Study on Development and Utilization of Construction Robots

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ABSTRACT

The objective of this study was to establish an effective and practical method for developing construction robots. Therefore, a survey of construction robot developers was conducted regarding the development process and the degree of robot utilization. This survey suggests that although the development of robots is primarily conducted according to consumer demand, utilization of completed robots is not as high as expected. While the majority of developers are quite satisfied with completed robots, users often find these robots unsatisfactory because of their uncertain economic effects, their unclear capabilities, and their lack of general applicability. The survey shows that a gap exists between the robots that are created by developers and the robots that users desire. Based on both the results of this study, and the results of a consumer survey, the Construction Robotics Committee plans to create indices for robot development that will be acceptable to users.

1. INTRODUCTION

The introduction of robotics technology into construction work is often described as much more difficult when compared with other industries. The main reason for this difficulty is the complexity and variety of the buildings themselves, the engineer and manual laborer organizations, and the environment in which buildings are constructed. Despite these difficulties, however, demand for the introduction of robots into construction work is becoming significant as an alternative means of coping with the decreasing number of skilled laborers and the increasing number of aging laborers. More than 100 types of construction robots have been developed to meet this demand. However, very few have been commercialized or produced for practical use, and the cause, it has been suggested, is problems with development, application, and management. In order to better understand these problems and devise solutions, the Construction Robotics Committee has been conducting a study for the past 7 years to support the development and promotion of construction robotics. The Construction Robotics Committee has targeted users of robots such as (1)construction companies, (2) machine manufacturers and lease/rental companies, and (3) designers, and has been presenting the results of these studies.

In the present study, the Construction Robotics Committee reports on the results of a questionnaire survey of general contractors and machine manufacturers concerning their views as developers about robot development in response to the need for construction robots.

2. SURVEY METHOD

2.1 SUBJECT OF SURVEY

Of the approximately 100 publicly announced construction robots, the 12 described in Table-1 were chosen as examples of successful robot development because of their relatively wide use, and a direct survey of the developers of these robots was conducted. A total of 16 companies and 85 individuals responded to the questionnaire, with general contractors represented by 11 companies and 74 individuals, and manufacturers represented by 5 companies and 11 individuals.

Table-1 Robots developed

#	Robot Name	Response	#	Robot Name	Response
1	Stone stacking robot	1	8	Tile setting robot for exterior wall	3
2	Automatic construction material transport system	14	9	Exterior wall painting robot	17
3	Concrete placing distributor	8	10	Automatic work execution system for pre-cast concrete panels on exterior walls	5
4	Concrete floor slab leveling robot	13	11	Multiple purpose construction hand	14
5	Concrete floor slab finishing robot	12	12	Light weight manipulator for interior finish work	15
6	Remote shackle	6	13	Other	17
7	Column welding robot	9			

2.2 CATEGORIES SURVEYED

The development process was provided to survey subjects with 7 phases, which includes 1.Goal creation, 2.Development objectives, 3.Basic design, 4. Detailed design, 5.prototype creation, 6.Experimentation, and 7. evaluation of the degree of utilization, and 25 questions were asked with respect to each of these development phases.

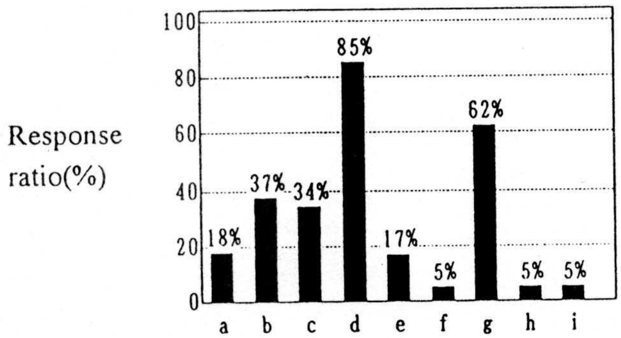
2.3 ANALYSIS METHOD

There are some cases in which a single developer was involved in more than one robot development project, and therefore, multiple answers were accepted for all multiple choice questions. The ratio of respondents selecting each choice was calculated in order to evaluate the relative significance of each choice. Questions requiring written responses were first checked for content and repetition. Then, the Construction Robotics Committee analyzed the relationship between the different opinions and determined the number of similar opinions in order to evaluate the significance of each question.

