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TASK AND MOTION PLANNING TECHNIQUE FOR DESIGNING GROUP CONTROL SYSTEM IN ROBOTIC CONSTRUCTION WORK

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ABSTRACT

The purpose of this paper is to describe a task and motion planning technique for designing a group control system in robotic construction works. This technique deals with hierarchical control of multiple robots and peripheral machinery in an automated construction work-cell. The technique consists of two phases: the task planing and the motion planning. The task planning phase illustrates the interactive task sequence diagram for the group control of the work-cell. The motion planning phase describes the interactive motion relationship graph for respective robots and peripheral machinery according to the illustrated task sequence. This proposed technique facilitates the interface between construction automation designers and robot control software developers. The technique is applied in a systematic design of a control system, in terms of an experimental model of a steel column assembly, composed of four robots and four computer controllers.

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1. INTRODUCTION

As expectations of the future robotic construction sites, the automated work-cells in individual construction works will consist of multiple robots, automatic machines, peripheral equipment, and technicians. A total automated construction site will be integrated with respective construction sub-works to process and fabricate work-pieces automatically transferred between each other's work-cells. The performance of the control systems in the work-cells greatly influences reliability, safety, and profitability with regards to a total construction system. Therefore, the researches on the group control of multiple automated machines are indispensable to realization of the automated construction work-cells.

The purpose of this paper is to develop a task and motion planning technique for designing the group control system which operates various robots and peripheral machinery in the construction work-cell. This technique defines interactive signal communication between multiple automated machines, such as synchronous, exclusive, and interlock signals according to the task sequence in the work-cell. Firstly, the task planning phase illustrates the interactive task sequence diagram including communication signals between the respective machines. Secondly, the motion planning phase shows the interactive relationship graph to describe various machine motions automatically controlled in the work-cell. This proposed technique facilities the interface between construction automation designers and robot control software developers.

2. CONVENTIONAL RESEARCH TRENDS OF SEQUENCE CONTROL FOR AUTOMATIC SYSTEMS

Presently, the ladder diagrams are actually used among software developers of control programs. These diagrams which fragmentarily describe respective control steps involved in a task sequence have weak points, namely, difficult understanding of a whole control flow and actions of controlled machines in response to each control step. Even programers, who developed the programs with the ladder diagram technique, must struggle for rearrangement of their previously developed programs at frequent production alternation, and at diagnosis of broken-down manufacturing facilities.

For developing the control programs with flexibility and easy understanding in view of the automatic system designers, the researches on description techniques of group control programing have been pursued from the following two standpoints:

1) Control programing technique based on the motion flow models, and
2) Control programing technique with rule-based description similar to the natural language relating the artificial intelligence.

Regarding the former technique, several researches extending the petri-net theory are proposed: Mark Flow Graph [1], GRAFCET [2], Petri-Net-Based Sequencer [3], and Control-net [4, 5]. As the later technique, several researches are studied by using the "production system", a kind of rule description languages in the A.I. field. The examples of describing various rules generated in actual job sites are Rule Based Language [6], and Station Coordinator [7, 8].

3. RESEARCH PROCESS OF TASK AND MOTION PLANNING TECHNIQUE FOR GROUP CONTROL

The research processes of this proposed technique shows Figure 1. Each of task and motion planning processes includes three steps.

The task planning phase designs a hierarchical structure for a computer control system, and determines a task sequence at the command level of a host controller supervising other terminal controllers. STEP 1.2 in PRO-1 illustrates an interactive task sequence diagram, as shown in Figure 4, which describes the signal communication between the host controller and the terminal controllers for individual robots and peripheral machines. STEP 1.3 defines the required sensing functions to generate the synchronous, exclusive, and interlock signals between each other machine.

In the PRO-2, the motion planning phase illustrates an interactive relationship graph to express machine motions for each robot and peripheral equipment according to the task sequence. As shown in Figure 6, this graph defines the mutual exchanging control signals between the automated machinery. These control signals, in terms of the motion start, the motion completion, and the interlock, play the roles in automatic operation of respective equipment. After defining the relationship of each other's machine motions, additional conditions and parameters for controlling the automated machinery are filled in the graph. Details of Figure 4 and Figure 6 are discussed later.

