"HUMAN-ROBOT COOPERATION TECHNOLOGY" AN IDEAL MIDWAY SOLUTION HEADING TOWARD THE FUTURE OF ROBOTICS AND AUTOMATION IN CONSTRUCTION

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ABSTRACT: The current construction industry has different environmental characteristics compared to other industries. Problems such as the instability of labor force demand and supply and the increasing labor costs are surfacing. Thus, in response to a high growth rate of the construction market, it is advisable to lower the level of labor force dependence and increase efficiency by applying a specialized automation in a construction site for improving its productivity.
Currently, a construction automation robot is being developed mainly as a professional service robot. The majority of its abilities rely on the human's control skill and its level of recognizing the external environment is also inadequate. It is therefore inappropriate to say that the complete and fully automation in construction is accomplished. A high level of environmental cognitive skill and such as the same level of human ability in judging the situation are needed at construction sites in order to accomplish complete automation. It is expected that in the future, the automation and robotics in construction would be replaced with robots having artificial intelligence similar to that of humans. However, the current level of technology cannot meet the specifications yet, it is appropriate to utilize the Human-Robot Cooperation (HRC) technology as an alternative to the current and future vision of robotics and automation in construction. The HRC allows a high efficiency at the present automation level because it uses both advantages of humans who have a remarkable set of nervous system and of robots which functions at a superior physical ability.

Keywords: *Human-robot Cooperation (HRC) Technology, Sensing Technology, Control Technology, System & Interface Technology*

1. INTRODUCTION

The construction projects, including the one under extreme circumstances, are done in various environments. This is one of the distinct characteristics of the construction industry which allows its work to be done on the ground, under the ground, or even underwater. Moreover, construction workers have to handle everything in an irregular environment from minimal subsidiary materials to heavy materials. This is the biggest difference compared to other industries, and this highlights the fact that a construction work is indeed a very difficult task.

As stated in part of the global construction market is continuously expanding amidst difficulties that still exist in construction sites. Until 2008, the average growth rate of the construction market was 17.3%, with 14.3% in the domestic construction market and with 22.3% in the overseas market. In 2009, the sales growth rate has declined due to the global economic crisis; the construction market's sales, however, have increased [1]. Compared to the increasing construction market, the construction sites are experiencing numerous difficulties due to labor shortage (Fig. 1).

The aging phenomenon accelerates all over the world. Consequently, by 2030, most countries, excluding the developing nations, will enter a super-aged society where people ages 65 and up comprise 15% of the population. Thus, the aging of construction site workers in most nations will lead to a shortage of skilled laborers. However,

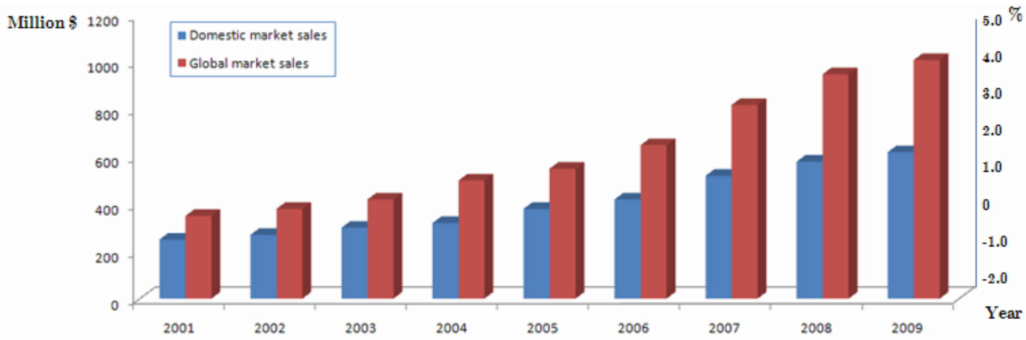
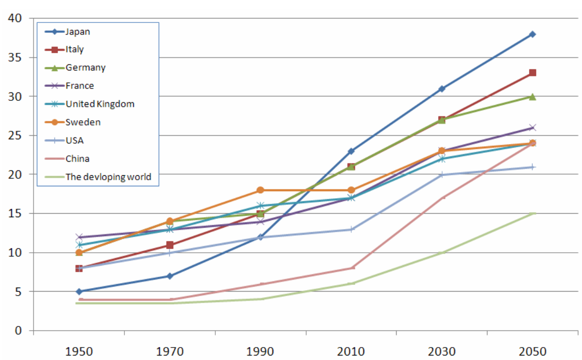
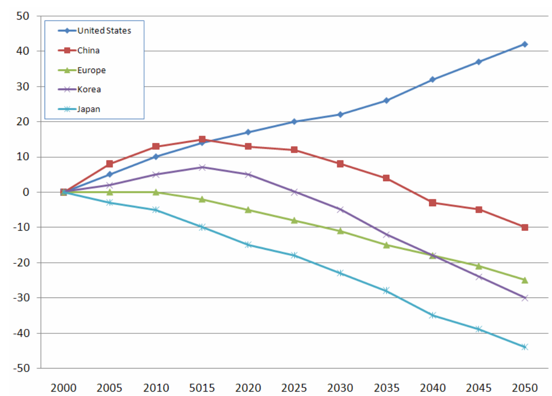