3. SURVEY RESULTS

3.1 DEVELOPMENT GOALS

Responses to the question "How do you determine the development goals when creating construction robots?" are indicated in Figure-1. The response choices were a through c which indicate goal setting methods, and d through h which indicate the factors determining these goals. In terms of goal setting methods, the answers "b. Interviews", chosen by 37%, and "c. Analysis by operation assessment", chosen by 34%,were marked most often, indicating a preference for direct contact. In response to the question concerning the factors determining development goals, the answers "d. demand from construction sites", chosen by 85%, and "g. needs of society", chosen by 62%, were most frequently selected. In summary, development goals are ideally established by interview survey of the demand at construction sites or by operation assessment by developers themselves, as well as by consideration of social needs.

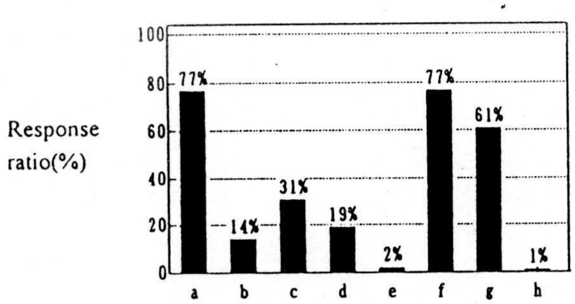


a. Survey by questionnaire
b. Interviews
c. Analysis by operation assessment
d. Needs at construction sites
e. Needs of collaborating companies
f. Requests from co-developers
g. Social needs
h. Continuing goals from past projects
i. Other

Figure-1 Establishment of development goals

Responses to the question "How do you evaluate and select development goals?" are indicated in Figure-2. The answers "a. Based on the needs of the construction site" chosen by 77%, "f. Based on the degree of expectation " chosen by 77%, and "g. Based on the probability of a high secondary technological effect" chosen by 61% were the most frequently marked.

When asked to identify whether these goals would be evaluated by personnel at the construction site, by the developers, or by company-assigned executives, approximately 80% indicated personnel at the construction site rather than company-assigned personnel. In summary, development goals should ideally be selected based on the needs at construction sites, and on the degree of expectation or the potential for a high secondary technological effect.

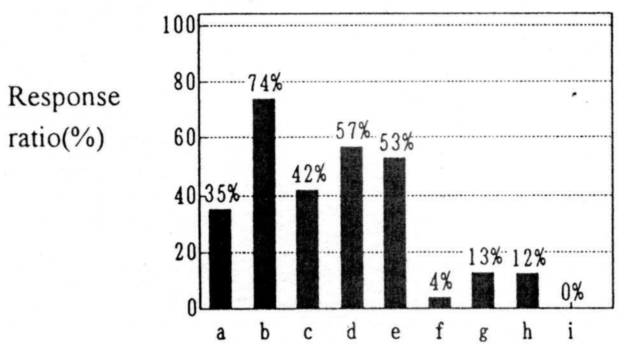


a. Based on the needs at construction site:
b. Based on evaluation by developers
c. Based on technological possibilities
d. Based on urgent needs
e. Based on decisions by the company
f. Based on the degree of expectation
g. Based on the probability of a high secondary technological effect
h. Other

