MODULE ROBOT APPLICATION FOR FLEXIBLE BUILDING CONSTRUCTION

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ABSTRACT

The biggest barrier to obstruct successful introduction of robots into building construction sites is complexity of the construction system. In the building construction sites, many types of technicians have to work in parallel. Therefore, in the case of introducing conventional and single function types of robots, too many types of robots have to be prepared, and these great numbers of the robots and peripheral equipment have to be transferred from one site to others in response to the mobility of the construction sites. For coping with the problem of complexity, we are developing construction module robots. As the first step of the research and development, key technologies for modularization, development methodology, data collection and analysis of construction materials, task processes of robotic tasks, and design specifications of robot hardware modules in finish works are reported.

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1. INTRODUCTION

Recently, research and development in automatization and robotization for construction works are carried out by construction and machinery companies, public research laboratories, universities, and related governmental organizations. For the robotization in comparison with conventional limited mechanization in the building construction sites, we must solve new problems which include the following unique characteristics of construction production systems:

1) Most of robots require locomotion functions by reason of frequent transitions of working places in huge construction buildings.
2) The great numbers of the robots and other automatic facilities have to be transferred from one site to others in response to the mobility of the construction sites.
3) Construction robots require versatile functions to perform multiple motions

and tasks, compared to conventional industrial robots applied in repeating motions and tasks in manufacturing factories.

4) Existence of diverse construction methods.
5) Use of various types of construction materials and work pieces, for example, from big and heavy steel columns to small screws.

In the construction sites many process technicians are needed to construct a building, for instance, more than 100 technicians in the case of a middle office building. It is not economically feasible to simply introduce conventional limited purpose type of robots to construction systems because a great many different types of robots would be required at a construction site, and all robots would be transferred to other sites after completing a construction work.

Therefore, a robot modularization concept is proposed as a new and reliable tool for solving these problems on the occasion of developing effective construction-use robots. In this paper, this modularization concept is applied into the board application for ceilings, walls, and floors, since the application for backer and finish boards is a principal task in the construction finish work.

2. TECHNOLOGY ASSIGNMENTS FOR MODULARIZATION

The key technology assignments for implementing the module robots are enumerated and categorized from the following points of: 1)systematic design of robotic task systems, 2) development of robot hardware modules, 3) development of control software, and 4) operation and management of the developed module robots. Fig. 1 focuses on the category of "1)systematic design of robotic task systems", and illustrates the individual assignments with a hierarchal structure.

3. TASK CONTENTS OF ROBOTIC BOARD APPLICATION

This section includes data collection and analysis of the board types used in actual construction finish works, and robotic task processes of the board application.

3.1 Data Collection and Analysis of Board Types

The boards used in the inside finish work are about 90 types for the backer boards, and about 50 types for the finish boards. Fig. 2 and Fig. 3 show the length and the width about respective backer boards and finish. In Fig. 2 the backer boards mainly use 1500 to 2000 mm for the length, and 800 to 1000 mm for the width (1820 * 910 mm). As shown in Fig. 3, typical finish boards are divided into two types. The first type is 500 to 1000 mm for the length, and 200 to 800 mm for the width (600 * 300 mm, and 900 * 450 mm). The second is the same size to the main backer board.

Fig. 4 and Fig. 5 illustrate the weight distributions of the backer and the finish, respectively. Most of the backer are 5 to 30 kg. Contrarily, the finish boards are almost less than 5 kg.

3.2 Task Processes of Robotic Board Application

Fig. 6 shows the task processes of the board application by using a robot and a board provision vehicle. In this figure the horizontal and vertical center lines in the floor are two reference lines for applying backer and finish boards, and the numbers on the boards are the applying orders. Fig. 7 illustrates a flow chart of the robotic task processes. Fig. 8 explains in detail "Board Application by the Module Robot" involved in Fig. 7. The outline of the board application is described as follows:

1) Cooperative operation between the applying robot and the board provision vehicle.
2) As shown in ordering numbers on the individual boards, the applying operations perform from the boards closer to the reference lines, to far from them.
3) The vehicle follows behind the applying robot. The applying robot picks up a board one by one from the vehicle, and applies each other board to the ceiling. When there is no board on the vehicle, the vehicle automatically return to the temporarily stock place in order to replenish the next boards.

4. DESIGN FACTORS OF MODULE ROBOT

4.1 Functions for Module Robot

The robot hardware modules are composed of five type parts: 1)End Effector Module, 2)Wrist Module, 3)Arm Module, 4)Body Module, and 5)Locomotion Module.