4. SMALL SCALE SIMULATION MODEL FOR STEEL COLUMN ASSEMBLY BY CRANE ROBOT AND POSITIONING ROBOT

For rationalizing building construction systems with robots, the WASCOR (WASeda COnstruction Robot) research project had been organized since 1982 at System Science Institute, Waseda University.

In this research project, the technical possibility of the robotic operation system was studied by using small scale models of actual robots. The steel assembly system was adopted, and the scale models of actual robots such as a crane robot, a positioning robot, a base movement robot, and a adjusting robot were developed in Figure 2. The aim of the model was to verify the feasibility of cooperative motions between the crane robot and the positioning robot.

Simulation of the cooperative motions such these models is significant for researches on construction robotics because heavy and large fabrication is frequently used in all construction sites. Theses small models are treated as a case study in order to apply the proposed task and motion planning technique to design of a group control system.

5. APPLICATION OF PROPOSED TECHNIQUE TO SIMULATOR OF SMALL SCALE MODELS

Based on the research processes of previously shown in Figure 1, a case study in the task and motion planning for developing a group control system is described with the simulator of the small scale models.

5-1. PRO-1: Task Planning Technique

Figure 3 shows a configuration of the hierarchical control system of four robots in the models. This system consists of three personal computers and a special controller for the positing robot. Ordinarily, each robot is independently controlled according to the commands generated by the two terminal controllers which receive sequential control commands from the host controller. Especially, the cooperative motions between the crane and the positioning robots are performed by the use of the synchronized control when the steel column is lifted up and down so as to install it.

Figure 4 illustrates the interactive task sequence diagram concerning the column assembly. The sequence control commands of the host controller are sent to the two terminal. After individual robots have completed the pre-determined actions in accordance with the given commands, the terminal computers send back the completion status signals to the host controller. In this figure the sequence command "No.15" and "No. 17" are the steps of the cooperative motions between the crane and the positioning robot. Sensors for detecting the status of respective robots, and instruments of power resources for performing the actions are listed up in Figure 5.

5-2. PRO-2: Motion Planning Technique

Figure 6 illustrates an example of the interactive motion relationship graph between four robots in the models. Referring to the concept of "Control-net" [4, 5] previously mentioned in the conventional researches, this graph is developed in consideration of the following factors: 1) unique characteristics of robotic construction tasks, for example, frequent intervention by operators during a sequence control, 2) complicated signal communication including the cooperative motions, for instance, the cooperative control between the crane robot and the positioning robot. The crane robot supports the vertical load of the steel column so that its reaction force against the positioning robot is decreased.

In Figure 6, "Command of Host Controller" corresponds to the sequence control commands defined in Figure 4. In this figure the mutual motion relationship between the crane robot (CR), the positioning robot (PR), the base movement robot (MR), the adjusting robot (TR), and the operator are described with "box", "transition", and "arrow" signs.

Table 1 and Table 2 show types of the "box" and the "transition", respectively. The "box" describes contents of motion and process, and each "box" is illustrated with representative command names in correspondence with the contents of the motion and the process. The "transition" defines the synchronous condition, the exclusive, and the interlock .

6. CONCLUSION

The developed task and motion planning technique for the group control was applied in the hierarchical control system of the small scale models so as to verify the feasibility of the cooperative motions between the crane robot and the positioning robot. In addition to further enhancement of this planning technique, the research on the error recovery is indispensable to actual utilization of the designed group control system.

