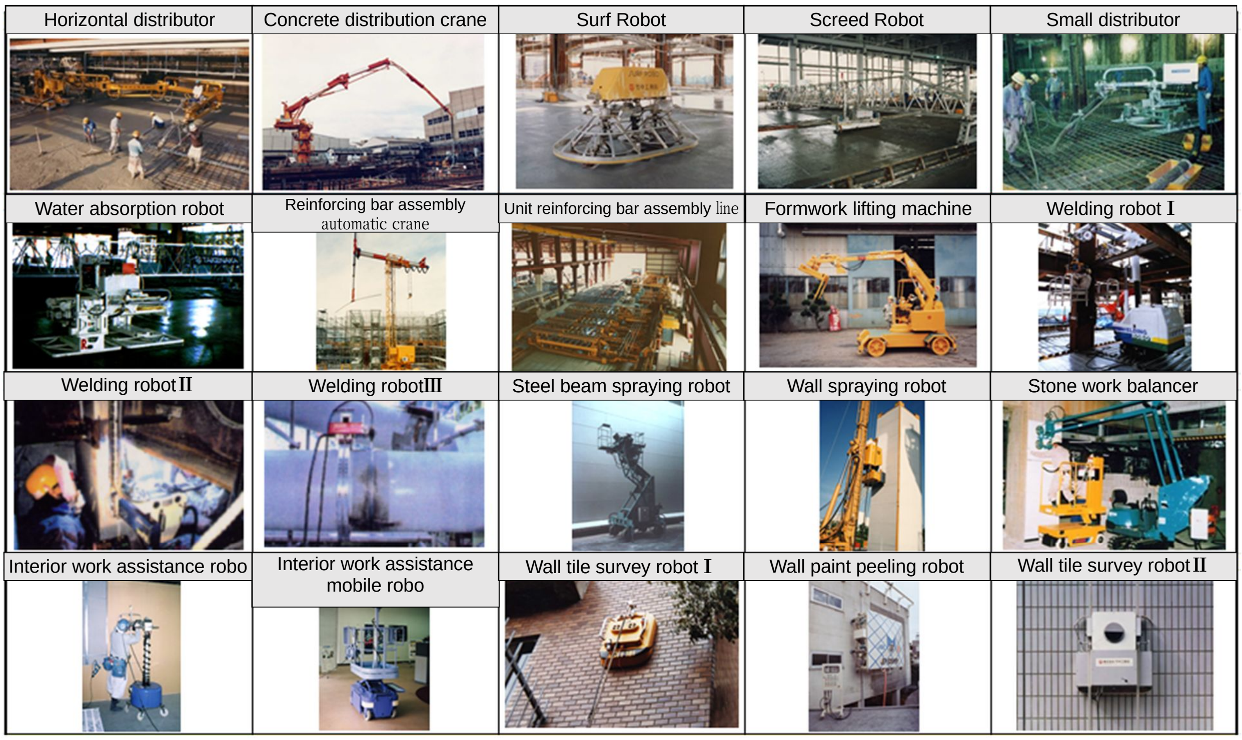


Fig.3 Robots developed in the past by Takenaka

3 Future Construction Sites and Robots

Mikita Miyaguchi*1

Robots have been developed over the last 20 years, and robot technology has grown significantly. Still, the difficulty of robot implementation and automation of construction work or processes remains exceptionally high. The reason for this is the complexity of construction work. What is made for each item is different in construction work, and complicated work and operations are needed on site. Diverse working conditions and flexible decision-making are difficult even with advanced robot technologies. Therefore, it is not easy to envision the future of construction sites when machines and robots will be the mainstream. There is no doubt that there will be a significant dependence on human ability. Future construction sites will require robot implementation focusing on people.

With people as the central idea in robot development, robot implementation in construction sites will be expected to play a different role beyond labor-saving. First, the rewarding feeling among people must be increased. People constantly seek rewarding and motivating jobs in construction work, for example, contributing to society by constructing wonderful buildings that will remain for several decades. Therefore, the collaborative vision should be in which people perform the rewarding jobs and robots either support or substitute non-rewarding work.

Second, the focus should be on reducing physical and mental burdens. Construction work has often been described as complex, dirty, and dangerous. For example, the recent heat waves in summer have led to decreased production efficiency and an increased risk of heat stroke. Furthermore, construction work often involves straining postures such as bending over and work such as lifting and supporting heavy objects. The accumulation of fatigue leads to physical injury and may force employees to leave their jobs. Cooperation between humans and robots may reduce these physical and mental burdens.

Human-centric robot implementation, which increases rewarding feelings in people and reduces physical and mental burdens, can also increase the workplace’s attractiveness. It is identified that this should be the aim of the construction industry for handling the concerns about future labor shortages.