Figure-2 Evaluation and selection of development goals

3.2 DEVELOPMENT OBJECTIVES

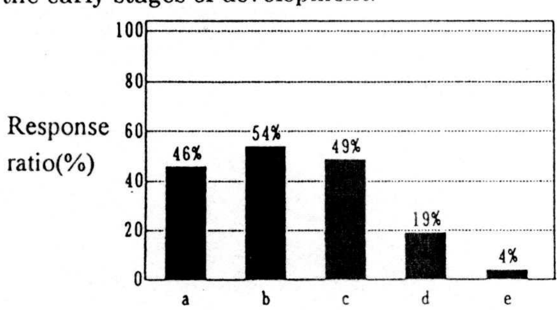
In response to the question "What kind of development objectives are best to establish when creating a construction robot?" the answer "Quantitative objectives", selected by 81%, was overwhelmingly chosen, followed by "Concept-level objectives", which was marked by 28%. From these responses, it appears that developers engage in development with quantitative objectives in mind. This trend was the same regardless of the type of robot developed, or whether the respondent was a general contractor or manufacturer. Responses to the question What specific development objectives must be established?" are listed in Figure-3. The answer "b. Performance criteria" was chosen most often at 74%, followed by "d. economics (price of robot, etc.)" at 57%, "e. Ease of use (size, weight etc.)" at 53%, "c. energy savings" at 42%, and "a. Range of finish quality" at 35%. These five choices had the highest response ratio. When analyzed by robot type, "Range of finish quality" was chosen by more than 50% for machines such as concrete floor finish robots which perform tasks by themselves. The choice that was the same for all robot types was "Performance criteria".



a. Range of finish quality
b. Performance criteria
c. Energy savings
d. Economics (price of robot, etc.)
e. Ease of use (size, weight, etc.)
f. Maintenance
g. Improvement of work environment
h. Improvement of safety
i. Other

Figure-3 Specific development objectives

Responses to the question "Which development objectives were difficult to establish and in what way were they difficult?" are indicated in Figure-4. The answers "b. Difficult to determine limitations" chosen by 54%, "c. Difficult to assess costs" chosen by 49%, and "a. Difficult to establish quantitative specifications" chosen by 46% were the most common responses. When analyzed by robot type, the percentage choosing "Difficult to determine limitations" was high for general-purpose robots such as concrete floor finish robots which can be used at various construction sites. This result indicates the difficulty of taking into account a variety of different conditions during the early stages of development.

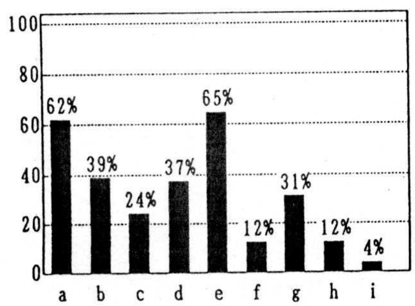


a. Difficult to establish quantitative specifications
b. Difficult to determine limitations
c. Difficult to assess costs
d. Difficult to determine ease of use and etc.
e. Other

Figure-4 Development objectives which are difficult to establish

3.3 DESIGNING OF ROBOTS

Responses to the question "What robot design issues do you have to solve, and how do you solve these problems?" are indicated in Figure-5. The answer "e. Assessment of currently replaceable operations by robots", chosen by 65% of respondents, received the highest response ratio followed by "d. The way tasks are performed by skilled laborers" chosen by 37%, and "h. Advance evaluation of robot's capability such as ability to avoid obstacles, etc." chosen by 12%. As solutions to these problems, "a. Survey or experiment to obtain quantitative specifications" received the highest response ratio at 62%followed by "b. Experiment on mobility, finish function, etc." chosen by 39%, and "g. Inspection of robot's performance, speed, etc." chosen by 31%. When analyzed by robot type, "The way tasks are performed by skilled laborers" showed the highest response ratio when examining robots such as exterior wall painting robots that perform tasks themselves in place of skilled laborers.



a. Survey or experiment to obtain quantative specifications

b. Experiment on mobility, finish function, etc.

c. Experiment to establish proper conditions for robot control

d. The way tasks are performed by skilled laborers

e. Assessment of currently replaceable tasks by robots

f. Simulation

g. Inspection of robot's performance, speed, etc.

h. Advance evaluation of robot's capability such as ability to avoid obstacles, etc.

i. Other

Figure-5 Issues to be examined for robot design and countermeasures

3.4 CREATION OF ROBOTS

Responses to the question "After the robot is created, what methods are necessary to solve problems that occur during experimental operations or performance tests?" were "Perform necessary experiments in advance and obtain data for unclear items during the design process" chosen by 66%, "Select engineers who have sufficient knowledge as members of the team" chosen by 42%, and "Perform thorough design review during the design stage" chosen by 32%. In reality, if problems develop after the robot is complete, adjustment in design is made where needed as described by some respondents in the choice "Other". However, developers' experiences indicate the necessity of performing various experiments and obtaining sufficient data before the creation of robots.