ACKNOWLEDGEMENT

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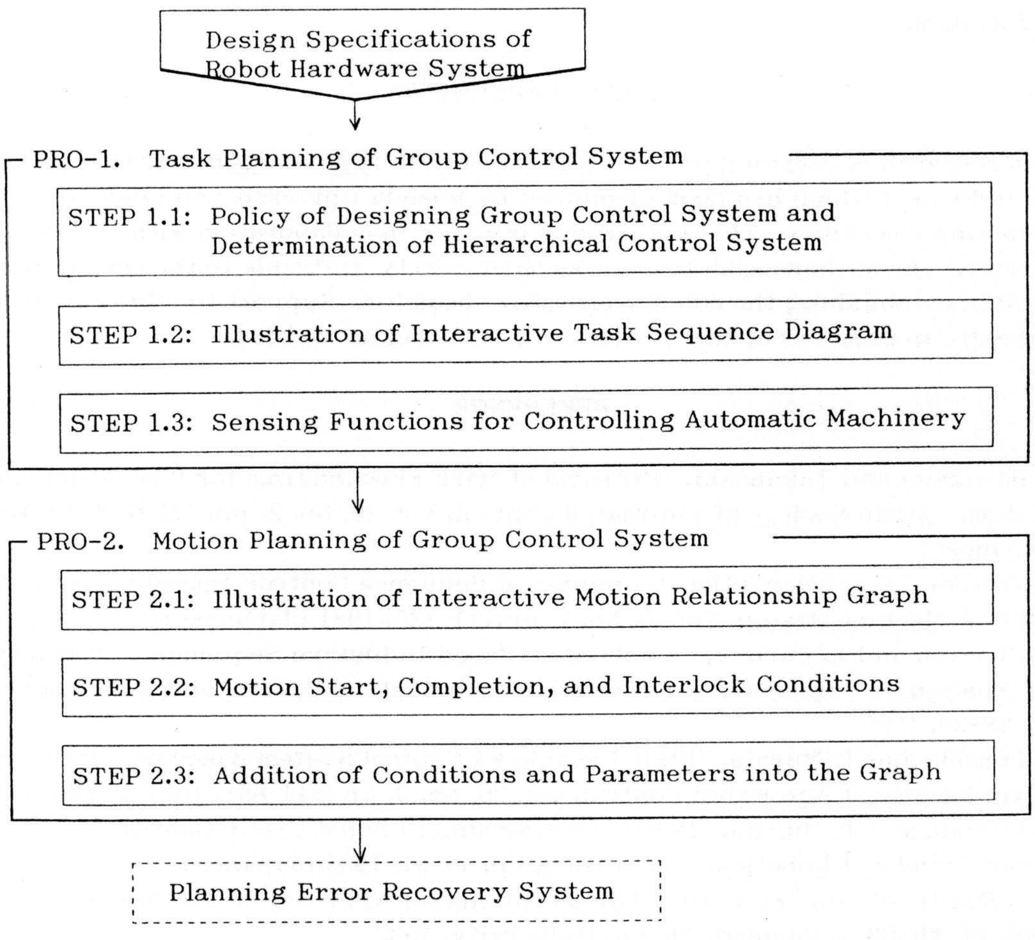

Figure 1 Research Processes of Task and Motion Planning Technique for Designing Group Control