4 Construction Robot Development Policy

Mikita Miyaguchi*1

The authors have established the following three robot development policies to achieve human-centric robot implementation effectively based on the lessons learned from the analysis of prior development cases:

① Identifying users and their actual needs

Identify the users using robots and the merits provided to those users.

② Examining pinpoint and simple solutions

Examine methods for simply resolving actual needs to ensure the usage of robots’ limited functionalities.

③ Collaboration with service providers

Construct a robot production, operation, and support system from the development stage to popularize robots widely.

These are explained in this section.

4.1 Identifying Users and their True Needs

Before development, we decided to thoroughly explore users’ advantages to developing genuinely utilized and widespread robots.

In the initial stages of introducing robots to construction sites, it is thought that it is adequate to select development targets, allowing almost all workers to use them. Skilled workers working in over 50 occupations work at construction sites and swap jobs daily as the work process advancement. Here, applying a robot to a unique task in one occupation will have a limited effect on the entire construction. However, using a robot for everyday work across multiple occupations is thought to have a considerable ripple effect (Fig. 4).

Work common across multiple occupations includes incidental work, such as marking, material transportation, cleaning, and tidying up. Substituting and supporting this incredible work with robots will increase the time devoted to the main work, such as processing and assembly, with higher value-added skilled workers. Therefore, improved labor productivity can be expected. Furthermore, as the main work requires advanced skills, it can be expected that the effect of the rewarding feeling will increase. In this manner, it is concluded that robot implementation, such as marking out and material transportation, is a genuine need for many occupations.

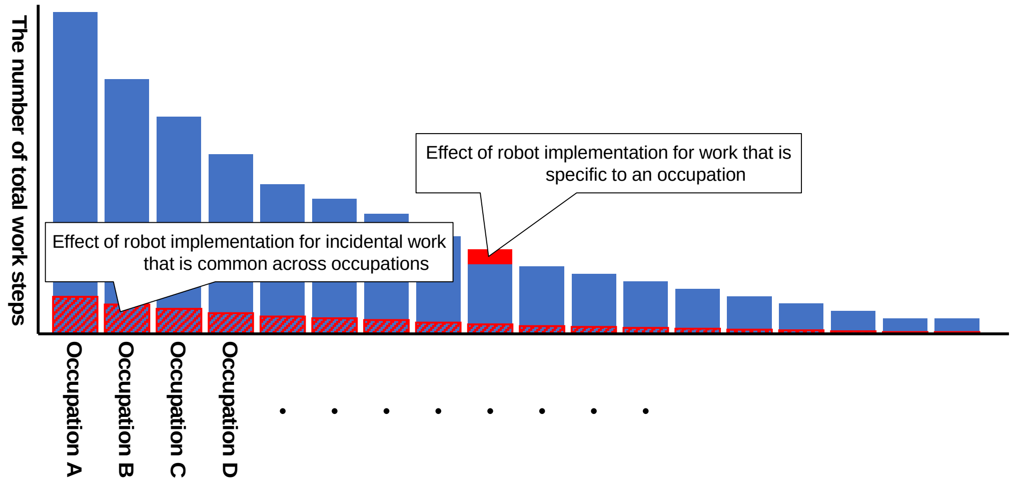


Fig.4 Total number of people by job type at construction site

4.2 Examining a Pinpoint and Simple Solution

When a robot has various functionalities, it becomes large and heavy, and its operations also become complex. Earlier case analyses have also shown that the initial costs increase, hindering its widespread use. Therefore, we decided to explore this issue in more detail to search for pinpoint and simple solutions that may work on the critical aspects based on actual needs.

In cleaning, a series of steps are followed, including garbage and dust collection from the site, their separation, and putting them in the garbage basket. A person can do all these tasks alone but assigning them to a single robot will require various functions and increase the difficulty. Therefore, instead of trying to replace all the work with the robot, the robot could replace only the work of sweeping the floor and collecting the garbage. Pinpointing the part (the longest in a series of work) and the most challenging part allows for narrowing the robot's functions and solving them with simple technologies.

Simplifying the technologies mounted on the robot allows the robot to become smaller and lighter and manufactured at a lower cost. Furthermore, the machine becomes easier to operate, which does not increase the burden on the user and makes it easier to become widespread.

4.3 Collaboration with Service Providers

Widely disseminating the robot without ending it at the trial phase requires considerable measures from the operational stage. Therefore, we investigated the production, operation, and support system after development from the initial stage of development and promoted early participation in robot development of the stakeholders of this system.

The stakeholders at the operation stage may include robot production/sales, possession/maintenance/rental, and on-site user support. There is also a need to continue improving and developing robot hardware and software in response to technological advances and new demands from users. We believe that it is essential for general contractors, robot manufacturers, dealers, rental companies, etc., who may be in charge of such aspects, to collaborate and develop from the initial stages to disseminate construction robots widely.

