AUTOMATION AND ROBOTICS IN CONSTRUCTION, STATE OF THE ART IN JAPAN

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ABSTRACT

This paper reports on the current state of the art in automation and robotics Research and Development (R&D) activities in Japanese construction industry. At present, building constructions are activated and a shortage of construction workers has been serious in Japan. Accordingly, there has been a growing need for automation and robotization of construction operation to overcome this problem.

R&D of construction robots are generally conducted by general contractors, however, the R&D was not in time to make the serious labor shortage relieved. Various kinds of automated construction equipments have been developed for construction field application in such areas as concreting and finishing operation, however, they are not practical enough. Recent R&D is concentrated in more practical and overall system automatization using robotic technology. A turning point is coming in construction Automation and Robotics in Japan changing R&D policy from stand alone robot development to system integration combining advanced technologies.

1. INTRODUCTION

From 1988, a prosperous economy prevails in Japan and investment in the construction industry is growing rapidly. Particularly in large cities, a lot of construction projects are being planned or are already under way. In such a circumstance, the shortage of skilled construction workers has become prominent, especially in building construction using formwork carpenters and reinforcing steel fabricators. The shortages of these workers have resulted in sharp increase in labor wages, thus creating further escalation in construction costs.

In 1982, research and development (R&D) in automation and robotics (A&R) for construction operations started in Japan, developing a construction robot to improve in operating efficiency, to eliminate works in hazardous environments, and to save labor force. Motivation at initial stage of R&D was to free workers from hazardous operations. The aims of R&D have been shifting to save manpower and improve productivity at sites. This R&D covers various aspects of construction work such as reinforcement assembly; placing, screeding, and finishing of concrete; erecting and welding of structural steel exterior finishing and painting; and interior finishing. Recently, automated construction systems applied robotic technology are experimented at several building construction and civil works. They could save manpower successfully to propose an advanced construction system for future generations.

The objectives of this paper is to describe the state of the art of construction A&R in Japanese construction industry.

2. BACKGROUND OF A&R SYSTEM DEVELOPMENT IN CONSTRUCTION

The basics of the background for automation and robotization of construction work have not changed for these years. However, the volume of construction work has increased rapidly during the past several years, due to which the shortage in skilled workers has become even more serious. Consequently, the need for further A&R in the construction industry is no longer an imagination but a reality which must be accepted.

Figure 1 shows investment growth of the construction industry in Japan. As can be comprehended from this chart, the amounts invested in construction have increased sharply in the past three years. Figure 2 shows the total contract amount of orders awarded by major Japanese construction companies (50 major contractors). These amounts have rapidly increased during the past few years, especially in building construction. Almost all construction companies which are interested in and promoting construction A&R are included in these 50 firms.

With such rapid increase in construction volume the shortage of construction workers has become more and more serious. Figure 3, shows the shortages of skilled labor for construction comparing to various industries. The ratio of shortage in the construction sector is higher than others, and this gap has increased after 1987. Skilled construction workers such as reinforcing steel fabricators, masons, and

formwork carpenters have risen to the highest level of shortage. As a consequence, delays in construction projects have been common in Japan.

Under such circumstances, a strong demand for development of A&R systems enabling work to be done with fewer workers rose in the construction industry. Development of practical construction A&R systems to perform various construction works has become near term R&D goals for many contractors.

3. CONSTRUCTION A&R SYSTEMS DEVELOPED IN JAPANESE CONSTRUCTION INDUSTRY

Construction companies which are committing construction A&R are activated in A&R of construction work for the past ten years. Unlike general purpose construction equipment, construction robots generally have not been identified, and construction equipment manufacturers have taken negative attitudes to robot development up to now. Therefore, major construction companies have assumed the leadership in development of A&R in construction. Almost all theses companies have researchers and construction experts who are knowledgeable about actual on-job operations and and interested in improving construction systems introducing advanced technologies. These human resources have provided a strong base for major construction companies to aggressively perform R&D in this area.

In the past several years, construction equipment manufacturers have joined the construction A&R activity participating in producing hardwares cooperating with these construction companies. A&R systems developed for construction work announced since 1982-1991 are listed on table 1.

To describe the features of recent development examples by type of work, a large number of cases are concentrated in concrete construction-related works, and interior and exterior finishing related operations. The cases of development are concentrated in floor concrete work, and automation and robotization have been pursued to cope with the various steps of placing, screeding, and finishing. In interior finishing, there are examples aiming for automation of fixing gypsum boards to ceilings, and development of a manipulator for aiding in sticking boards to walls. For exterior finishing work, robots that perform pneumatic application of coatings to the exterior walls of buildings have been developed by three firms. Tele-operated equipments developed for simple operations, also called "Robot", were developed and are on market.