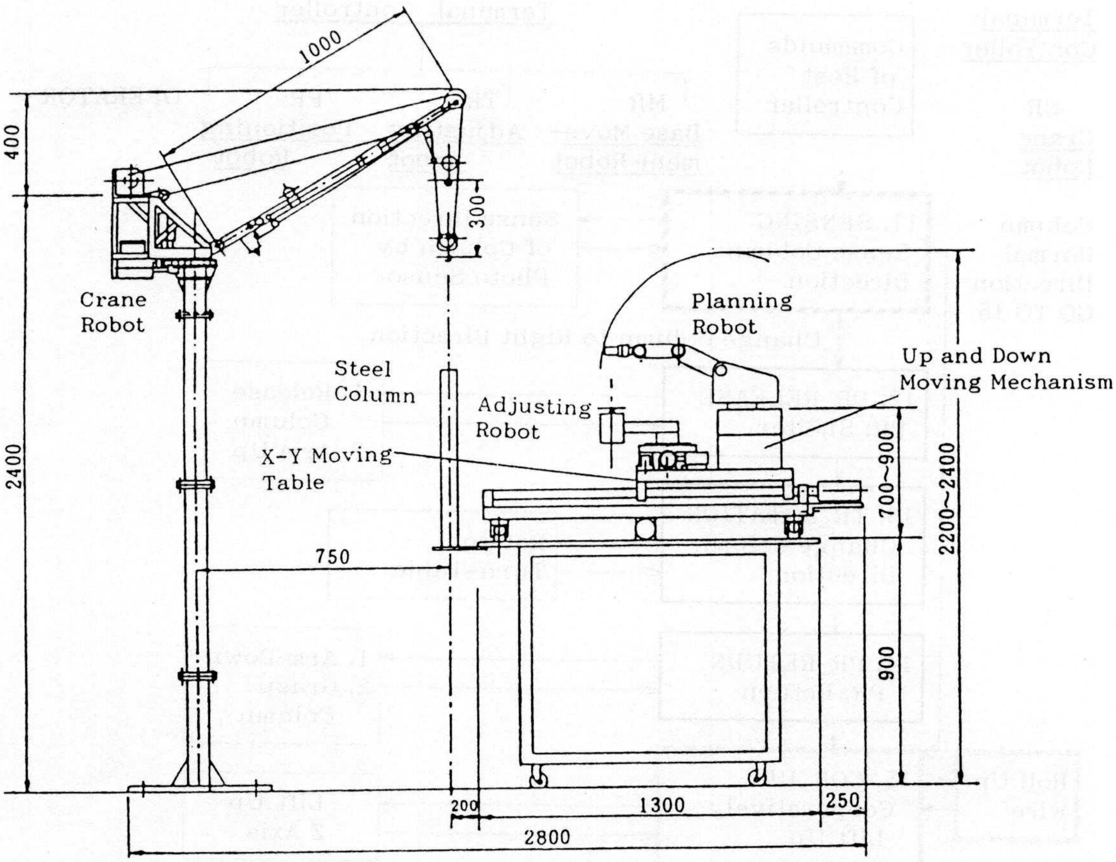

Figure 2 Small Scale Simulator Models for Steel Column Assembly

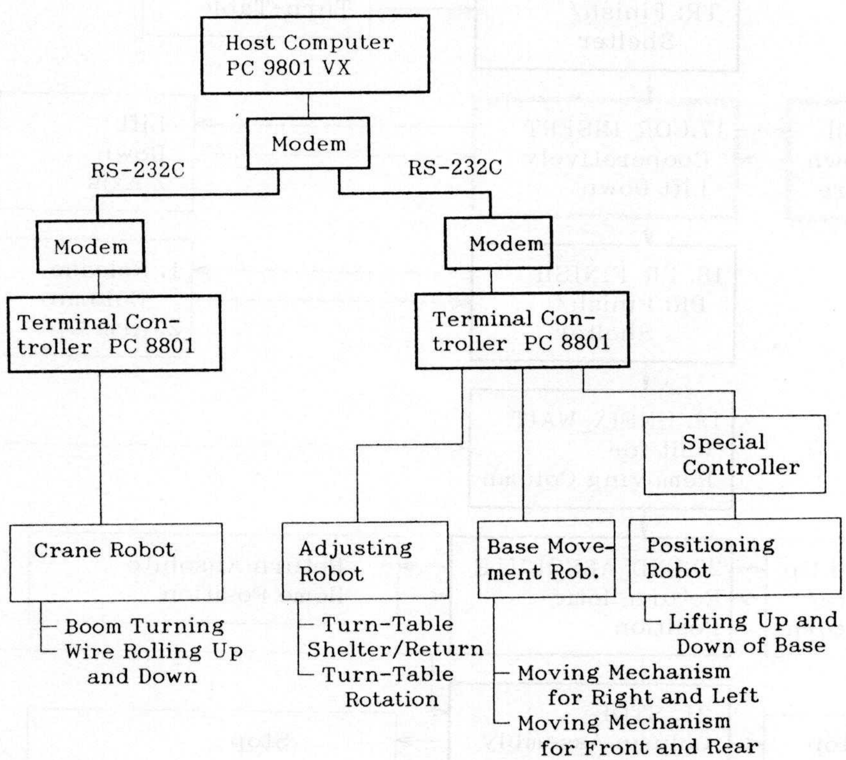

Figure 3 Data Communication Network of Column Assembly Simulator

