SIX YEARS EXPERIENCE OF DEVELOPING ROBOTIZED BUILDING CONSTRUCTION SYSTEM
—— WASCOR Research Project Report (Part 1) ——

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ABSTRACT

For rationalizing building construction systems with robots, we organized WASCOR (WASeda COnstruction Robot) research project at System Science Institute, Waseda University in 1982. The Project Team is composed of 10 university professors in the field of civil, mechanical, industrial engineering and system science, management and engineers from 9 general contractors and 2 construction machinery manufacturers.

In autumn of 1988, we finished the second three year period of the research. As the result of the six years university-industry co-operative research, in this paper (Part 1), we would like to report:

1) Methodology of the research.
2) Results of the needs survey and operational priority decision to the robotization.
3) System design condition analysis and measurement.
4) New technologies developed in the project.
5) Problems to be solved and future direction of the research.

In the followed papers, Part 2 and 3, result of the system design and applied new technologies are reported.

1. Introduction

System Science Institute, Waseda University, founded in 1966, has consistently chased research themes in production systems design and rationalization. In the robotics field, the institute has continuously handled robotization research themes of how to automate difficult, dangerous and tedious operaitons such as stamping, casting, forging, and so force.

It was about 10 years ago that we started to consider construction by sponsorship of Japan Industrial Robot Association. We organized a project team in the institute with professors, guest research staffs from general contractors and construction machinery manufacturers, and graduate assistant students.

At that time the people sho considered the robotization of construction work were very few, and it was understood mostly like a hobby of the robot specialists. After four years of survey and conceptual robotized construction system design stage, we decided to accelerate the research under more tight mutual co-operation, because of huge necessity to solve the problem.

This was the start of the WASCOR (WASeda COnstruction Robot) research project. As a nature of university-company co-operative research project, the institute proposed the total procedure of the research and the following fundamental themes of the project.

(1) Educate and train the research staff engineers about robot application technology to be the core members in each company
(2) Make robot introduction needs survey and decide operational priority to the robotization
(3) Design the robotized building construction system for an model building plan
(4) Do system design condition analysis and measurement by our originally developed method
(5) Develop new necessary technologies and facilities for the project
(6) Clarify the structure of the problems to be solved and search future direction of research

2. Methodology of the Research

We separated the six years research period of time into two parts and named WASCOR I and II. General procedure of the research is shown of Fig. 1 (Detail procedure is shown in reference). This procedure is mainly traced during WASCOR I, and the following points were emphasized by the project team members.

(1) To confirm the significance of construction robot development
(2) To understand the structure of the research themes
(3) To grasp the construction and robot technology development flow
(4) To pararelly apply to the analytical and design approach
(5) To confirm the quantitative design conditions by applying to newly developed work measurement technologies
(6) The robotized construction system design started from upper general level and down to detail component level

Working members come to the institute one day in a week and they study the fundamental analysis and design technologies as their assigned jobs. At the end of WASCOR I period, we sould draw general picture of the robotized structure work of the model building construction.

In WASCOR II we put emphasis on the developing supporting technologies and the equipments for refinig the system design result and enforcing feasibility of the plan. The following is the items especially considered during WASCOR II period.

(1) Modification of the model building structure and construction methods from the standpoint of robotization feasibility
(2) Development of work robot moduralization technology
(3) Development of work study technology and equipments
(4) Development of a structural model for detail operation analysis
(5) Development of 3 dimensional scale down model for assisting the model construction system design
(6) Development of a 3 dimenstional computer graphic simulator
(7) Development of robot-crane co-operative operation feasibility evaluation simulator
(8) Proposal of a typical medium size construction robot research and development laboratory model

3. Results of the Needs Survey

Before the appropriate area of robotization is decided, needs must be accurately grasped by obtaining opinions from people concerning building construction.

(1) Questionnaires

The questionnaires were given to 282 people of general contractors who were engaged in construction management and field supervision. The main results are as follows.

(a) Expectation of Rationalization

The construction works in which robots are greatly expected to be used were extracted from seven expected rationalization items such as reducing labor shortages, eliminating dangerous work, shortening the construction lead time, and so forth. From the result, high demands for robots in formwork and reinforcement work were shown in most responses.