5 Current Construction Robot Development Cases

Mikita Miyaguchi*1 Kohei Nagata*2 Takehiro Tsuruta*3

Based on the above considerations, the "transport robot," "cleaning robot," "marking robots," and "remote control systems" developed by the authors in recent years are introduced in this section.

5.1 Transport Robots

Heavy construction materials are placed on carts and pushed by people. The daily transportation volume is enormous, and in some cases, over 1,000 carts are installed on a single site. Since transporting materials with a cart is time-consuming and labor-intensive, robots have been demanded to automatically transport materials or support human transportation.

Therefore, the authors developed two types of transport robots that could handle different situations. The first is the transport robot cart “Kamon” that automatically follows people. The other is the robot “Crawler TO” that assists in transporting the cart by going under a typical cart.

5.1.1 Auto-following Cart "Kamon"

Automatically driving a material transport cart requires advanced functions of automatic driving in the cart and the time and effort to secure a travel route and give driving instructions to the cart. Various issues must be resolved before the introduction of the robot. The auto-following cart “Kamon” is a technology that achieves efficient transportation and reduces burdens with the more straightforward function of following people and things without requiring advanced tasks up to automatic driving (Photo 1, Table 1).

“Kamon” can follow the first person or things recognized by the two-dimensional range laser sensor (LiDAR) placed at the front of the cart body. It also automatically avoids obstacles such as pillars, and it can follow without collisions. Since it can also follow a person and other carts, one can link several “Kamon” in a row and guide them. Meanwhile, it is equipped with an electric-assist mode by lever operation to handle cases that require accurate and delicate movements, such as loading and unloading from an elevator (Photo 2).

It also has a safety function for automatic tracking. “Kamon” has anti-collision bumper switches attached to the front and rear of the vehicle (Photo 3). An emergency stop is activated when encountering a person or vehicle. Additionally, using LiDAR installed in the front for the following function automatically avoids people that may enter its path from the side in the middle of a line of carts.

In this manner, the auto-following cart “Kamon” does not involve requiring it to perform all functions in an attempt to streamline material transportation but instead limits the functions to be installed and help humans in decision-making regarding changes in the travel route and environment to reduce the labor and cost of introducing robots.

Photo 1 Auto-following cart "Kamon"

Table 1 Specifications

Loading platform length	1250 mm
Loading platform width	800 mm
Loading platform height	360 mm
Mass	190 kg
Maximum load capacity	600 kg
Traveling speed	Up to 4.5 km/h

＊2 Manager, Western Japan Engineering Depot
＊3 Chief Researcher, Research & Development Institute

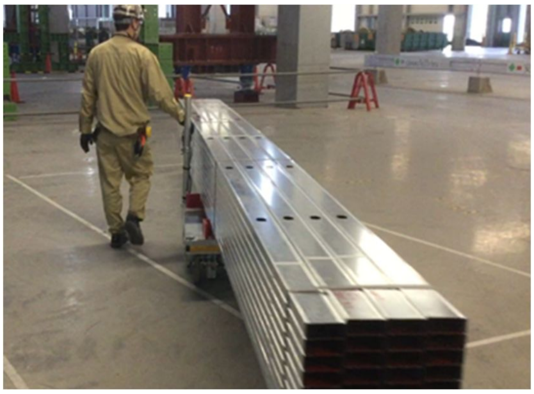


Photo 2 Electric assist mode

Photo 3 Collision prevention bumper switch

5.1.2 Transport Robot "Crawler TO"

Ready-made carts used for transporting materials and equipment at construction sites are generally four-wheel casters. Moving a cart loaded with heavy objects is a very labor-intensive task, and a considerable amount of labor is required for moving materials on steps, slopes, etc. (Photo 4). The “Crawler TO” is a robot that facilitates the movement of these ready-made carts (Table 2).

The “Crawler TO” is designed to be at a height that allows it to go under a four-wheeled cart (Photo 5). After going underneath a cart, the robot uses a lifter mechanism set up in the center of the robot to raise the top by 25 mm, and the materials and equipment are lifted together with the cart (Photo 6). Now integrated with the cart, the robot can be moved by remote control operation. This allows skilled workers to move equipment and materials without exerting force on the cart.

The omnidirectional crawler mechanism “OMNICRAWLER” is used for the movement mechanism of the “Crawler TO” in consideration of high running performance on rough terrain (e.g., steps and climbing slopes) and rough roads (Photo 7). The “OMNICRAWLER” is a mobile mechanism that machine manufacturers have put into practical use based on the research results of Associate Professor Kenjiro Tadakuma of the Tohoku University Graduate School of Information Sciences [4)]. The rotation of the standard crawler mechanism enables movement in the front and back directions, and the rotation of the rolling mechanism allows movement in the left and right directions (Fig. 5).

