CONSTRUCTION ROBOTIC EQUIPMENT MANAGEMENT SYSTEM (CREMS)

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ABSTRACT

Robotics application to the execution of construction tasks has been attracting attention in the engineering community since early 1980's, both in Japan and in other highly industrialized nations. First working prototypes of construction robots have been appearing in Japan on a number of construction sites operated by several leading Japanese construction firms. This paper outlines a research project focused on the planning and management aspects of the use of robotic equipment in construction tasks. This project concentrates on four system modules: Construction Task Analysis Module (CTAM); Robot Capability Analysis Module (RCAM); Robot Economics Evaluation Module (REEM); and Robot Implementation Logistics Module (RILM). This paper briefly describes each of these modules, and presents a summary of results obtained from research completed to date on CTAM.

1. INTRODUCTION

Robotics application to the execution of construction tasks, both in Japan and in other highly industrialized nations, not only has been attracting attention in the engineering community since early 1980's, but also has introduced important technical and economical implications. To analyze these issues, researchers have conducted several comprehensive studies such as Hasegawa [1], Warszawski and Sangrey [5], Paulson [3], and Skibniewski [4], which focus on the technical and economic feasibility of robot use.

For the last few years, several leading Japanese construction firms have been implementing working prototypes of construction robots on a number of construction sites in Japan. Some examples prototype applications include horizontal concrete distributors (e.g., Takenaka Komuten Co.); fireproof spraying and paint spraying robots (e.g., Shimizu Construction Co.); wall inspection robots (e.g., Kajima Co.), and material handling robots (e.g., Tokyu Construction Co. and Hitachi Construction Co.). These robot prototypes, specifically designed and built for construction sites operations, usually are single-purpose machines.

Unfortunately, this single-purpose approach currently prevents a more extensive use of robots in construction operations. Construction firms, which have their own fleets of robots, are finding that the single-purpose robots have been applied in relatively isolated work environments and on an *ad-hoc* basis. Thus, they have identified a need to rationalize robot use to be able to derive the maximum technical and economic benefits that stem from their application.

The Construction Robotic Equipment Management System (CREMS) project is conceived as a response to this need. The principal objective of CREMS is to develop a comprehensive construction robot management system. Such a system should prove highly desirable to manage a fleet of diverse single-purpose construction robots and increase the application efficiency of the robots currently or potentially available to a company. The project concentrates on the development of the system's four modules: Construction Task Analysis Module; Robot Capability Analysis Module; Robot Economics Evaluation Module; and Robot Implementation Logistics Module.

This paper provides an overall description of the system, and focuses on a summary of the results obtained from research completed to date on the first module.

2. OVERALL DESCRIPTION OF THE SYSTEM

A detailed explanation of the specific configuration of CREMS is beyond the scope of this paper. However, three elements are crucial to understand the overall system: 1) the global context for its application; 2) the specific modules that configure the system; and 3) the software environment of the system. Each are described next.

2.1 Global Context of the System

The global context of the CREMS project is shown in Figure 1. It contains three different subcontexts that influence the individual modules of the overall system, and highlights the complexities of the interrelationships among them.