(b) Actual Work Conditions

The respondents put one of three evaluation grades (bad, neutral, and good) on each item indicating actual work conditions such as degree of danger, work efficiency, technical skill, work load, and labour shortening ratio.

From the result, form, reinforcement, and structural steel works were evaluated badly in all items.
Furthermore, compared with other items, the evaluations of degree of danger and work load were sevious in particular.

(c) Needs for Robots

Reinforcement work, formwork, concrete placing, and structural steel work were proposed as the work requiring robots. The demand for robots in works related to the building frame was 48.8%, while the demand for the use of robots in finishing was 18.5%. Fig.2 shows the five highest-ranking works to be robotized.

(2) Interviews

General contractors' field supervisors, and construction management staffs were interviewed to supplement the result of the questionnaire survey. These nine interviewees, who are highly interested in robots, have approximately twenty years working experience. The main results are as follows.

(a) Regarding the area in which robots are used, it was confirmed that needs for robots centered upon building frame construction work.

(b) When applying robots, cost reductions brought about by the technical development are not easily linked with profit, and parties on site resist the introduction of new technology.

(c) For successful introduction of robots into building construction , the present construction work is not replaced only by robots, but a new construction system must be developed through the rationalization of construction methods and works in consideration of robot technology.

4. Determination of Design Conditions

4.1 Supposition of a Model Building

In designing a construction production system in which robots are applied, a model building was set up in order to prescribe concrete design conditions. From the results of surveys on "Robotization Needs", and "Problems Expected When Introducing Robots" in the construction industry, the building described below was used as a model. This type of building is one of the most common in Japan.

Usage: Office Building, Site Area: Approximately 850m², Building Site: Approximately 700m², Total Floor Area: Approximately 5,000m², Structure: Steel Reinforced Concrete, Floors: Seven plus Penthouse above Ground and One below Ground

4.2 Selection of a Plan of out of All Alternatives for a robotized Construction System

As for this model building, nine over all design plans for a robotized operation system were prepared. In order to select a specific plan out of thise nine alternatives the following evaluation items were supposed.

(a) Trends in construction technology
(b) The degree of influence upon construction design
(c) Subjects concerning construction and robot technology
(d) Effect of the labor savings through the utilizaiton of robots.

Based of these items, an robotized structural steel and reinforced concrete system plan was selected. A detailed design process of the robotized construction system is described in Parts 1 and 2 of the WASCOR Research Project Report.

5. New Technology

5.1 Work Study

For robotization of construction works, it is of vital importance that the items for work study which should be carried out at each stage in the course of the robot development process are thoroughly investigated in order to apply the data obtained from measurement effectively. The main purpose of this work study consist of the following.

(1) Decision of priority for work to be robotized based on the measurement of the burden on workers.
(2) Quantitive confirming of the design restrictions for robotized work systems.

Motion of work pieces and tools for which no particular consideration is made when the improvement of work which is done by men is aimed at is necessary to be measured. Furthermore, the input information and the items of recognition and judgement which are required for the execution of construction work must be analyzed. In WASCOR project, a New Work Study Methodology with a VTR system as the central method was developed. Many data have been accumulated through measurements made at construction site using this methodology. On the basis of these data the functions of the robotized work system and restricting conditions were identified. Table 1 shows the result obtained from analysing workers fixation points during reinforde steel bar arrangement work for walls using an eye-mark recorder(Fig. 3).

5.2 Three-Dimensional Computer Graphic Simulation for a Robotized Operation System (3D-CG)

3D-CG simulator was developed, in order to make a visual investigation of a layout, a operaiton process, motion trajectories, and obstacle collision regarding construction of framework components, robots and peripheral machinery.

The structure of this 3D-CG system is composed of a load share system between a SONY- News work station and an NEC-PC98(Fig. 4). In the WASCOR Research Project, the 3D-CG simulator was applied to visual simulation of the steel assembling system (Report: Part 3).

The first stage of this applied 3D-CG system is to simulate the processes of assembling structual steels for an entire building from the macro point of view. As the second stage, the movements of robots and peripheral machinery, which are involeved in the assembling system, are simulated in detail from the micro point of view (Fig. 5).

5.3 Simulation through the Use of Small Scale Models of Actual Robots

At the next stage of the verification of the 3D-CG simulator the technical possibility of the robotized operation system is studied using small scale models of actual robots. The steel assembly system mentioned above was adopted and scale models of actual robots such as a crane robot, a positioning robot, and a adjusting robot which are used in the assembly system were developed (Fig. 6).