P

Photo 5 Construction site cart and "Crawler TO"

Photo 6 "Crawler TO" submerged state

The operation of “Crawler TO” can be performed with an application dedicated to smartphones (or tablets) (Photo 8). The robot is designed so that a skilled worker can operate it with one hand by connecting to the robot body via Wi-Fi. The robot’s driving directions include four directions forward, backward, left, and right; diagonal movement; and 360° turning. Furthermore, the battery level can be checked on the smartphone screen. Specifications using a joystick are under development in addition to the operation method using smartphones and tablets.

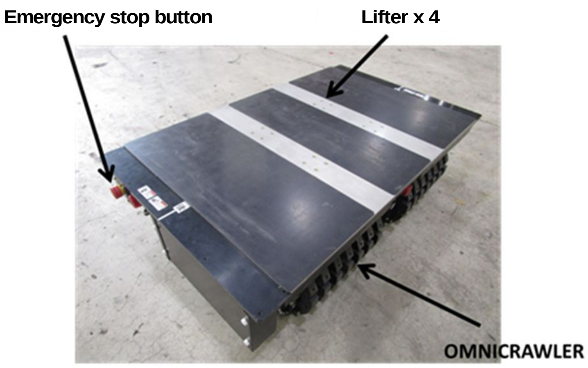
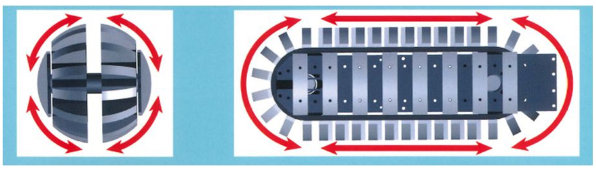


Photo 7 Functional Configuration of the Transport support robot "Crawler TO"

Table 2 Specifications

Item	Specifications
Movement mechanism	Omnidirectional OMNICRAWLER
Size	W:540×D:920×H:246 mm
Dive height	Over 250 mm
Lifter mechanism	Electric rack and pinion
Lifter elevation height	25 mm
Load capacity	Up to 500 kg, towing up to 1,000 kg
Mass	120 kg
Driving speed	3 km/h
Allowable step height	25 mm
Climbing angle	10° (~1/6) *robot alone: 20°
Battery capacity	480 W lithium ion battery
Operating time	2–4 h
Operation method	Smartphone Wi-Fi



Rolling mechanism Crawler mechanism

Fig.5 Mechanism of OMNICRAWLER

5.1.3 Deployment Status and Future of Transport Robots

These two transport robots have been appreciated on-site and have already achieved operational results in various construction works. Rental companies have also increased their own rates of these robots as products, and the operation rate is also at a high level. We plan to increase production of the same type of machine, increase variations such as miniaturization and upsizing according to the site’s needs, and gradually apply this to other applications regardless of construction or civil engineering.

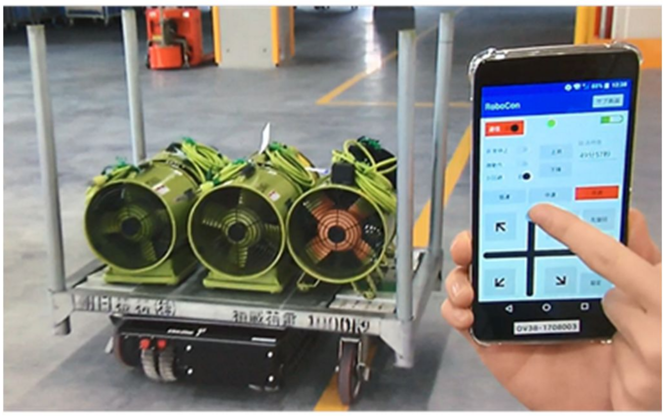


Photo 8 Operation smartphone screen

5.2 Sweeping Robots

The work of sweeping dust and building material scraps generated at construction sites at the end of the day is performed by skilled workers themselves. The increased amount of time spent is a factor that hinders productivity and affects health. Therefore, there has been a demand for a robot that saves labor and workforce in sweeping work.

The authors have developed two cleaning robots: a sweeping robot “To Gather” that collects large cotton-like dust, such as refractory covering materials, and a suction cleaning robot “AX Kyuiin” that can even suck and clean fine dust.

5.2.1 Sweeping Robot "TO Gather"

In spraying a semi-wet type refractory coating on steel frames, a large amount of refractory that does not adhere to the steel frame thus keeps on falling to the floor (Photo 9). Around one-fifth to one-fourth of the daily work, time is spent on sweeping this material, and there has been a need for a solution that increases work productivity and improves the working environment.

Therefore, in collaboration with a trading company that sells robots, we developed a sweeping robot “TO Gather” that collects cotton-like dust that was generated at construction sites as a measure to reduce the burden on skilled workers at construction sites and factories (Photo 10).