Fig. 1 Annual growth rate of construction industry ('01-'09)



(a) Aging society



(b) Labor force growth (growth in age 15-65)

Fig. 2 Impact of an aging labor force

the U.S. is expected to solve the shortage problem with its high birthrate [2]. Furthermore, there is a problem with manpower supply and demand due to the rising labor costs which increase annually while the construction labor cost is likewise on the rise (Fig. 2). Compared to other industries, the construction industry has lower labor productivity. This is why the rise in labor costs will lead to a problem of increase in construction costs rather than in productivity.

Another problem of construction industry is a high accident rate. As mentioned before, the construction projects are being done in many different environments, with highly dangerous tools being used. As a result, the accident rate in the construction industry is much higher than that in other industries. The construction accident rates take up 42% of the whole industrial accidents [3].

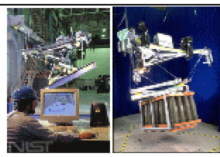
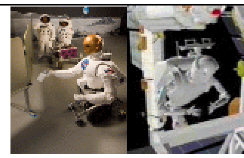
Therefore, it is urgent to come up with solutions that will help overcome these problems in response to a high growth rate of the construction market. The current construction industry has different environmental characteristics compared to other industries. Moreover, problems such as the instability of manpower demand and supply and the increasing labor costs are surfacing [4]. Thus, in response to a high growth rate of the construction market, it is advisable to lower the level of manpower dependence and increase efficiency by applying a specialized automation in a construction site for improving its productivity (Fig. 3).

2. CURRENT STATUS OF DOMESTIC AND FOREIGN RESEARCH AND DEVELOPMENT

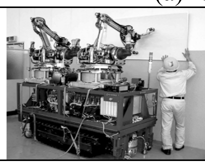
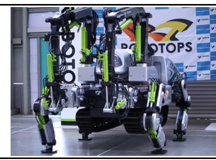
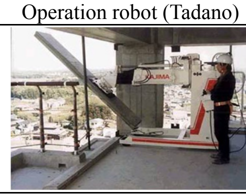
A. Current status in the US

Since the 1980s, the U.S. has been engaging in research and development in the construction automation field as part of its major national projects, such as its space development projects (Table 4). Its national research facilities, such as NASA and NIST, and several universities are leading the construction automation studies therein, and the representative research and development items are as follows:,

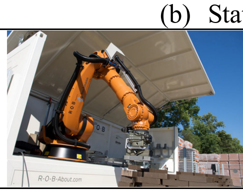
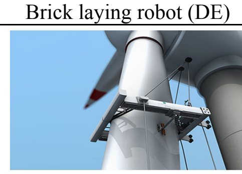
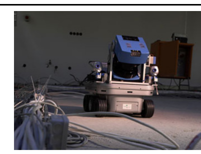
Table 1. State-of-the-art of automation and robotics

		
TETRA & RoboCrane (NIST)	Robonaut (NASA)	Pipe installation robot (NCS Univ.)
		