These scale models satisfied the essential functions which are required for these actual robots. These scale models aim at verifying the feasibility of cooperative motions between the crane robot and the positioning robot. Simulation of the cooperative motions using these models is significant because heavy and large fabrics are frequently dealt with in a mosts of construction sites.

5.4 Robot Modularization Technology

In construction sites many processes are done by cooperative group efforts of works, and varied types of skill workers are needed to construct a building. It is not economically feasible to simply apply conventional limited purpose types of robots to construction systems because a great many different types of robots would be needed at a construction site. Robot modularizaion is one effective means overcoming the difficult problems existing in the development of construction robots. The following explains the significance of modularizaion.

(1) Through the integration of the operational functions and conditions accomplishing a robotized construction system, the required-specifications for one modular type robot are established. Then a modular type robot hardware modules (structural elements of a modular type robot) developed in accordance with these specifications. As a result, the total number of robots utilized on an entire construction site can be minimized and the initial cost also can be reduced.

(2) By systematically utilizing all robot hardware modules in a construction site, under consideration of the progress of construction and the ratio of operation, the running cost can be saved. The hardware modules of the modular type robot are the end effector module, the wrist module, the arm module, the body module, and the locomotion module (Fig.

7). In the view of, the functions, capacities, and dimensions, the robot hardware modules were classified into some types, and the lists of the each robot hardware module were prepared.

The robot hardware modules suited for certain required-specifications are selected from these lists and the complete body of a modular type robot is created by connecting each hardware module.

Application examples of robot modularization techniques were shown in the "WASCOR Research Project Report: Part 2".

6. Future Themes and Direction of Research

Through the six years university-industry co-operative resarch project, we learned that in robotization of construction systems, there are many difficult themes to be solved beside automatization in manufacturing industry as follows:

1) Systematic and consistent rationalization of design and construction processes.
2) Introduction of fundamental production engineering technologies such as quality contorol, work study, group technology and so forth.
3) Intoduction of modularization concept for copying again complexity of construction system.
4) Development of more sophisticated total; automation technologies such as intelligent wallking robots,artificial intelligent,advanced data processing and communication technologies and so forth.
5) Deveopment of simulation technologies for solving prototype system cost problem in design and evaluation process.

The authors belive that we need to enforce the research project team for more fundamental and advanced direction.

7. Conclusion

Dr. J. Engelburger, who is admired by many people as a father of industrial robots, directly mentioned to one of our authors, "We have spent two decades for evacuating and let the robots grown up in manufacturing industry. You need to understand that the accomplishment of real innovation always takes a long time!!".

The authors beleive that the main purpose of this symposium is to understand real problems to be solved and encourage the people who are involved in automatization and robotization of construction systems from the standpoint of international co-operation.

References

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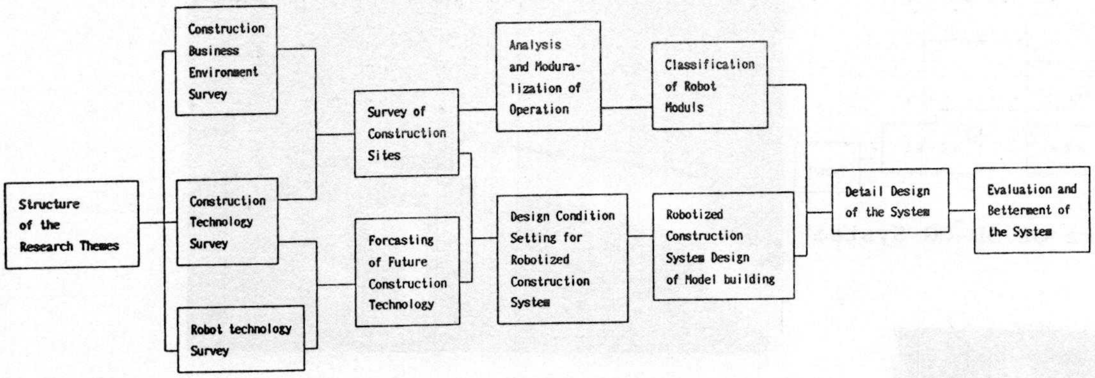