In the development of “TO Gather,” it was assumed that skilled workers would use the robot themselves. The goal was to make the operation simple and inexpensive by narrowing down the functions to the extent possible.

Color cones that are commonly used in construction sites are set up at the four corners of the area to be cleaned. Further, the start button of the robot is pressed, after which the laser scanner of the robot confirms the color cone markers and automatically determines the sweeping area and generates a sweeping route to begin sweeping autonomously. As the robot collects the waste in one direction, it is easier for humans to dispose of it later (Fig. 6).

In the case of cotton-like dust, conventional suction cleaning robots quickly become full. Thus, there is a hassle emptying the waste in the robot tank. However, since “TO Gather” only collects trash on the floor by sweeping them to one side of the sweeping area, this does not provide any hassle of throwing away waste in the robot tank. The cleaning time can be significantly reduced since the skilled worker gathers the debris collected on one side after the work is completed. This enables the skilled worker to utilize the time during the conventional work time that was set aside for sweeping to more productive work (main work). This enabled a skilled worker to increase the area sprayed per day during fireproof coating spraying work from 80 m^2 to 125 m^2, which was an increase of approximately 1.5 times.

Furthermore, this does not require a large dust suction tank or suction motor, unlike the suction type. Hencrobot’s weight robot can be reduced to 30 kg or less, and this becomes a handy robot that even a single worker can use.

Photo 9 Cleaning work in fireproof coating work

Photo 10 Sweeping robot "TO Gather"

5.2.2 Suction cleaning robot ”AX Kyuiin"

Construction work involves a significant amount of time on cleaning work other than fireproof coating spraying work. Therefore, the suction robot “AX Kyuiin,” which automatically cleans floor surfaces, was developed in collaboration with an industrial cleaning machine manufacturing company and two rental companies.

Similar to “TO Gather,” “AX Kyuiin” is a robot designed not only to collect large dust but also to suck fine dust to make the floor cleaner (Photo 11). Automation is achieved by attaching a laser sensor to an existing easy-to-use hand-push industrial cleaning machine and installing an application for automated driving.

At the beginning of development, the robot only had the function of recognizing color cones (markers) that were installed at the four corners and autonomously running inside this area in a single stroke similar to that of “TO Gather.” However, improvements in the automatic driving algorithm, an obstacle avoidance function (Photo 12), and a function to return to the vicinity of the start position after cleaning were added.

Photo 11 Suction cleaning robot ”AX Kyuiin"

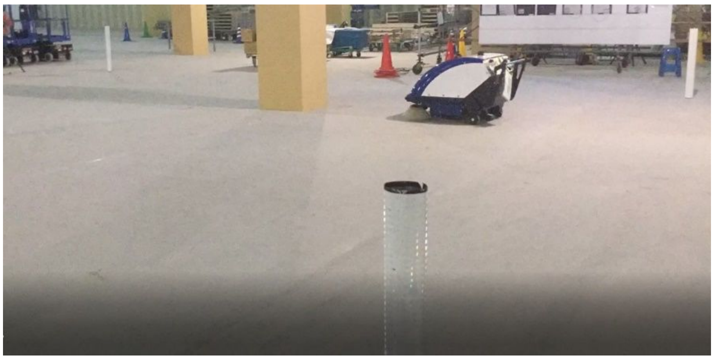


Photo 12 Verification of obstacle avoidance function in the sweeping area

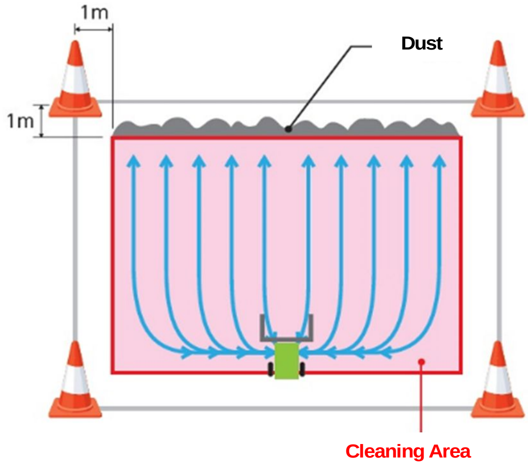


Fig.6 Setting up sweeping areas and routes

5.2.3 Deployment Status and Future of Sweeping Robots

Similar to the previously discussed transport robot, these two types of cleaning robots have been exceptionally well received on-site and have already achieved operational results in various construction works. Rental companies have also increased their ownership rates of these robots as products, and the operation rate is also at a high level.

We plan to increase the production of the same type of machine in the future and meet the market’s needs.