4. CURRENT R&D TRENDS IN CONSTRUCTION A&R

4-1 System Automation

From 1990-1991, several construction companies have paid much R&D effort to introduce automatic construction systems into actual sites. Their activity includes to establish a new construction method, and to develop automatic equipments and computer management network for the system. Original concept for the system automations has come from "Site Automation" which has been proposed before, recent examples developed are the first 2 step for implementation[1].

From the industrial point of view, every trial at sites using a new method or approach are regarded as one of the beneficial business. Robotics engineers and site managers involved in these R&D were so successful overcoming various kinds of technical problems and tough negotiations from the initial stage of planning through actual operations. There might be some contribution of their experience developing stand-alone construction robots shown on Table 1[2], [3], [4].

4-2 Developing Multi-purpose Manipulator For Building Works

A lot of single task robots and prototype machines have been developed in these ten years. A new trend is to use a multi-purpose manipulator exchanging endeffectors or tools for tasks. Applied tasks for the manipulators are heavy components handling arm and mobile manipulator for vertical wall surface works. Their performance and system architecture are completely different, however, they will be more practical to be applies to many tasks obtaining potentials[5], [6].

4-3 Transportation Automation

At a large scale tunnel construction site and nuclear power plant construction site, advanced material and component transfer systems automated by using robotics and computer technology were successfully applied to save labor force and to shorten construction period. They could be a good example applied factory automation engineering to construction material handling. Transfer system with sensors feedback, computer network for planning and production control, robotic arms to pick up and position components and information transfer code system have worked well under hazardous environment for electronic components[7].

4-4 Research On Advanced RoboticTechnology

Robotics engineers in construction companies are very aggressive to get an advanced robotic technology such a fuzzy control, neural network, sensor fusion, flexible arm control and artificial intelligence.

These efforts are executed as an inhouse research at their institute however, a few examples became visible by their report papers(8), (9).

4-5 Accelerated R&D On A&R

Many construction companies are shifting their A&R to one of the major R&D targets in their companies, recruiting engineers in robotics, electronics and computer science. Their organization for A&R are including not only research institutes but also other divisions such as design, planning, engineering and construction to increase the capability applying A&R to their business(10).

Enhanced R&D potential for A&R could realize an overall advanced system integration for a tunnel construction and civil works. Reviewing these projects, many clients, governmental agencies and electric companies are understanding and heavily will be involved to promote A&R activity at their construction sites in the near future(11), (12).

5. CONCLUSION

Many Japanese construction companies have made an excellent developments on A&R in construction for these 10 years. Their efforts are directing more practical area from developments of stand-alone robot system for specific construction work. Recent phenomenon on construction A&R in Japanese construction industry indicates that A&R technology are supporting improved construction projects from an early stage in a sophisticated way.

Details of their advanced A&R system will be reported at technical conferences and in journals.

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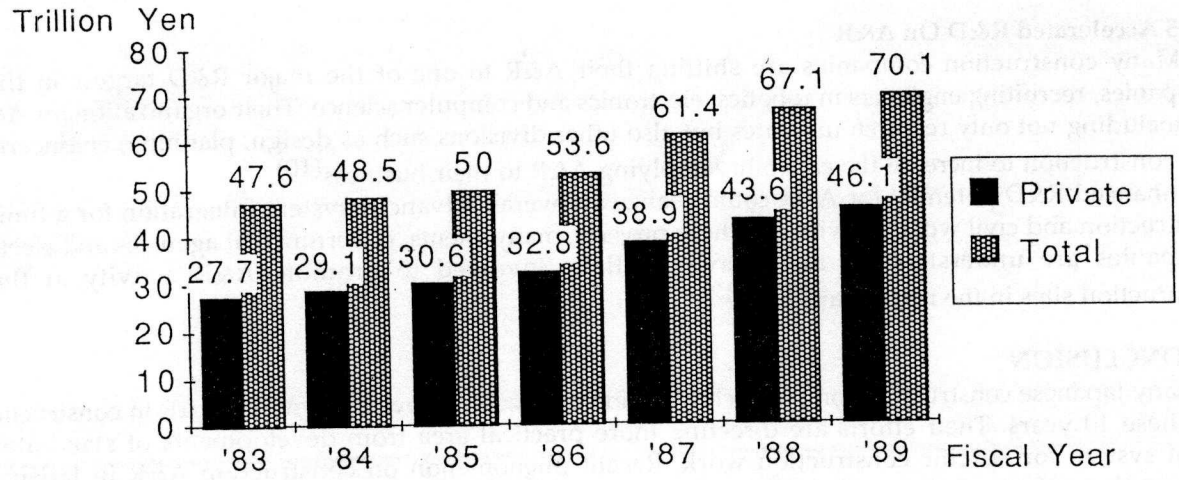