MPFR (AFRL)	Oil tank inspection robot (OTIS)	IES/ILS (Caterpillar/ CMU)

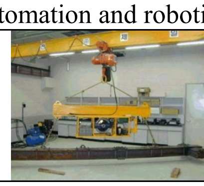
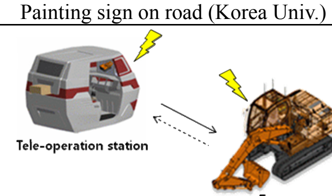
(a) State-of-the-art of automation and robotics in construction in case of US

		
Pannel installation robot (NIIS)	Operation robot (Tadano)	Painting robot (Taisei)
		
SMART (Shimizu)	Pannel handling robot (Kajima)	Concrete plastering robot (Takenaka)

(b) State-of-the-art of automation and robotics in construction in case of Japan

		
Brick handling robot (CH)	Brick laying robot (DE)	Automated robotic excavator (UK)
		
Demolition robot (SE)	Maintenance robot (DE)	Maneuvering robot (DE)

(c) State-of-the-art of automation and robotics in construction in case of EU

		
Hume installation robot (Inha Univ.)	Beam balancer (Samsung)	Painting sign on road (Korea Univ.)
		
Ceiling-glass installation robot (Hanyang Univ.)	Curtain-wall installation robot (Hanyang Univ.)	ITD for Intelligent Excavating System (Hanyang Univ.)

(d) State-of-the-art of automation and robotics in construction in case of South Korea

(1) automation of earth-moving equipment: application of automatic or semiautomatic DGPS (differential global positioning system), remote control and various sensing technologies;

(2) development of moving and working robots for extremely dangerous workplaces: nuclear waste and explosives disposal, and maintenance of a spaceship with a robot (Robonaut) via a remote control system;

(3) development of a multipurpose manipulator system for the handling and recovery of heavy materials: a laser sensor controls the member's transfer location and its transportation by evading obstructions;

(4) development of robotics for maintaining pavements and bridges: sealing pavement cracks, laying pipes, underground facility detection, underwater pier inspection, drain pipe inspection, etc.; and designing tools and equipment for improving work ergonomically.

B. Current status in Japan

Japan, a well-known robot powerhouse, had recognized the necessity of construction automation early on and started its related research and development in the 1970s. Thus, after being inspired by the manufacturing robots, which carried out rapid dissemination at the time, the testing and manufacture of numerous construction robots was begun by a large construction company as a countermeasure against the labor force shortage resulting from the aging of the construction labor force, the site conditions, etc. By the mid-1990s, Japan had produced tangible results by incorporating the field application of a fully automated building construction system, and showed promise of a large complex automated construction system through robotics (manless system) of an individual process, such as plastering robots, as well as the development and application of factory automation systems in large construction companies.

Currently, many companies, including large firms such as Sony, Honda, NEC, Matsushita, Mizubishi, and Omron, are set on taking over the personal-robot market, which is expected to become a mass market. Japan defines its research and development on construction robots, and its related business, over the next ten years as follows:

(1) application of humanoid robots at construction sites;

(2) automation of infrastructure safety evaluation and maintenance;

(3) robots for disaster recovery;

(4) automation of resuscitation construction; and

(5) application of RFID technology in construction.