3.5 DEMONSTRATION EXPERIMENTS

Responses to the question "How many construction sites are used to perform demonstration experiments before the robot is ready to be used?" are indicated in Figure-6. The answer that received the highest response ratio was "b. 3 sites", chosen by 35%, followed by "c. 5 sites" chosen by 29% and "d. 10 sites" chosen by 22%. Developers prefer to perform prototype experiments at approximately three different sites in order to make the robot practical. In reality, however, it is quite difficult to standardize robots due to the different conditions and environments at each site, and developers indicate that different adjustments are necessary depending on the conditions encountered at each individual site.

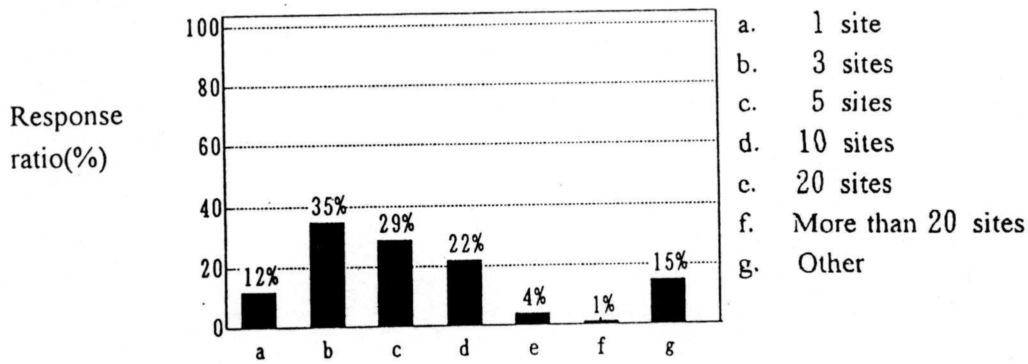


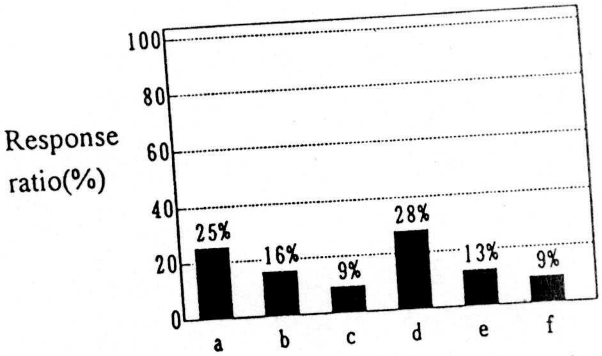
Figure-6 Number of contractor sites used for demonstration experiments

In response to the question, "How do you evaluate the robot's performance during demonstration experiments?", the answers "Whether or not development objectives are attained" and "Evaluation by skilled laborers" both showed the highest response ratio at 78%, followed by "Evaluation by general contractor employees" at 46%. Developers indicated that while it is important to evaluate whether or not the development objectives are attained by the completed robot, it is also necessary to consider evaluations made by skilled laborers.

Responses to the question "How are improvements made when they are found to be necessary following demonstration experiments?" were "Make improvements that are considered most important" chosen by 62%, "Depends on the development deadline and development expense" chosen by 38%, and "Make all necessary improvements" chosen by 22%. The results indicate that the majority of developers attempt to make improvements under various limitations when they are found to be necessary at the demonstration experiment stage.

In response to the question "After prototype demonstration experiments, are second and third prototypes developed?", the answer "Develop a second prototype only" showed the highest response ratio at 52%, followed by "Develop up to a third prototype" which was chosen by 25%. Together, these responses show a total of 77% choosing to develop a second or third prototypes. On the other hand, the answer "End development after prototype" was chosen by 21%. These results indicate that developers commonly create and conduct experiments on two to three prototypes in order to make the robot practical.