Figure 1 Investment in Construction

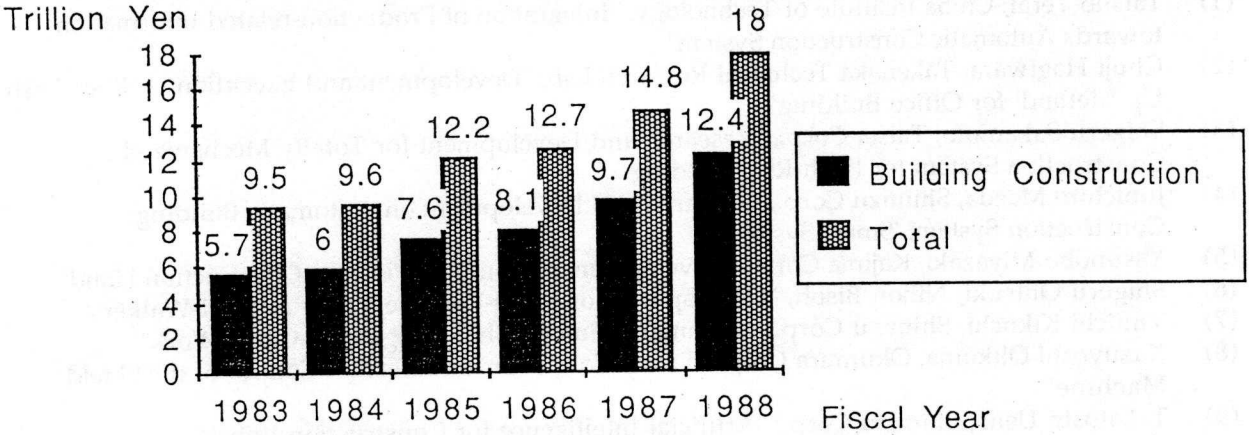

Figure 2. Total Contract Amount
(1983-1984: 43 Major contractors;
1985-1988: 50 Major contractors)

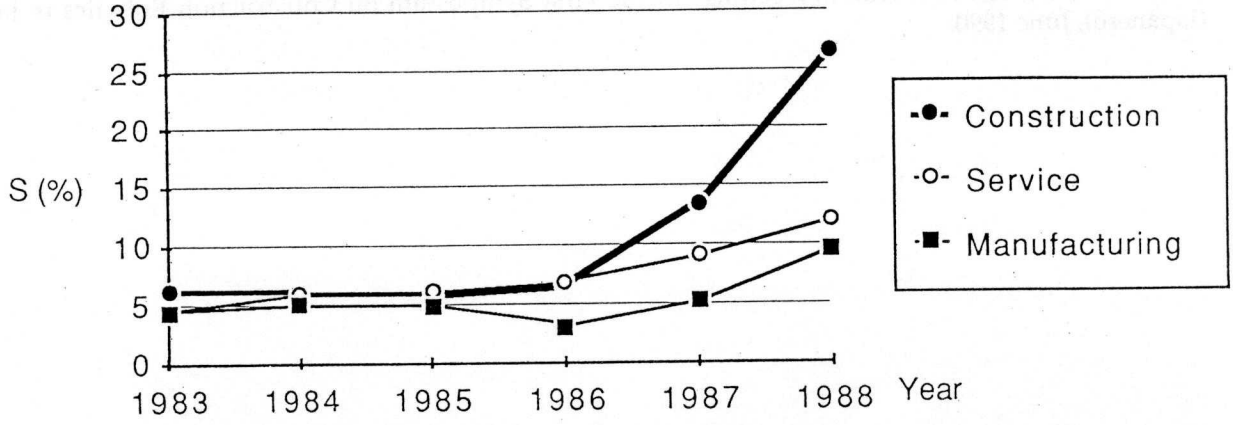

Figure 3. Shortage Ratio of Skilled Labor
S=(Shortage numbers/employee numbers)x100

Table 1: Construction A&R System Developed by Japanese Construction Industries (1982-1991)
(Prototype or Commercial Models)