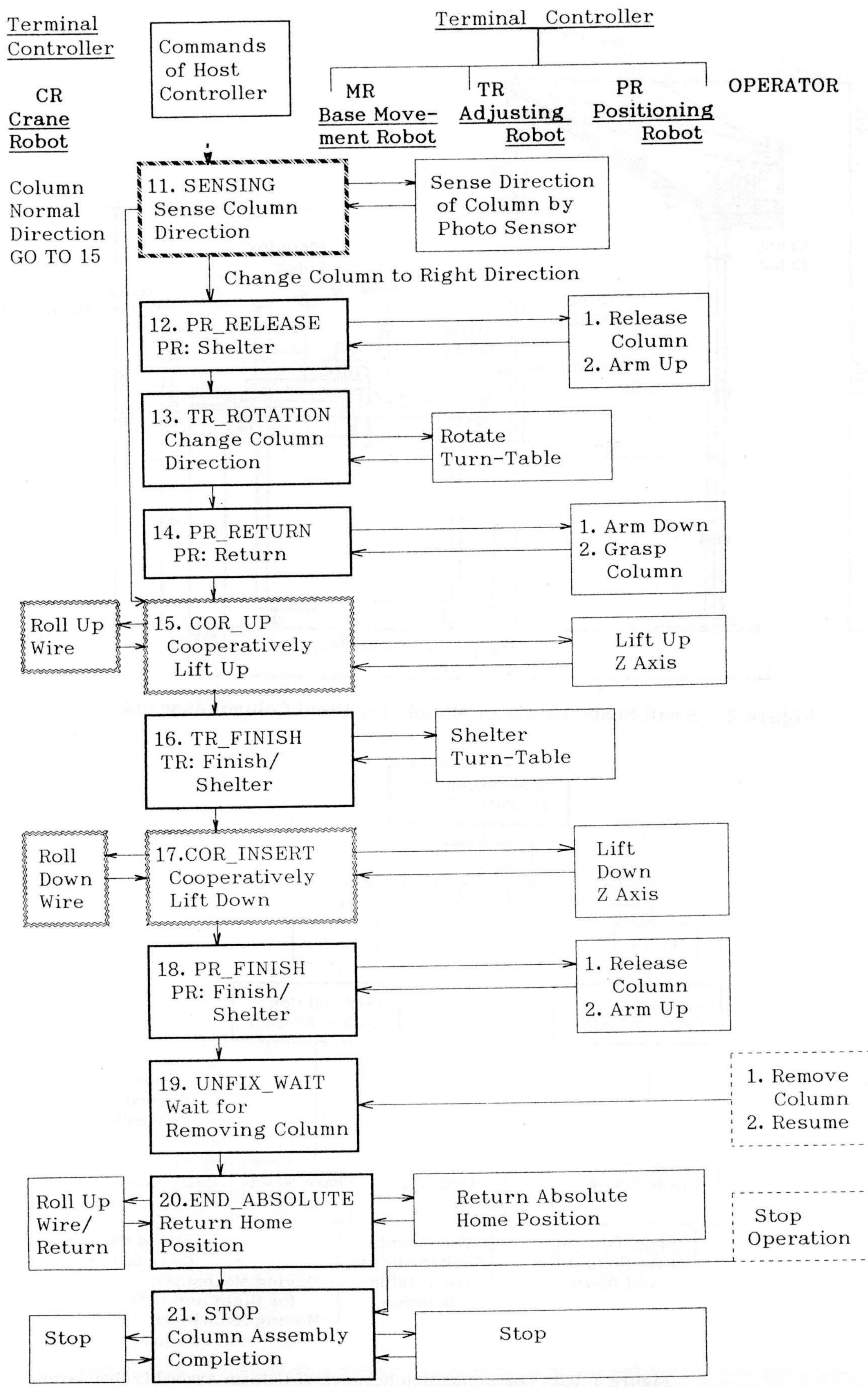

Figure 4 Interactive Task Sequence Diagram of Column Assembly Simulator

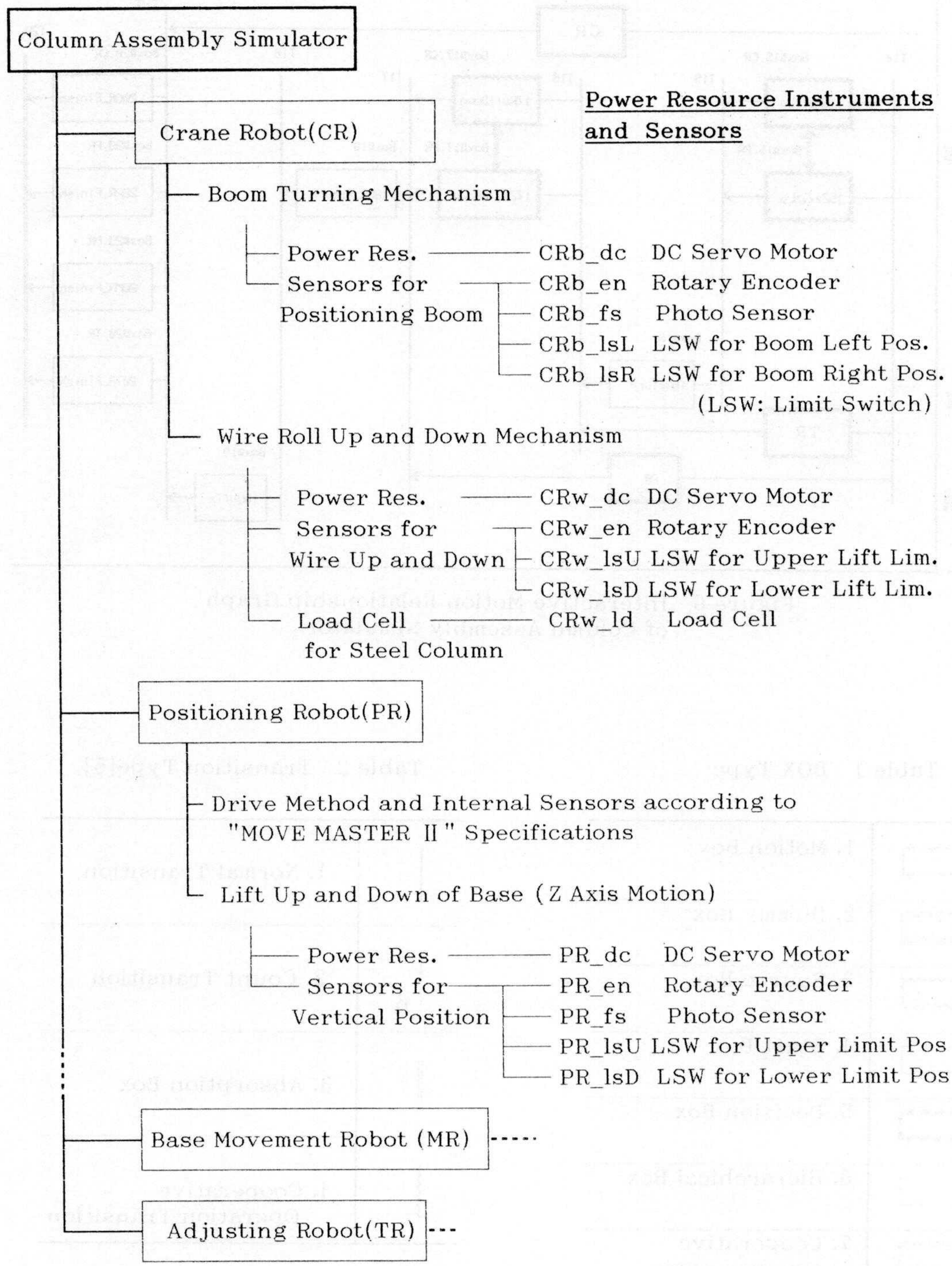

Figure 5 Power Resource Instruments and Sensors for Column Assembly Simulator