Reasons given for the response "End development after prototype" are indicated in Figure-7. Among developers who discontinued development at the prototype creation stage, 28% selected "d. No future development of the prototype was possible" and 13% selected "e. Development time and development budget, etc. was not sufficient and development was discontinued", showing an approximate total of 40%. Developers who actually developed a prototype to the point of practical use were 34%, including those answering "a. Made the prototype work for practical use" (25%) and "c. Made the prototype work for practical use with major modifications" (9%).



a. Made the prototype work for practcal use

b. Attained anticipated objectives by gaining development know-how at the prototype creation stage

c. Made the prototype work for practical use with major modifications

d. No future development of the prototype was possible

e. Development time and budget was not sufficient and development was discontinued

f. Other

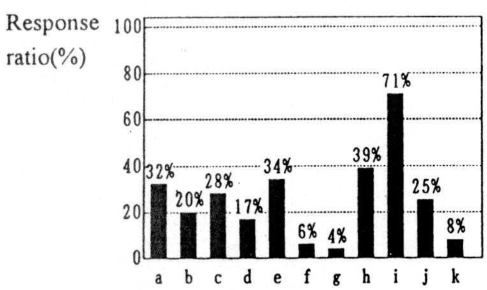
Figure-7 Reasons for discontinuing development after creation of prototype

In response to the question "When developing second and later prototypes, do you reconsider the development objective?", 78% selected "Reconsider development objectives, such as adding objectives, and continue developing", showing that experimental installation of the prototype provides a clearer and more concrete picture of various problems.

3.6 MAKING THE ROBOT PRACTICAL

Responses to the question "What measures are effective in promoting the use of the completed prototype?" are indicated in Figure-8. The response choices are roughly divided into two types, items a through c regarding manuals, education, and etc., and items d through f, i, and j regarding information disclosure. Concerning manuals and education, the answer "a. Creation of installation plan manuals" had the highest response ratio at 32%, showing a high interest in the readiness of the receiver at the time of robot installation. This answer was followed by "c. Education of robot operators" chosen by 28% and "b. Creation of robot operation manuals", chosen by 20%.

Concerning information disclosure, the answer "i. Make the effectiveness of usage clear, such as robot cost and installation effectiveness" showed the highest response ratio at 71%, followed by "e. Disclose information inside and outside of corporation" at 34% and "j. Prepare documentation such as installation records, etc." at 25%, both of which are also demands made by robot users. The answer "h. Consideration of robot introduction in advance during the design stage" was also chosen by approximately 40% of developers. This indicates that developers are trying to promote the use of robots by preparing a better user environment.



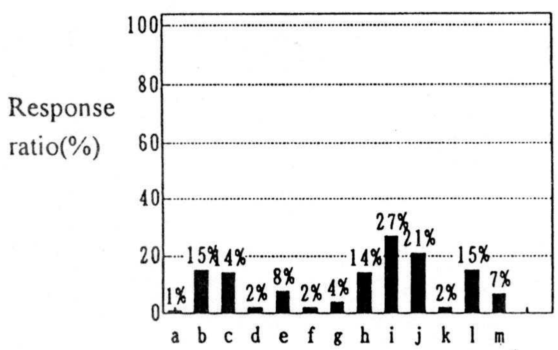
a. Creation of installation plan manuals, etc.
b. Creation of robot operation manuals, etc.
c. Education of robot operators
d. Distribution of technical documentation within the corporation
e. Disclosure of information inside and outside of corporation
f. PR through magazines, etc.
g. Obtain mechatronics taxation qualification
h. Consideration of robot introduction in advance during the design stage
i. Make the effectiveness of usage clear, such as robot cost and installation effectiveness.
j. Prepare documentation such as installation records, etc.
k. Other

Figure-8 Measures to promote the use of robots

In response to the question "As a developer, how did you feel about the robot you developed?", the majority of people (62%) answered "mostly satisfied", while 32% responded "Not as satisfactory as expected".

In response to the question "How do you feel about the degree of utilization of the robot you developed?, 53% answered "Not satisfactory" and 26% answered "Sufficient usage for application at specific building sites." This second response indicates that a high level of robot completeness is possible when robots are designed for use at specific buildings because of the ease of focusing on specific goals and of identifying how the robot will be used. The answer "Almost satisfactory state of usage" was chosen by 15%.Although the majority of developers evaluated their completed robots as "satisfactory" in the previous question, they did not feel that the degree of robot utilization was satisfactory. This indicates that there is a difference between what robot developers consider satisfactory and the actual robots that users desire. It is difficult to increase the utilization of robots unless developers conduct further research and bring their development objectives up to the level of the users' demand.