Fig.1 General Procedure of WASCOR Research Project

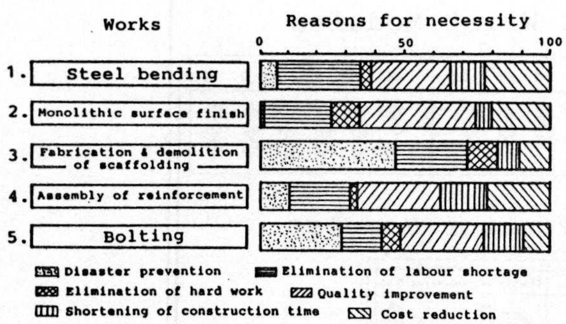


Fig.2 Works to be robotized and Reasons (Five Highest Ranking Works)

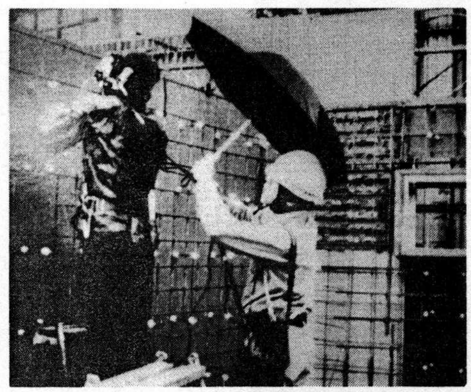


Fig.3 Measurment of Fixation Point Using Eye-Mark Recorder

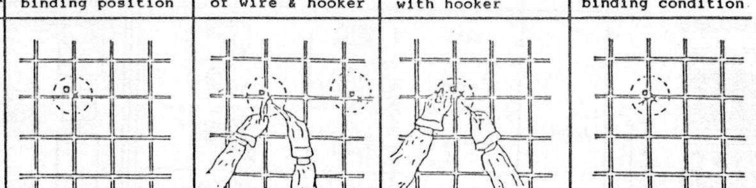
Motion	Decision of a binding position	Setting position of wire & hooker	Winding of wire with hooker	Confirmation of binding condition
Outline figures				
Fixation points	Position for binding & reinforcement	Binding wire and hooker, crossing part of bar	End part of hooker and binding wire	Wound binding wire
Duration sec	0.23	0.77	1.10	1.33
Main points of motion	Grasping of binding position and the diameter of reinforcement to decide a binding method	Decision of the relative position of a binding wire and reinforcement while confirming the horizontal level	Adjustment of locus, rotational frequency and force to obtain a winding method suited to the binding method	Confirmation of whether or not a wound condition is the same as estimated