5.3 Automated Mobile Marking Robot

Marking work in construction is not necessary only for a specific occupation, but is also indispensable for many fields related to construction work. We thought that introducing a robot would be a massive effect if we could develop a low-cost and easy-to-use robot that automates the marking work common to various occupations; hence, we developed the marking robot. The development of the prototype has been completed to date, and its effectiveness has already been confirmed by applying it to several sites. Currently, we are developing a commercial machine in collaboration with a construction equipment rental company.

5.3.1 Achieving Both Accuracy and Low Cost

Previous examples of marking robot development by other companies [5) 6) 7) 8) 9)] used a complete station that measured the position while tracking the measuring prism attached to the robot for the accurate position control of the robot. However, this was a barrier to reducing the cost of the robot since even cheap products cost more than 2 million yen. Therefore, the authors focused on a 3D laser surveying instrument, which is relatively more affordable than a total station (Fig. 7). This has the problem of highly accurate robot movement control because it does not have the function of measuring the position while tracking the moving prism. Therefore, we devised a marking robot control method that uses this surveying instrument and camera images. The marking robot is equipped with a mechanism for drawing characters or figures on the floor on an independent two-wheel-drive mobile cart platform (Fig. 8). The laser surveying instrument irradiates a range-finding laser toward the marking position. The marking robot moves to the marking position and stops after reaching it. At this time, accurate position information cannot be obtained while moving, unlike the method using a tracking type surveying instrument. Therefore, there will be a gap between the marking and stop positions if proceeding in the preset direction and distance. For this reason, measuring the laser spot position (Fig. 9(a)) that is projected on the light-receiving plate at the stop position using the camera image (Fig. 9(b)) enables the accurate calculation of the deviation between the marking position and stop position, thereby achieving high-accuracy marking.

Fig.7 3D measuring instrument

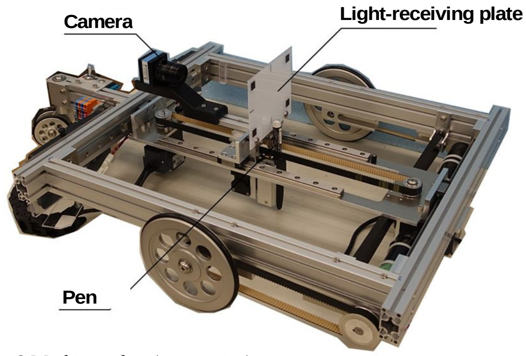
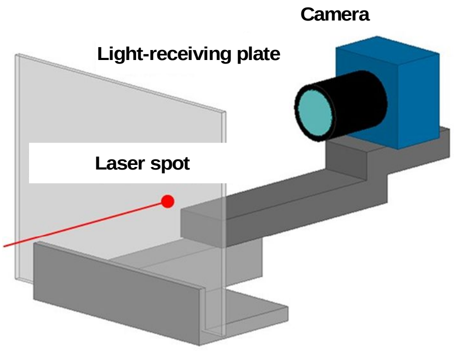
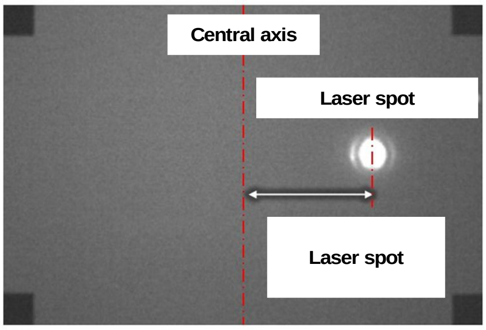


Fig.8 Marking robot (no exterior)



(a) Laser spot on the light-receiving plate



(b) Camera image

Fig.9 Principle of position measurement

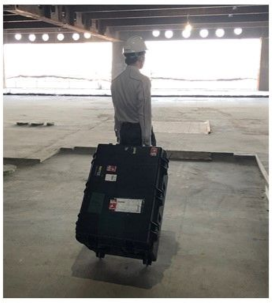
5.3.2 Simplification of Preparation Before Starting Work

Marking robots that have been developed to date are large and heavy, which was one of the factors hampering their widespread use on site. The authors achieved a compact and lightweight robot with external dimensions (W) 450 mm × (D) 730 mm × (H) 320 mm and a weight of 20 kg (Fig. 10(b)) by adopting a drawing mechanism based on the pen plotter method (Fig. 10(a)), which has a simple structure, and the selection of appropriate parts. On-site delivery is possible by courier, and transportation within the site is accessible (Fig. 10(c)).

The marking robot work requires settings of figures and characters, including their locations on the site. As this is not realistic for the operator to manually select on an individual basis, we have developed an application that can easily create work data for the marking robot in a short period by utilizing CAD data.