C. Current status in EU

In Germany, Stuttgart University's Fraunhofer Institute for Manufacturing Engineering and Automation (IPA) conducted research on the demands and development cases of construction robots, and developed a supersized long-reach manipulator and an electro-hydraulic actuator equipped with a computer-aided loading (CAL) system. In the United Kingdom, universities are leading the development of construction robots. Nottingham University is conducting research on the construction

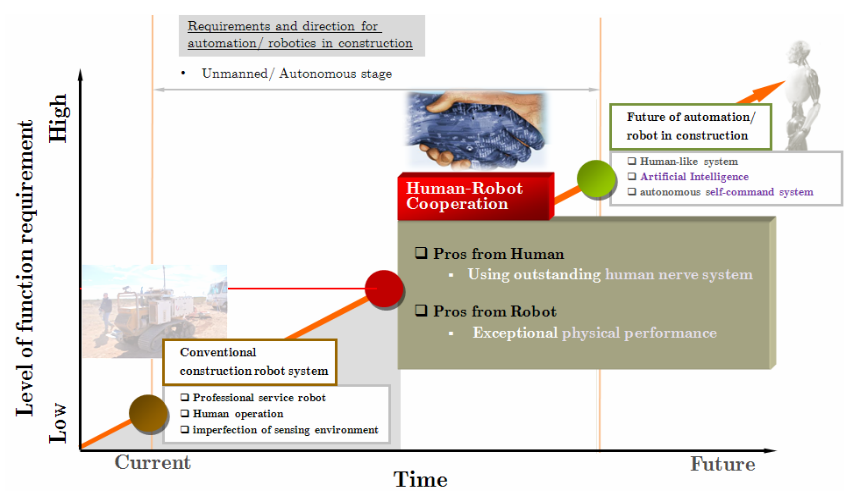


Fig. 3 In the middle of way to future vision of robotics and automation in construction

companies' use of artificial intelligence for project planning, and Lancaster University is conducting research on the automation of construction equipment such as an automated excavator. Wales University did a study on mobile-robot navigation and on bolt-welding robots for steel bridges. In Switzerland, ETH developed a robot bricklayer, which is an automobile with an articulated robot.

D. Current status in South Korea

In South Korea, from 1980 to 1990, the Korea Institute of Construction Technology (KICT) conducted theoretical research on the country's construction automation needs and on the selection of eligible construction companies. Additional researches on the automation of the existing equipment, including the semi-automation of vibratory rollers and tower cranes for field application, were also conducted. In the 1990s, the Korea Institute of Industrial Technology (KITECH) developed a high-performance robot for concrete floor finishing, and KIST and Samsung Heavy Industries Corporation developed an automatic steel-welding robot system. Since 2000, concrete-pipe-laying robots, automatic robots that control a PHC pile's vertical movement and cutting work, construction robots for curtain wall installation in a skyscraper, pavement-crack-sealing robots, pavement-sign-painting robots, and automatic robots for removing road signs using high-pressure water jet had been developed in the construction and maintenance field. Thus, various construction robots that carry out individual processes or tasks are actively being researched on and developed.

To this day, however, most of the related researches are being conducted by the government or universities because the construction companies' will or research capacity for

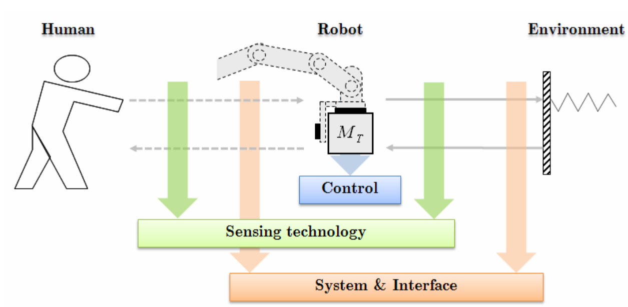


Fig. 4 Definition of HRC and its key technology

construction automation is insufficient, resulting in the inactive field application and evaluation of construction robots

3. IN THE MIDDLE OF WAY TO FUTURE OF ROBOT AND AUTOMATION IN CONSTRUCTION

Three things have to be considered for Human-Robot Cooperation technology HRC:

(1)Sensing technology for measuring interactions among humans, robots, and the environment,

(2)Control technology that make use of interactions,

(3)System and an interface for creating interactions among humans, robots, and the environment.