Responses to the question " Why do you think that developed robots do not have a satisfactory degree of utilization and what is the cause?" are indicated in Figure-9. The answers were divided into categories related to physical limitations, non-physical limitations, and effect of use, and analyzed. Concerning non-physical limitations, the answers "b. It takes long time to prepare for a robot introduction at construction site" and "l. Unclear ownership" showed equally high response ratios of 15%. The preparations (mentioned in "b") which includes transferring and fabricating robots are to make the environment of robot operation. "Unclear ownership" indicates that the developed robots are not quite ready to be commercialized. Concerning physical limitations of the robot itself, the answer "j. Structures that the robots can be used for are limited to large buildings and robots therefore lack general applicability" showed the highest response ratio at 21%, followed by "c. Robot function and performance is insufficient" at 14%. This lack of general applicability is mainly caused because many robots are created for special, limited purposes. Insufficient robot function and performance illustrates the technical incompleteness of some robots. Concerning the effect of use, the answers "i. Insufficient economic effect" and "h. Insufficient energy efficiency" showed response ratios at 27% and 14% respectively. Based on these results, the reasons for unsatisfactory robot usage include their low economic effect, their lack of general applicability, their insufficient function and performance, and unclear ownership, etc. These are the issues that developers need to solve in the future.



a. Lack of documentation(information) to plan robot istallation
b. Takes time to prepare for robot introduction
c. Insufficient robot function and performance
d. Complicated robot operations
e. Unable to obtain operator cooperation
f. Unclear countermeasures to be taken at the time of robot break-down
g. Insufficient quality (accuracy)
h. Insufficient energy efficiency
i. Insufficient economic effect
j. Structures the robots can be used for are limited to large buildings and robots therefore lack general applicability
k. Basic technology of robots is not developed
l. Unclear ownership
m. Other

Figure-9 Reasons for unsatisfactory robot utilization

4. CONCLUSION

By performing this survey of robot developers, we came to understand the robot development process, as well as some of the various issues relating to robot development.

The goals of current robot development are generally influenced by construction site demand and social needs resulting from the lack of a large manual labor force. Among these goals, those in high demand or those expected to be effective are chosen.

Objectives based on the development goals are established with an emphasis on the robots' performance, its economic impact, and its ease of use, etc. However, when these objectives are established in a real construction situation, the individual sites' environmental limitations vary, and it is difficult to create general quantitative specifications. This is mainly because the production methods used at construction sites are based on manual labor operations. Therefore, changing the production method is an important issue, along with the design process, which must be addressed in order to promote the development of construction robots in the future.

When the prototype is created, demonstration experiments are carried out at 3 - 10 construction sites, although the number depends on the development period and the type of robot.

When robots have been developed to a point of practical use following the prototype stage, developers are generally quite satisfied with the completeness of the robots. However, the degree of utilization of the completed robots is low because of the unclear effects of robot application, differences in what developers think is appropriate and what users demand, and insufficient PR activity. In particular, standards for evaluating the effects of robot application should be developed by the construction industry, and production methods at construction sites should change.
Except for robots studied for academic purposes, it is common for the performance of robots to be evaluated by degree of utilization. The Construction Robotics Committee is planning to conduct a survey among the users of robots to understand differences in opinion between developers and users. The Construction Robotics Committee will also create indices for robot development and will promote the development, application, and utilization of construction robots in the future.

The Construction Robotics Committee, the primary entity which conducted this study, is made up of the following members:

E. Muro (Takenaka Corp.), A. Suzuki(Takenaka Corp.), T. Wakisaka(Obayashi Corp.), K. Arai (Kajima Corp.), S. Tokioka (Kumagaigumi Corp.), S. Oura(Sato Kogyo Co.), M. Nishigami (Shimizu Corp.), S. Sakamoto (Taisei Corp.), J.Watanabe(Tokyu Const. Co.), T. Shinozaki (Toda Corp.), H. Katano (Nishimatsu Const. Co.), M. Kobayashi (Hazama Corp.), M. Kameda (Haseko Corp.), T. Takimoto (Fujita Corp.) and N. Miura (Kokushikan Univ.).