(a) Pen plotter

(b) Marking robot appearance



(c) On-site transportation

Fig.10 Small and lightweight marking robot

5.3.3 Improvement of Work Efficiency

Reducing the moving distance to the marking points scattered on the site effectively improves the efficiency of the marking work. The problem of performing marking work by the shortest route without waste regarding the marking centers scattered in the work area is similar to the traveling salesman problem (TSP). The TSP involves several cities on a map and finding the shortest route between all the closed routes that visit all cities once and return to the original city. We implemented an algorithm to solve the TSP in this robot so that we can work in the optimal route. It was confirmed that the shortest path was generated while avoiding obstacles (Fig. 11).

5.3.4 Deployment Status and Future of Marking Robot

The marking robot has been demonstrated at seven construction sites (Table 3). The most critical performance metric, marking accuracy, is comparable to other companies’ advanced development cases. Comparisons of the work amount of the robot with the work amount per skilled worker in terms of work efficiency showed that, although there were significant variations depending on the marking, the work efficiency in the case of keeping the anchor position in an automated warehouse was high at 300%. There are various types of marking, and it could be considered that the robot could handle multiple occupations.

In the future, we will collaborate with a rental company and develop robots to improve convenience further to start the service in spring 2022.

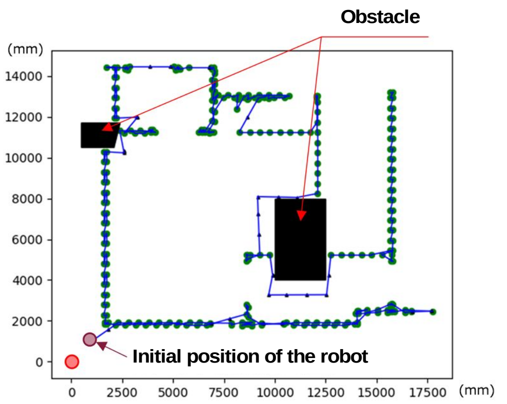


Fig.11 Confirmation of Work Efficiency Improvement Technology

Table 3 Results of Field Demonstration

No.	Building Type	Area	Marking type	Number of marks	Precision	Work efficiency
1	Office	40m^2	Free-access floor	182	3mm	33%
2	Housing	20m^2	Free-access floor Anchors for facility	92	1mm	-
3	Office	200m^2	Partitioning wall	62	2mm	-
4	Office	120m^2	Free-access floor	524	2mm	33%
5	Factory	225m^2	Partitioning wall	249	3mm	-
6	Housing	20m^2	Floor QR code for AGV	393	2mm	200%
7	Office	200m^2	Anchors for automatic warehouse	405	1mm	300%

5.4 Remote Control System

Remote control technology for construction machinery, such as tower cranes and robots, has the potential to free skilled workers from the location constraints of the site. This enables the acceptance of workers who do not have confidence in their physical strength (e.g., elderly individuals and women) or the remote operation of multiple construction machines or robots alone. This improves the working environment and productivity of skilled workers.

5.4.1 Tower Crane Remote Control System "Tawa Remo"

As the number of construction workers decreases, it is becoming difficult to secure operators for tower cranes, and there is concern that the number of skilled operators will decrease. Furthermore, many tower cranes have been highly self-supporting in recent years, and operators need to move up and down a ladder up to 50 m to the cockpit installed in the turning section every day. Once in the cockpit, the worker works in a high-altitude and constantly-swaying environment until the end of the work. This is a heavy physical burden, particularly on elderly operators, and there was an urgent need to reduce the physical burden and improve the working environment. Therefore, we developed the “Tawa Remo” technology, which allows for remote operation of a tower crane, collaborating with a general contractor and construction equipment rental company.

This system can operate the tower crane remotely from the dedicated cockpit installed on the ground. A high-performance camera and vibration sensor are installed on the tower crane side. The image obtained from the cockpit of the actual tower crane is displayed on the monitor screen, and even the sound and vibration can be experienced on the cockpit side (Fig. 12). As a result, the tower crane operator could operate the tower crane from a distance as if it were the cockpit. Furthermore, “Tawa Remo” enables a cockpit to be installed far away, and installing cockpits on various bases reduces the travel time to the site.

