CURRENT RESEARCH AND DEVELOPMENT AND APPROACH TO FUTURE AUTOMATED CONSTRUCTION IN JAPAN

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ABSTRACT

Automated construction technologies have been developed and introduced in the Japanese construction industries since the 1980s. However, the construction industry remains a craft-oriented and labor-intensive industry with minimal automation of tasks. Automation of construction processes has potential significant effects on construction of buildings. This paper describes the history of research and development of automation technology in Japan and the advantages to using construction robots and automated building construction system at the field level, and examines possible application and requirements in future construction operations. In addition, current research and development of robotics technology is introduced with concrete examples.

KEYWORDS

Construction robot, Automated building construction system, Maintenance, Renewal, RFID, Humanoid robot

INTRODUCTION

The year 1980 has been called “the first year of the robot era” because industrial robots attracted a great deal of interest from the manufacturing industry. The construction industry also showed interest in adopting robotics technology in the construction site, because the technology was expected to improve productivity and working condition. Construction companies raced to develop various types of robots that was applied to actual construction site. According to the Architectural Institute of Japan, 150 types of construction robots have been developed in the field of building construction. However, not all of these robots have been used at the field level and many technological problems remain to be solved. Accordingly, it is necessary to develop future research and development approaches from a long-term viewpoint.

Based on the previous development of construction robots in Japan, this paper examines possible application of robotics technology in future construction operations and describes ongoing research and development on construction robots.

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HISTORY OF RESEARCH AND DEVELOPMENT ON CONSTRUCTION ROBOTS IN JAPAN

DEVELOPMENT OF VARIOUS ROBOTS (1980s)

Research and development on construction robots was actively conducted by major construction companies in the mid-1980s. The objective was to develop robots that can perform many dangerous work operations on the construction site and increase construction productivity. The committees for fundamental research studies to introduce robotic technology into construction process were established in the Architectural Institute of Japan and Japan Society of Civil Engineers. The results from the above-mentioned research and development gave birth to many construction robots between the 1980s and the 1990s.

The following task-specific construction robots were developed.

1. Robots for structure construction works, including fire-proofing, steel welding, iron-bar placing, concrete placing, concrete finishing, and remote wire-releasing.
2. Robots for work completion, including exterior wall spraying, ceiling panel placing, and light-weight wall panel handling.
3. Robots for inspection works, including outer wall tile inspection, and clean room inspection.
4. Robots for maintenance works, including coating glass cleaning, and floor cleaning.

Figure 1 shows some typical construction robots developed by Shimizu Corporation.[1] Other major companies also developed their own characteristic robots. The benefits of these robots to industry include freeing workers from dirty, dangerous labor, decrease in the number of industrial accidents, and consistently high quality products. However, productivity improvement, such as reduction of working hours and shortening of construction period, has yet to achieve expected results. Construction companies recognize that robotics technology is critical to future construction operations, and continue relevant research and development work.

DEVELOPMENT OF AUTOMATED BUILDING CONSTRUCTION SYSTEM (1990s)

In parallel to the development of construction robots, research and development on the automated building construction system was started in the 1990s. Combining the newest information technology for management control, the new construction system was developed by integrating automation technologies -various construction robots, automated conveyance system, etc., and construction technologies -prefabrication, unitized production, etc. A total of 12 systems has been thus far developed by eight construction companies and introduced on more than 20 construction sites. Figure 2 shows the automated building construction system developed by Shimizu Corporation[2],[3]. Table 1 shows the classification of the above-mentioned 12 automated systems.

The automated building construction system allows builders to work under weather-independent environment and free from dangerous and heavy labor, and risks of work at height, including potential fall hazard. In addition, good working conditions and prefabricated/unitized production techniques substantially contribute to consistently high
quality construction operations. Productivity is also improved by automated conveyance, assembly work, introduction of construction technology, and all-weather covering technology, thereby reducing working hours and shortening construction period. However, construction cost is not necessarily lower than that incurred by traditional construction method.