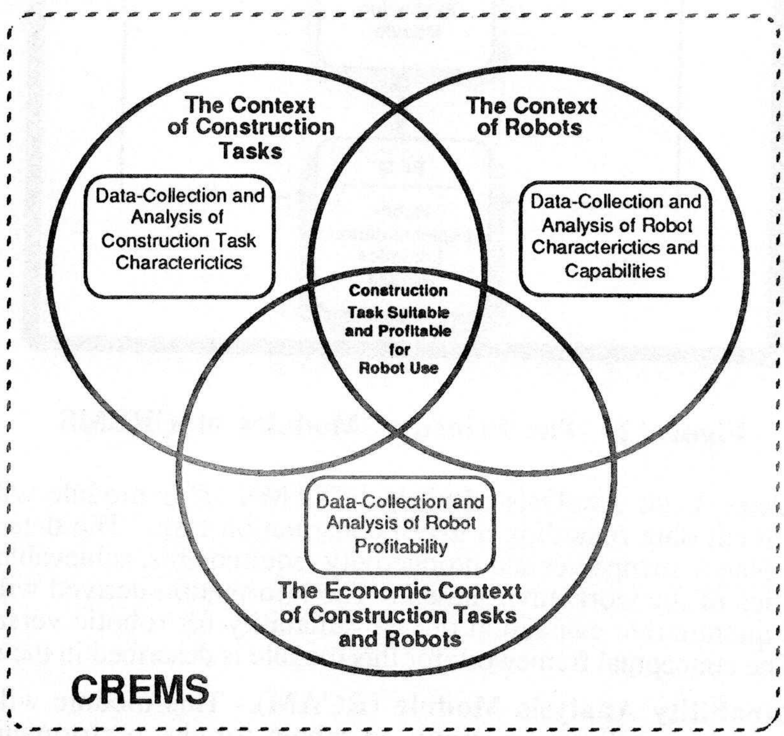

Figure 1.- The Global Context of CREMS

The first is the context of construction tasks. This context identifies and analyzes all the relevant characteristics and parameters that are associated with a given construction task (e.g., physical layout, construction methods, materials, labor, equipment, specifications, and quality). The second is the context of robots. This context identifies and analyzes all the relevant capabilities and parameters that are associated with a given robot (e.g., physical specifications, performance specifications, capabilities, and constraints). The third is the economic context of both construction tasks and robots. This context identifies and analyzes all the relevant parameters associated with using a given robot in a given construction task from an economic point of view.

2.2 Principal Modules of the System

The system, as shown in Figure 2, has four basic modules: Construction Task Analysis Module; Robot Capability Analysis Module; Robot Economics Evaluation Module; and Robot Implementation Logistics Module. These are described briefly next.

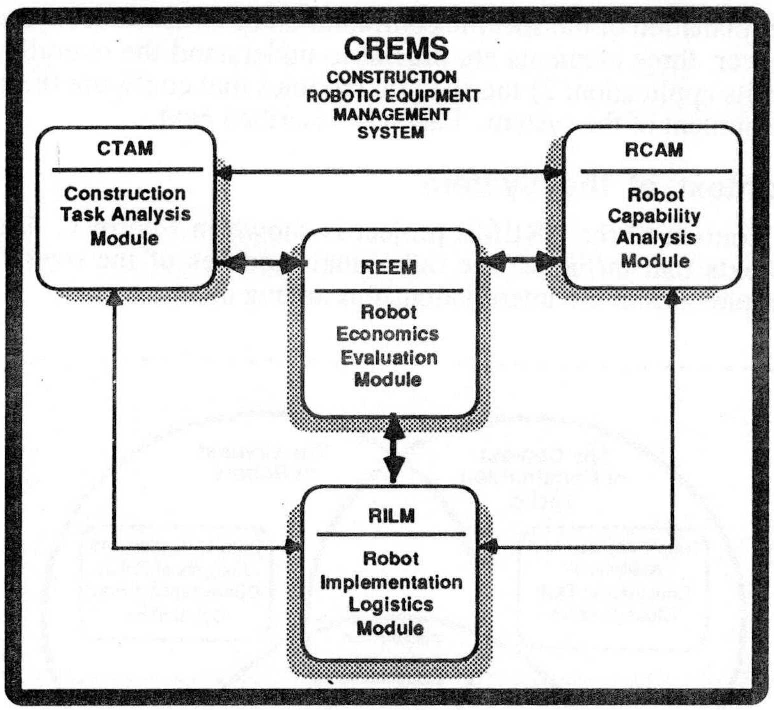

Figure 2.- The Principal Modules of CREMS

Construction Task Analysis Module (CTAM).- This module will acquire and analyze all pertinent data regarding a given construction task. The data analyzed will include, among others, manpower and productivity requirements, achievable work quality, and characteristics of the work environment. The information derived will include both qualitative and quantitative evaluation of task suitability for robotic versus non-robotic performance. The conceptual framework for this module is described in the next section.

Robot Capability Analysis Module (RCAM).- This module will examine the capabilities of a given robot or a group or robots for the performance of a given construction task(s). The data analyzed will include, among others, robot weight, power supply, payload, work envelope, available tools, control and sensory systems. The method for related evaluations of manufacturing robots is presented in [2]. A knowledge base to match these capabilities with the requirements of the considered construction jobsite will be designed within this module.