In a human-robot cooperation task, the sensing technology measures the interactions between a human and a robot, as well as between a robot and its environment. The sensing a robot, as well as between a robot and its technology measures the interaction between human and environment This technology includes a sensor, a signal processor, and a sensor fusion algorithm which comprehends the worker's movement intention by checking interactions between a human and a robot, and grasps the robot's current contact state with the environment. These signals serve as the controller's feedback or input and thus play an important role in developing the HRC controller.

In a human-robot cooperation task, a control represents the technology that operates robots using interactions among humans, robots, and the environment. In a HRC task, a closed loop is formed by a human as well as a robot's sensor and motor in terms of control. Therefore, the interactions among humans, robots, and the environment are measured by a sensor, entered by a controller. A motor command is then formed for the operation by selecting a suitable algorithm. The human controller creates the muscle movements based on the signals that are transferred through the nervous system; whereas, the robot controller creates the movements by moving each limb's muscle based on the environment signals that are transferred through the attached sensor.

The core technology of the 3rd HRC is a system and interface technology, a design technology that smoothly connects the sensing and control technologies. The system and interface technology enables the user's input signal to be transferred to the robot by being strong against the disturbances. This means that it has to be built in a way that it will resist damages so that the materials or the robot cannot be destroyed, as in the case of the robot contacting the environment. Moreover, it has to be designed so the disturbance information can be delivered to the worker again by the robot. Four factors have to be considered for these technologies to be possible. First of all, the robot system and interface has to be designed in consideration of the existing work process. Secondly, it has to be designed in a way that the force reflection from the environment can be delivered intuitively to the worker. Thirdly, it has to be designed so that the safety of the worker and the material is ensured. And lastly, it has to be designed ergonomically to the advantage of the worker.

4. SUGGESTIONS OF UTILIZATION STRATEGY FOR CURRENT ROBOT AND AUTOMATION IN COSTRUCTION

Construction automation researches have been actively conducted at home and abroad due to the definite needs in various respects. While Japan, however, one of the advanced countries in the world that spearheaded the research and development in this area, has developed approximately 170 types of robots, of these, only 20 types are at the stage of practical application. The most common reason is that it is impossible to acquire the same automation environment as in the general industry. The non-homogenization of construction sites and resources is a severe obstacle to a robot system that depends on sensing and intelligence. Construction deals with large objects, and the actual place of construction and its design are different. Thus, if a robot will be used at a site, the robot has to be moved, disassembled, and stored for the next use. In the latter case, it has to be assembled again at the construction site. Thus, it hinders the usability of the workers, which drives the workers to continue employing the existing construction method. The site workers who utilize the existing equipment are reluctant to receive training on new construction robots and other related systems. While the aforementioned issues may be seen as constraining factors or problems of construction automation, from another perspective, they are merely obstacles that must be overcome. Japan adopted a construction automation system, and albeit partially, experienced definite improvement in its construction work environment as well as increase in safety. It also opened up possibilities for all-weather construction, unaffected by the outdoor climatic conditions. In addition, factory automation has been adopted to address the issue of an individual automated robot's movement and to increase its productivity; this resulted in the dramatic decline of construction material dissipation. Semi-automation should be adopted preferentially: full automation in the standardized construction environment and man-machine collaboration in the mobile and non-standardized construction environment. Robotization for individual processes should be utilized gradually while a factory automation type of system, such as an automated large complex construction system, should be adopted for large construction projects. As the intensive arrangement and high-efficiency enhancement of IT-based information technology are taking place rapidly, the standardization of the construction process and the integration of design and construction, as well as the prefabrication and modularization of construction resources, have to be adopted. These will not only control the construction materials, the field workers' movements, and the work efficiency but is also intimately linked to the adoption of robotization through the standardization of the construction materials.

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