(Fire-proofing robot)  
(Steel welding robot)  

(Concrete finishing robot)  
(Exterior wall spraying robot)  

Figure 1: Examples of Developed Construction Robots

(Outer view)  
(Inner view)  

Figure 2: SMART System (Shimizu Corporation)
Table 1: Classification of Developed Automated Building Construction Systems

<table>
<thead>
<tr>
<th>Structure</th>
<th>Type of Plant</th>
<th>Plant Handling</th>
<th>Transportation</th>
<th>Assembly Handling</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRC</td>
<td>Fixed</td>
<td>Push-up Mechanism</td>
<td>Lower Floor Covering</td>
<td>Handling System</td>
</tr>
<tr>
<td>RC</td>
<td>Lifted-up</td>
<td>Lift-up Mechanism</td>
<td>Outer Mast Covering</td>
<td>Overhead Crane Lift</td>
</tr>
<tr>
<td>S/SRC</td>
<td>Lifted-up</td>
<td>Lift-up Mechanism</td>
<td>Mast on Column</td>
<td>Overhead Crane Lift</td>
</tr>
</tbody>
</table>

**THE PRESENT CONDITION OF ROBOTIZATION (2000s)**

Since overall construction activity has declined sharply after the collapse of the 'bubble' economy, many construction companies raced to win contracts of construction projects. Offering competitive price is most instrumental in winning contracts, and the use of construction robots and automation technology is severely evaluated in terms of cost effectiveness.

**Capability of existing construction robots**

There are not many construction robots which have been actually used on the construction sites. The 1997 survey by the Building Contractors Society of Japan revealed that 150 types of construction robots were developed, of which 21 robots were commercialized, including steel frame remote releasing system, concrete floor finish robot and wall panel handling robot. Figure 3 shows the steel frame remote releasing system developed by Shimizu. The following items are enumerated as factors that these robots succeed in practical use. It matched to needs of the site, it was possible to make to a small, light machine, and the operation is very easy, etc. The construction company and the manufacturing company established an intimate cooperative relationship from the development phase to each robot, and the improvement was done repeatedly from the prototype many times.

**Progress in automated building construction system**

The automated building construction system has been improved through the modification of automation level of machine equipment and simplification of temporary equipment, thereby making the system more cost effective. One typical example of the improved automated building construction system is Automated Building Construction System of Obayashi Corporation (Figure 4).[4] The system has already been introduced into four sites after it developed, and the improvement was added to this system every time it applied to a new site.
The majority of machine devices and the temporary equipment are diverted between sites, and a thorough simplification is done as for the temporary equipment.

Another example is the Shuttrise System of Kajima Corporation (Figure 5).[5] It is a highly mechanized construction method by integrating a newly developed building construction system in which large-sized precast concrete units are assembled. To achieve this system, a lift for construction was developed to carry very heavy materials and a mass overhead traveling crane was installed including a special automated lifting-up mechanism.

Application to environmental preservation and renewal project

Because of increased concern over environmental preservation, the construction industry has actively adopted robotics and automation technologies on the construction sites. The removal of such toxic substances as dioxin and asbestine has adverse effects on workers’ health and adjacent areas. Automation technology is regarded as an effective means to protecting workers from breathing hazardous materials in the air. The application of automation technology includes removing dioxin from the chimney of an incineration factory and asbestos inside the chimney. Figure 6 shows a dioxin removal system. [6]
With recent increase in the number of renewal projects, mechanization and automation have been strongly demanded. Investigation and repair works are conducted prior to renewal of a facility, and automation technology is expected to play an important role in implementation of investigation work. Accordingly, outer wall tile exfoliation investigation robot has been improved and used. Some construction companies are now working together to research possible application of automation technology in renewal projects.

APPLICATION POSSIBILITIES OF ROBOTICS TECHNOLOGY IN THE 21ST CENTURY

The following examines possible application of robotics technology in future construction operations from four aspects.