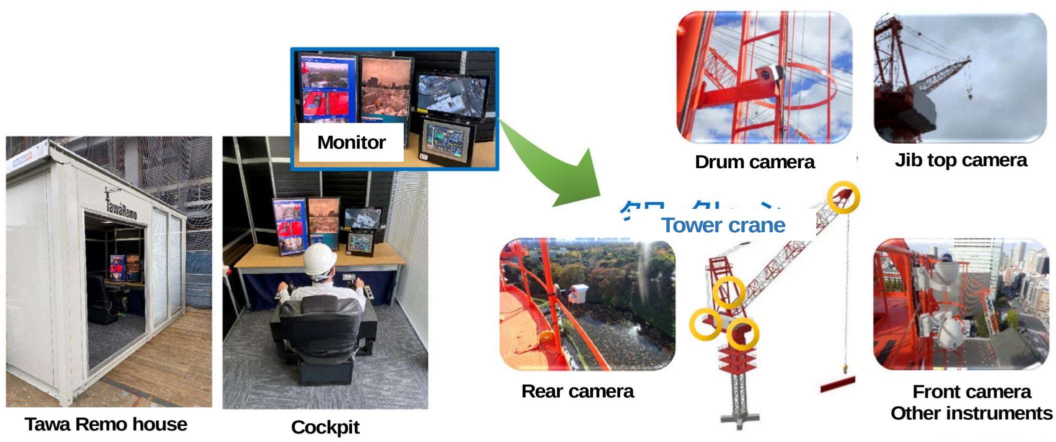


Fig.12 "Tawa Remo" System Overview

5.4.2 Deployment Status and Future of Remote Control System "Tawa Remo"

Currently, “Tawa Remo” is in the process of a trial run at an actual construction site. The system will be installed in the tower cranes that the two rental companies own, and the operation and maintenance of the cockpit will be shared, with full-scale operation scheduled to start within FY2021. Additionally, since multiple cockpits can be placed in one location to control numerous tower cranes remotely, one skilled operator could provide guidance and education to various operators simultanesously to pass on and improve the technology (Figs. 13 and 14 and Photos 13 and 14).

Fig.13 Simple cockpit

Fig.14 Dedicated cockpit


Photo.13 Crane in operation


Photo.14 Operation seat at the top of the crane

6 Conclusion

Mikita Miyaguchi*1

In this study, we identified the robots needed at construction sites. We have also analyzed the issues that can improve the introduction effect and create new ways of thinking and developing policy based on the knowledge obtained from past cases. Furthermore, we outlined the newly developed transport robot, cleaning robot, marking robot, and remote control system for tower cranes in collaboration with major general contractors. We want to encourage digital transformation (DX) of the construction industry to achieve a new era of construction sites where humans and robots can comfortably co-exist and create an attractive construction industry with further improvements in safety and productivity.

We will collaborate with other companies, such as the Construction RX Consortium [10] to promote the spread and development of these robots while further improving them to improve convenience and performance. We will also develop these technologies and promote the development and introduction of new robots adapted to the work content that is expected to be highly effective in introducing robots.

Acknowledgments

We have received a great deal of cooperation from Kajima Corporation, Nikken Corporation, Topy Industries, Okaya & Co. Ltd., Howa Machinery, Asahikizai Co. Ltd., Aktio Corporation, and Kanamoto Co. Ltd. for the development, operation, and dissemination of robots and remote-control systems that were introduced in this paper. We want to express our deepest gratitude to them here.

References

1) Tabulation from the Ministry of Internal Affairs and Communications Labor Force Survey (no national aggregate results in 2011 due to the impact of the Great East Japan Earthquake) https://www.stat.go.jp/data/roudou/index.html

2) Tabulation from Cabinet Office “National Accounts,” Ministry of Internal Affairs and Communications “Labor Force Survey,” and Ministry of Health, Labour and Welfare “Monthly Labor Statistics Survey.”
Labor productivity = Real gross value added / (number of workers × total annual work hours)
https://www.esri.cao.go.jp/jp/sna/data/data_list/kakuhou/files/2019/2019_kaku_top.html
https://www.stat.go.jp/data/roudou/index2.html
https://www.mhlw.go.jp/toukei/list/30-1.html

3) Koji Hamada, Production Technology Research Department, Obayashi Technical Research Institute, Transition of robot implementation and automation to date,
11th Workshop of the Architectural Institute of Japan “Current Status and Prospects of Building Construction Support Technology to Address Labor Shortages” (March 2018)

4) Kenjiro Tadakuma, Osaka University, Developmental research on a super symmetrical exploration robot that is mechanically robust against falls on rough terrain, KAKENHI (Grants-in-Aid for Scientific Research) Research Results Report (June 2013)

5) Tanaka, K. et al. Development of marking robot working at building sites, Proceedings of the 12th International Symposium on Automation and Robotics in Construction, 235–242, (1995)

6) Jensfelt, P. et al. A Mobile robot system for automatic floor marking, J. Field Rob. 23, 441–459, (2006)

7) Inoue, F. et al. Development of high accuracy position marking system in construction site applying automated mark robot, Society of Instrument and Control, Engineers Annual Conference 2012, 819–823, (2012)

8) DPR construction, Laybot Shows Promise in Speed and Accuracy
https://www.dpr.com/media/news/2013

9) Kitahara, T. et al. Marking robot in cooperation with three-dimensional measuring instruments, Proceedings of the 35th International Symposium on Automation and Robotics in Construction pp. 292–299, (2018)

10) Establishment of a consortium on technical cooperation in the field of construction robots and IoT, released by Takenaka Corporation (September 22, 2021)
https://www.takenaka.co.jp/news/2021/09/03/