Table 1 Fixation Points of Worker during Bar Arrangment

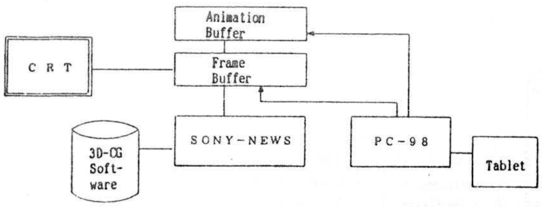


Fig.4 Structure of 3D-CG System

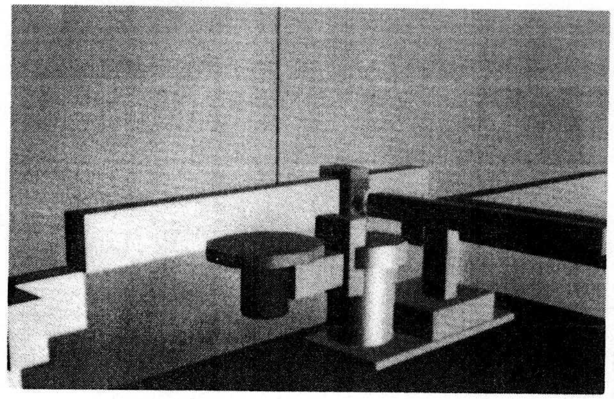


Fig.5 3D-CG Simulation for Movements between Robots and Peripheral Machinery

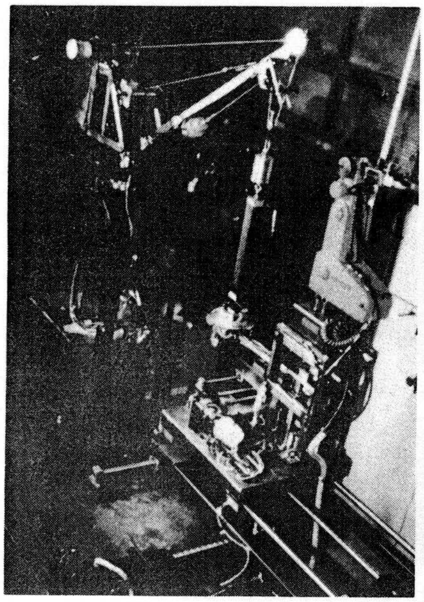


Fig.6 Small Scale Simulation Model for Studying Co-Operative Motion of Crane Robot and Positioning Robot

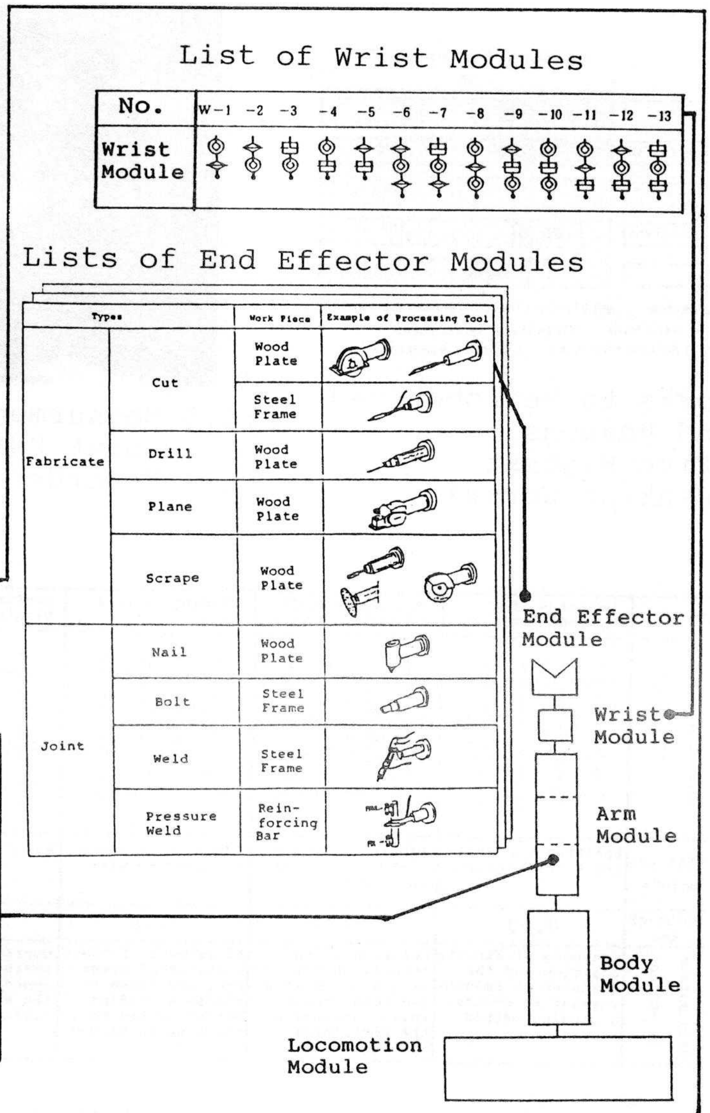
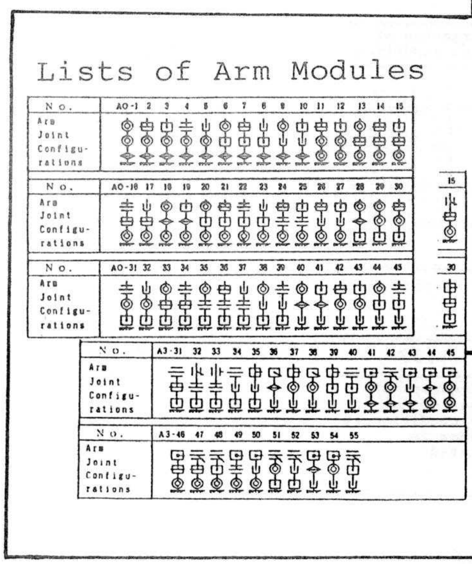



Fig.7 Structure of Robot Hardware Modules