CORRESPONDENCE TO THE AGING SOCIETY IN CONSTRUCTION FIELD

It is obvious that the Japanese construction industry will face a substantial decrease in the population of productive age in the foreseeable future, while the number of persons in post-productive age will increase. Labor shortage should be solved by effectively using know-how and experience of skilled personnel in post-productive age on the construction sites. The manufacturing industry has been cooperating with universities to create a new production system under the leadership of Ministry of Economy, Trade and Industry. Although the construction industry has not taken concrete approaches, any production system based on know-how and experience of elderly persons will have to be created. Robotics technology, as well as information technology, will help elderly persons involving in production activity safely and comfortably.

IMPROVEMENT IN LABOR PRODUCTIVITY IN CONSTRUCTION SITE

It is thought that birth rate will continue to decrease. Since many young people today consider construction work to be dirty and undesirable, the labor pool is clearly draining. Young labors want to become independent in a short time without undergoing apprentice training over a long time of period. Moreover, the increased number of foreign workers will be employed if relevant regulations are eased. Although labor shortage may be solved to some extent, continuous efforts must be made to improve the production system and raise labor productivity. Because of accelerated increase of unskilled personnel, robotics technology is regarded as an effective means of raising labor productivity.

CREATION OF NEW INTELLIGENT SPACE INTEGRATING ROBOTICS TECHNOLOGY

With increase in the number of persons in post-productive age, one important issue is social security/aid to the elderly. In short, we must provide safe and comfortable living environment with the elderly. Housing designers will have to incorporate various means of improving the quality of life of the elderly. Also, public facilities, such as office, hospital, school and road, will have to be designed with sufficient consideration given to elderly friendliness. Not only elderly persons but young and middle-aged persons will ask for new architecture and
infrastructure that can meet the needs of diversifying life styles. Ubiquitous computing to connect the intelligent electric appliances, new sensing materials, and service robots will offer an opportunity to create a new living space that serves as a huge robot. It is one important issue to create a new intelligent space integrating new construction and robotics technologies.

**Efficient Maintenance and Renewal System of Social Infrastructure**

Maintaining and renewing building increases every year and will reportedly exceed 40% of Japan’s construction activity in 2025. The building constructed during the post-war period must be fully redecorated and demand for maintenance management or renewal is growing. Also, public facilities, such as highway, tunnel, subway, bridge, water and sewage, will be required for maintenance or full-scale renewal. Demolition work through the renewal must be conducted with sufficient consideration given to environmental effect. Robotics technology is expected to play more important role efficient and safe diagnosis, cleaning, renewal work and demolition work of aging buildings and public facilities.

**Research and Development on Future Construction Robots**

**Research and Development on Automated Renewal Construction**

Given a fact that the renewal market is expected to grow in the near future, the Building Contractors Society of Japan has surveyed mechanization or automation system suited to the renewal since 2001. Based on needs survey for renewal construction, the association examines effects of the proposed mechanization or automation systems and identifies technological problems to be overcome and application requirements for construction of structure, outer wall and interior finishing. [7]

Construction of structure focuses on anti-seismic reinforcement construction. The proposed system conveys and attaches heavy materials in narrow space. In outer wall construction, diagnosis and repair work of exfoliated mortar and tile of a concrete outer wall were selected. Repair work is done by the man-machine system equipped gondola with automation repair equipment. The removal of asbestos was selected in interior finishing. The asbestos sprayed on the wall, ceiling, and steel column and beam is removed. The sprayed asbestos exfoliates using both rotation roller brush and vacuum in order to prevent coarse particulates from scattering.

**Research and Development on Application to Construction Process of RFID Technology**

A RFID (Radio Frequency Identification) tag is attached to construction members/parts and gathers information about design, construction and attributes of members from a database. The database is updated with progress in construction process. As an example of the case to do the progress management of the installation work of certain parts, the progress of work is recognized by reading the RFID tag installed in parts and the installation places with the tag reader, and the data that corresponds in the database is updated. Information required for
parts production and supply, construction management, maintenance, and renewal can be obtained from the database, thereby improving efficiency of business operations.[8] Figure 7 shows the concept of integrated parts information system by using the RFID system. A construction robot obtains required information from the RFID system, and performs and controls a given work. Technical issues to be overcome include installation method of RFID tag into a member, data gathering method, operation and the control methods of the construction robot, and updating method of database. [9]