Robot Economics Evaluation Module (REEM).- This module will produce a detailed analysis of expected robot profitability at the considered jobsite location. Factors for analysis include task performance cost with non-robotic work techniques, operational costs of robotic equipment, resulting labor and time savings, and quality improvements. Details of these calculations are presented in [4].

Robot Implementation Logistics Module (RILM).- This module will perform robotic equipment scheduling functions to ensure its optimal use throughout the company's projects. These functions will include robot work time determination, tooling and manpower allocation, robot maintenance schedules, robot site set-up and disassembly, and transportation schedules. This module will be designed with the use of the existing initial experience with the robotics use on the Japanese construction sites, as well as with the advise of robot system designers and builders. A knowledge base structuring the procedures for robot work scheduling will be designed for use with this module.

2.3 Software Environment

Specifically, the system is being developed at the microcomputer level, using existing software such as KES™, as the expert system shell; DBASE III, for database capabilities; LOTUS 123, for spreadsheet calculations capabilities; and conventional programming languages such as C and Fortran, to provide the link between the different components of the system.

One important consideration in the development of CREMS is that it should permit possible future extensions of the system to link with other related software, such as simulation programs. The modular approach used in the system supports this objective.

3. THE CONSTRUCTION TASK ANALYSIS MODULE (CTAM)

The specific objective of this module is to develop a decision support system that provides a quantitative evaluation of task suitability for the use of robots as compared to non-robotic performance.

A detailed explanation of the specific configuration of CTAM is beyond the scope of this paper. However, two elements are crucial to understand how this module fits within the overall system: 1) the specific context for its application; and 2) the specific submodules contained in CTAM. Each are described next.

3.1 Specific Context of CTAM

The specific context of CTAM is shown in Figure 3. In many ways, it is similar to the global context of CREMS shown in Figure 1. CTAM contains two distinct subcontexts. The first refers to the general context of construction tasks, which includes a preliminary analysis that determines whether a given task is suitable for using a given robot. Two possible outcomes exist: 1) the task is suitable, or 2) the task is not suitable for using robots. The second subcontext refers to the general context of robots. This context includes an analysis that determines whether a given robot is suitable to execute a given task. There are also two possible outcomes for this analysis: 1) the robot is suitable, or 2) the robot is not suitable for executing the task.

The intersection between these two contexts gives the subset of a given construction task suitable for a given robot. This subset leads to a third level of analysis that will determine, from a basic economic perspective, the decision whether to use the robot or not.

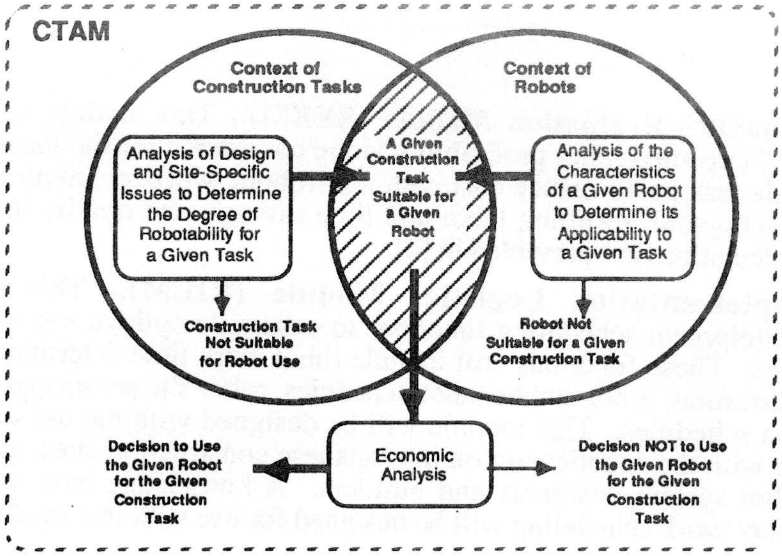

Figure 3.- The Specific Context of CTAM

3.2 Principal Submodules of CTAM

The principal submodules of CTAM are shown in Figure 4. They fall into two categories: 1) Input Submodules, and 2) Analysis Submodules. These are described next.