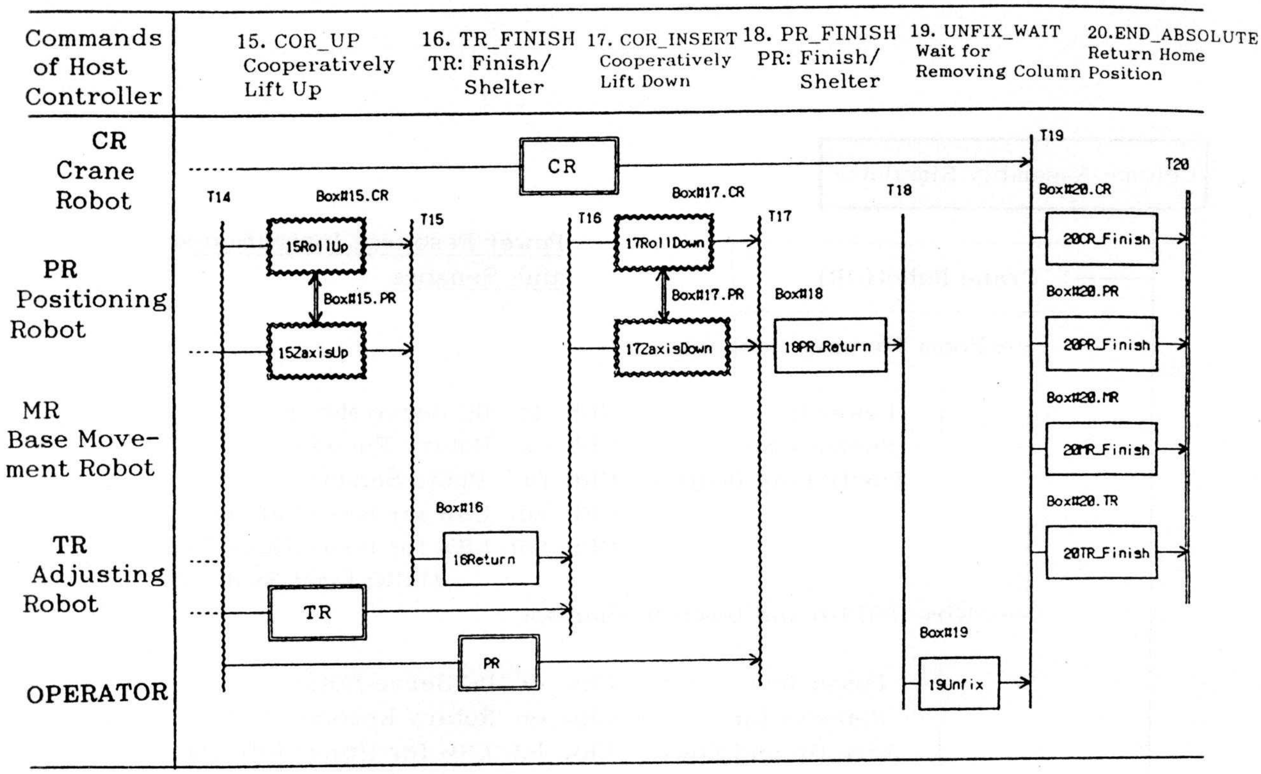

Figure 6 Interactive Motion Relationship Graph of Column Assembly Simulator

Table 1 BOX Type

	1. Motion Box
	2. Dummy Box
	3. Source Box
	4. Start Box
	5. Decision Box
	6. Hierarchical Box
	7. Cooperative Operation Box
	8. Operator Motion Box

Table 2 Transition Type[5]

	1. Normal Transition
n	2. Count Transition
	3. Absorption Box
	4. Cooperative Operation Transition