Figure 7: Concept of RFID-Based Integrated Parts Information System

DEVELOPMENT ON MAINTENANCE SYSTEM OF INFRASTRUCTURE

In order to prevent concrete from falling in a tunnel, diagnosis and repair system of concrete is being developed. The proposed nondestructive system uses blow sound, the electromagnetic wave, and infrared rays to investigate cracks and exfoliation of concrete. Research is also being conducted on the technology capable of real-time monitoring the state of concrete in a tunnel by using optical fibers or the like. Another research is being conducted on technological systems to detect the cave in the reverse-side of concrete in a tunnel constructed before World War II, and to fill up with the cave. Figure 8 shows cave detection system. [10] Regarding the bridge maintenance system, for example, a robot which can repaint the tower and body of a bridge has been developed.

Figure 8: Tunnel Cave Detection System (Shimizu Corporation)
RESEARCH AND DEVELOPMENT ON ROBOTICS FOR DISASTER RESTORATION

Based on lessons learned from the volcanic disaster of Mt. Fugen and the tragedy of the Great Hanshin Earthquake, research and development has been conducted on a "remote control robot" that can carry out fully automated construction using general-purpose construction machine in disaster area. Figure 9 shows remote controlled construction machines in Mt. Fugen.

Research was conducted on a nuclear disaster-specific robot after 1999 when the accident occurred at a nuclear fuel processing plant. Robots for information gathering, work surveillance, heavy material conveyance, and heavy-duty lifting were developed.

A national research project started in 2002, aiming at the development of a "rescue robot". Technological problems include sensing mechanisms, movement mechanisms, autonomous flight system, information gathering, environmental modeling, and human interface.

Previous research and projects resulted in the improvement of robotics technologies, including movement, operation, control, radio communication, and remote control technologies. Since these innovative technologies will contribute to the development of future construction robot, attention must be paid to the development trend.

RESEARCH ON THE APPLICATION OF A HUMANOID ROBOT ON CONSTRUCTION SITE

A national research project started in 2000, aiming at the development of advanced humanoid robot. Given a fact that most of construction operations require cooperation of two workers, a “man-robot” system was developed where a humanoid robot and a worker convey and assemble an outer wall panel of a building cooperatively. [11],[12]

Since conventional construction robots were a sort of automated machine, they could not achieve the required performance except in routine construction operations. However, the developed humanoid robot is able to manage irregular and complicated works and walk on the rough road. Moreover, the robot can work in harmony with the partner worker under the working condition where two workers assume responsibility. Thus, the humanoid robot is
expected to provide a breakthrough to robotization of construction works. Figure 10 demonstrates the cooperative work.

Figure 10: Exterior Wall Panel Conveyance and Assembly by Humanoid Robot

Figure 11: Vicarious Operation by Humanoid Robot

Figure 11 demonstrates "industrial vehicles vicarious execution operation", another application of a humanoid robot. The humanoid robot operates a construction machine -back hoe, for example – in accordance with instructions from the remote control room. Since the robot could be remotely controlled, construction machines do not have to be modified for disaster restoration work.

CONCLUSION

Robotics technology, including humanoid robots, progresses fast through recent research and development. Particularly, basic technologies, including technologies for movement, operation, control, sensing and image-processing, information processing/gathering, and remote control, will contribute to the development of advanced construction robots and to the creation of new living space.

At the advent of the 21st century, there has been decrease in birth rate and increase in post-productive aged persons in many countries, including Japan. The manufacturing and construction industries have to create a new production system to help solving the labor shortage problem. Since no advanced nations will enjoy high economic growth that they did several tens years, they have to establish a new system to meet social needs for maintenance management of existing housings and public infrastructure.

Robotics is expected to play a major role in meeting diversifying social needs. Keeping in mind that robotics is an important technological area, a road map should be created to advance research and development.

REFERENCES