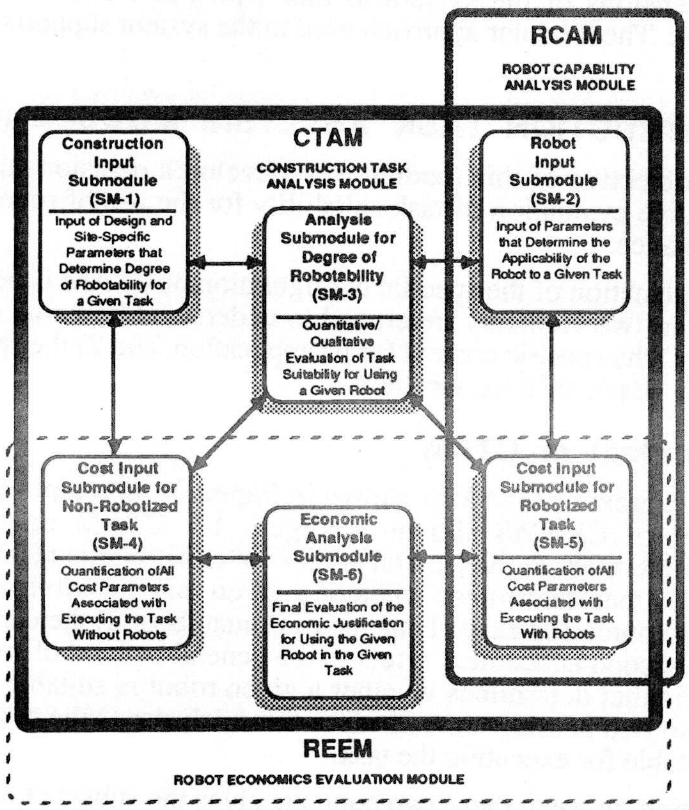

Figure 4.- Submodules of CTAM

Construction Input Submodule (SM1).- SM1 is structured to allow the input of the principal design and site-specific parameters that determine the degree of robotability for the given task. SM1 receives two main types of data: 1) information from the plans/drawings for the operation; and 2) information from the specifications that control the operation. These data will initially have *manual* input by the user prompted by the system. However, in the future, the system will have the additional capability of *automatic* input by direct file transfer from a CAD system for the drawings, and/or from a database for the specifications.

From the plans/drawings for the operation, the submodule structures and processes this information to obtain the relevant and necessary parameters that SM3 requires to perform the degree of robotability analysis. Specific examples of the type of data that are produced by this submodule include: areas, perimeters, borders, obstacles, clear heights, paths, corners, etc. From the specifications, the SM1 extracts all the relevant and necessary information about quality, materials, construction methods, and other specific issues that are required by SM3 to perform the degree of robotability analysis.

SM1 contains knowledge that establishes whether the information input at this stage of the analysis is sufficient or not to perform the evaluation with SM3. If the information is incomplete, the submodule will stop the process at this point, identifying the specific additional data that needs to be input, and providing the guidelines for data-collection efforts in the event that the data is not readily available.

The output of SM1 feeds directly to SM3.

Robot Input Submodule (SM2).- With a similar objective, SM2 is structured to allow the input of the principal parameters that determine the applicability of the robot to execute the given task. This submodule initially is self-sufficient, i.e., it works on a stand-alone basis. However, the idea is to use SM2 as the starting point for the development of RCAM.

SM2 receives three main types of information: 1) the physical characteristics of the robot; 2) robot execution capabilities for the operation; and 3) the performance constraints that control the operation of the robot. As with SM1, these data will initially have manual input by the user prompted by the system, but, in the future, the system will have the capability of automatic input by direct file transfer from other sources.

The submodule extracts all the relevant and necessary information about what the robot is, what it can do, and what it cannot do that is required by SM3 to perform the degree of robotability analysis.

SM2 will also contain knowledge that will establish whether the information input at this stage of the analysis is sufficient or not to perform the evaluation with SM3. As with SM1, if the information is incomplete, the module will stop the process at this point.

The output of SM2 feeds directly to SM3.

Analysis Submodule for Degree of Robotability (SM3).- The actual analysis that determines whether a task can be done with a robot, and to what degree it can actually be executed with the robot, is done in SM3.

The inputs to this submodule are SM1 and SM2. This analysis compares the design, site-specific parameters, and quality requirements of the given operation with the characteristics and capabilities of the robot to provide a qualitative/quantitative evaluation of the degree of robotability of the operation.