	Building Construction	
Foundation	(1) Concrete Block Laying Robot	TO
	(2) Automatic Piling System	AK
Body Construction		
Material Handling		
	(1) Radio Control Auto-Release Clamps	OH, SH
	(2) Steel Beam Positioning Robots	SH, TK, FU
Welding		
	(1) Steel Welding Robot	KW
	(2) Stud bolt Welding Robot	KA
Reinforcement Bar Construction		
	(1) Gross Steel Reimforcement Robot	KA
	(2) Reinforcing Bar Fabricating Robot	TS
	(3) Automated Reinforcement Work System & Control	OH
	(4) Automatic Bar Arrangement & Prefabrication Systems	SH
Concrete Works		
	(1) Placing Robot	TD
	(2) Automatic Placing Crane	OH
	(3) Horizontal Concrete Distributor	TK
	(4) Concrete Distributing Crane	TK
	(5) Concrete Floor Screeding Robots	TK, SH, FU
	(6) Concrete Surface Finishing Robots	SH, KA, TK
	(7) Concrete Chipping Machine	SH
System		
	(1) Roof Push Up Method for Office Building	TA
	(2) Totally Mechanized Construciton System for High-Rise Building	TS
	(3) Automatic building Construction System, "Smart System"	SH
Finishing & Assembling Work		
	(1) Spray Robot for Fireproofings	SH
	(2) Ceiling Panel Positioning Robots	TO, SH, TS, KD
	(3) Silo Interior Coating and Lining Systems	SH, FU
	(4) Spray Robot for Exterior Wall Painting	SH
	(5) Robot for Painting High Building Exterior Wall Coating System	TS, SU
	(6) Board Placing Manipulator	TS
	(7) Automatic Exterior Wall Spray Systems	SH, TK, KU
	(8) Tile Setting Robot	HA
Inspection		
	(1) Tile Inspecting Robots	KA, TS
	(2) Self Climbing Wall Inspector	TK
	(3) Room Cleaning and Inspection Robots	TD, OH, KU, KO, HA, TB
	(4) Auto Horizontal/Vertical Travel Equipment	NK
	(5) Gas Pipe Inspection Robot	TG
	(6) Automatic Inspection System for Pipe Corrosion	MI
	(7) Wall Inspection Robot	OH
Cleaning		
	(1) Multi-purpose Travelling Vehicle	SH
	(2) Window Cleaning Robots	MD, NB
	(3) Duct Cleaning Robot	ME
	(4) Automatic Laser Beam-guide Floor Robot	OH
	(5) Auot-travel Floor Cleaning Robots	TA, AU
Multi-Purpose		
	(1) Multi-purpose Wall Walker	NB
	(2) Multi-purpose Construction Hand	KA

Ocean	
(1) Remote Conyrol Underwater Surveyer	KO
(2) Pebbles Smoothing Robot	KO
(3) Submersible Walking Auto Dredger	PO
Dam Works	
(1) Automated Form Work Systems	SC, NI, TX
(2) Automated Concrete Decomposing Robot	KA
(3) Remote Control Piling Robot	KA
(4) Fully Automated Vehicle	TA, HA
Tunneling Works	
(1) Concrete Spraying Robots	OH, KA, TE, TO, MI
(2) Segments Assembling Robots	KU, TD, KA, NKK,MK, MJ, HI
(3) Shield Excavating Robots	MJ, HZ
(4) Auto Drilling Robots	FR, KU, MA, TA
(5) Tunnel Solidized Measurement Machine	KU
(6) Tunnel Reform and Lining System	TE
(7) Automatic Segment Carrier System	SH
(8) Concrete Chipping Robot for Tunnel Repairing	TEPCO
(9) Sliding Press Lining Robot	FU
(10) Automatic Direction Control System for Shield Machine Driving	MK
(11) Fuzzy Controlled Shield Machine	OK
Underground Works	
(1) Remote Controlled Excavation System for Pneumatic Caisson	KA
Road Construction	
(1) Road Recovering Robot	KO
(2) Pavement Cutting Robot	KD
(3) Automated Road Paving Equipment	KR
Bridge Works	
(1) Climbing Robot Jack System	FU
(2) Spraying Robot	KJ
(3) Remote-Conrolled Under Ground Excavation System	TEPCO
Nuclear Plant Demolishing	
(1) Biological Shield Concrete Wall Cutting Robot	SH
Investigation	
(1) Concrete Compaction Measuring Systems	MB, FD

AK: Asahi Chemical Industry*
FR: Furukawa Sakuganki*
HI: Hitachi Kenki*
KB: Kawaski Heavy Industries*
KU: Kumagai Gumi
MB: Mitsui & Company*
MI: Mitsui Construction
NB: Nihon Biso*
NKK: NKK*
SH: Shimizu
TB: Tobishima
TEPCO: Tokyo Electric Power *
TK: Takenaka Koumuten
TX: Takenaka Dobuko

AU: Automax*
FU: Fujita
HZ: Hitachi Zosen*
KD: Kandenko*
KW: KawataKogyo*
MD: Mitsubishi Electric*
MJ: Mitsubishi Heavy Indstrs.*
NI: Nishimatsu
OH: Ohbayashi
OK: Okumura
SU: Sugatec*
TD: Toda
TO: Tokyu Construction
FD: Fudou

HA: Hazama-Gumi
KA: Kajima
KO: Komatsu*
KR:KajimaRd
MA: Mazda Motor*
ME:Meidensha*
MK: Maeda
NK: JGC*
PO: Penta-Ocean
TA: Toshiba
TE: Tekken
TG: Tokyo Gas*
TS: Taisei
*: not general contractor