The knowledge base has both qualitative and quantitative elements because many stages of the analysis require "judgment calls." Specific examples of the type of calculations involved in this module include: paths, percentage of effective area (i.e., where the robot can actually perform the operation), expression of obstacle and other constraints in terms of effective areas, among others.

SM3 contains knowledge that will establish whether to continue or not the process of evaluating the use of the robot for the given task from an economic perspective. If the decision at this point is not to continue, SM3 will stop the process at this point, identifying the reasons for not recommending the use of the robot, and providing guidelines for increasing the degree of robotability by altering the design and site-specific parameters of the operation, or by changing the actual configuration of the robot.

SM4: Cost Input Submodule for Non-Robotized Tasks.- SM4 is structured to allow the input of the principal cost components associated with the execution of the given task without using robots. For a given operation, this submodule evaluates different non-robotic approaches and different resource configurations to select the most cost-effective one. SM4 identifies the principal cost components associated with each specific method of execution, and receives three types of information: 1) the direct cost components of the operation (i.e., labor, permanent materials, equipment allocated specifically for the operation); 2) indirect cost components of the operation (i.e, overhead, equipment distributed over different operations, temporary materials); and 3) other associated costs of the operation (i.e, preparation tasks, transportation, cleanup). As with the previous submodules, these data will initially have manual input by the user prompted by the system, but, in the future, the system will have the capability of automatic input by direct file transfer from other sources.

Using the most cost effective approach or method, the module extracts all the relevant and necessary data about the costs of executing the operation without using robots that are required by SM6 to perform the economic analysis. SM4 will also contain knowledge that will stop the process at this point if the data is incomplete, and identify the specific additional data that needs to be input, providing the guidelines for data-collection efforts in the event that the data is not readily available.

The output of this submodule feeds directly to SM6.

SM5: Cost Input Submodule for Robotized Tasks.- In a similar way, SM5 is structured to allow the input of the principal cost components associated with the execution of the given task using the robots. For the given operation, SM5 identifies the principal cost components associated with the execution of the task using the given robot and receives four types of information: 1) the direct cost components of the operation (i.e., labor, permanent materials, equipment allocated specifically for the operation); 2) indirect cost components of the operation (i.e, overhead, equipment distributed over different operations, temporary materials); 3) other associated costs of the operation (i.e, preparation tasks, transportation, cleanup); and 4) all costs associated with the robot (i.e., transportation, setup, calibration, operation, maintenance, dismantling). As with the previous submodules, these data will initially have manual input by the user prompted by the system, but, in the future, the system will have the capability of automatic input by direct file transfer from other sources.

A difference with SM4, is that in this module, there will be no comparative evaluation of alternatives since the objective is to determine the applicability of the given robot. SM5 also contains knowledge that will stop the process at this point if the data is incomplete, and identify the specific additional data that needs to be input, providing the guidelines for data-collection efforts in the event that the data is not readily available.

The output of this submodule feeds directly to SM6.

SM6: Economic Analysis Submodule.- Finally, SM6 performs the final qualitative/quantitative evaluation of the economic justification of using the given robot on the given task. The inputs to this submodule are SM4 and SM5. The result of the complete analysis of CTAM will be a decision with two possible outcomes: 1) it is economically justified to use the robot; or 2) do not use the robot because it is not economically justifiable. The possibility of over-riding this decision due to subjective considerations (e.g., the value associated with impressing a client) is embedded within the knowledge base of the system.

SM4, SM5, and SM6 provide the initial basis for the development of REEM.

4. CONCLUSIONS

This paper has provided an overview of the Construction Robotic Equipment Management System along with a summary of the research results obtained to date on the first module of the system, the Construction Task Analysis Module. Considerable amounts of effort have been devoted to the formalization of the conceptual framework for the system at two levels: 1) the contextual level that defines both the global context surrounding the project, and the specific contexts surrounding each module; and 2) the principal components, i.e., modules and submodules, of the system.

The next phases of the project will be devoted to the development and implementation of the initial testable prototype of the system. The principal efforts will be focused on defining the specific parameters for the input submodules; developing the algorithms required for the analysis submodules; and linking the different components of the system.

5. ACKNOWLEDGEMENTS

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