1) End Effector Module
The End Effector Module directly treats with work pieces. This module is classified into two categories such the constraint type and the processing type. The constraint type is used for holding the work pieces and handing tools. The process type is divided by functions of processing, and further classification is done by the kind of processing tools, for example, cutting, holing, and screwing tools.

2) Wrist Module
The Wrist Module has an orientation control function for the work piece or the end effector.

3) Arm Module
The Arm Module has a positioning control function for a work piece or the end effector.

4) Body Module
The Body Module has functions related to computer control and power resources.

5) Locomotion Module
The Locomotion Module has a traveling function. In the case of construction robots, the role of the locomotion module is a new field in robotics.

4.2 Design Factors for Respective Robot Hardware Modules

Fig. 9 illustrates the design factors which satisfy the functions required for the respective robot hardware modules described in the previous section 4.1.

The design factors for the End Effector Module of the constraint type are mainly influenced by characteristics of the handling work pieces such as shape, weight, surface condition, stiffness, and other physical features. The factors for the Arm Module and the Wrist Module, in conjunction with the design for a robot configuration, are determined through the analysis of motion trajectories, positioning motions, and motion ranges. After the design of the robot configuration, the data related to weights of the work pieces and the end effector, and the position accuracy are necessary for the design of robot mechanism and static force analysis.

5. ANALYSIS OF MOTION TRAJECTORIES AND POSITIONING MOTIONS FOR BOARD APPLICATION

Firstly, with regard to "gross motions" of the board application for the ceiling, motion trajectories, which include points from the constraint of a board to the final installation, are analyzed in Fig. 10 to Fig. 12. The application tasks for the ceiling need three patterns of the motion trajectories as shown in these three figures. The partial motion trajectories after the fundamental position "P3" or "P4" involved in these patters correspond to the identical motion path. Fig. 13 unifies all motion functions for the module robot to complete the board application tasks of the ceiling, the wall, and the floor.

Secondly, focusing on the difference of the "fine motions" for installing the boards to the final places, positioning motions of the boards are analyzed in Fig. 14 to Fig. 16. These positioning motions in terms of the ceiling are almost common to the positioning of the wall and floor boards.

6. DESIGN SPECIFICATIONS OF ROBOT HARDWARE MODULES

This section includes the design specifications of the End Effector Module, the Wrist, and the Arm.

6.1 Design Specification of End Effector Module

From results of the data collection and analysis of the backer and finish boards in the previous section 3, the typical boards used in the construction finish work are clarified from the point of the shape, the size, and the weight. In addition to these physical characteristics, the suction type for the end effector is selected in consideration of the surface conditions of the boards, and the positioning motions for the application tasks. The hardware designs of the End Effector Modules are illustrated in Fig. 17 to Fig. 19. The size variation of the various backer and finish boards is flexibly coped with the addition of the extra End Effector Modules.

6.2 Design Specifications of Arm Module and Wrist Module

Regarding the board application for the ceiling, the required degrees of motion freedom about the positioning motions are two degrees of translation freedom "X" and "Y" in the object coordinate system, and one degree of rotation freedom " γ ", from the results of the fine motion analyses in Fig. 10 to Fig. 12. Additionally, the degrees of motion freedom about the motion trajectories need three translation freedom "X", "Y" and "Z", and two rotation freedom " α " and " γ ", from the results of the gross motion analyses in Fig. 10 to Fig. 12. In terms of the board application for the ceiling, the wall, and the floor, Table 1 and Table 2 illustrate the degrees of motion freedom required for the positioning motions and the motion trajectories, respectively. Therefore, the Arm and the Wrist Hardware Modules, which satisfy five degrees of freedom such as "X", "Y", "Z", " α " and " γ ", have to be designed.

7. Conclusion

The typical types of the backer and finish boards used in the finish work were clarified by the data collection and analysis of the actual board application tasks for the ceiling, the wall, and the floor. The motion trajectories and the positioning motions for executing the tasks were analyzed. Based on the survey results of material characteristics and the motion analyses, the design specifications for the respective robot hardware modules, such as the End Effector Module, the Wrist, and the Arm, were determined. For the further enhancement of this modularization research, the robot configurations have to be concretely designed from the result of the motion analyses. In the continuing development of the robot modularization, the further construction tasks besides the board application have to be studied.

ACKNOWLEDGEMENT

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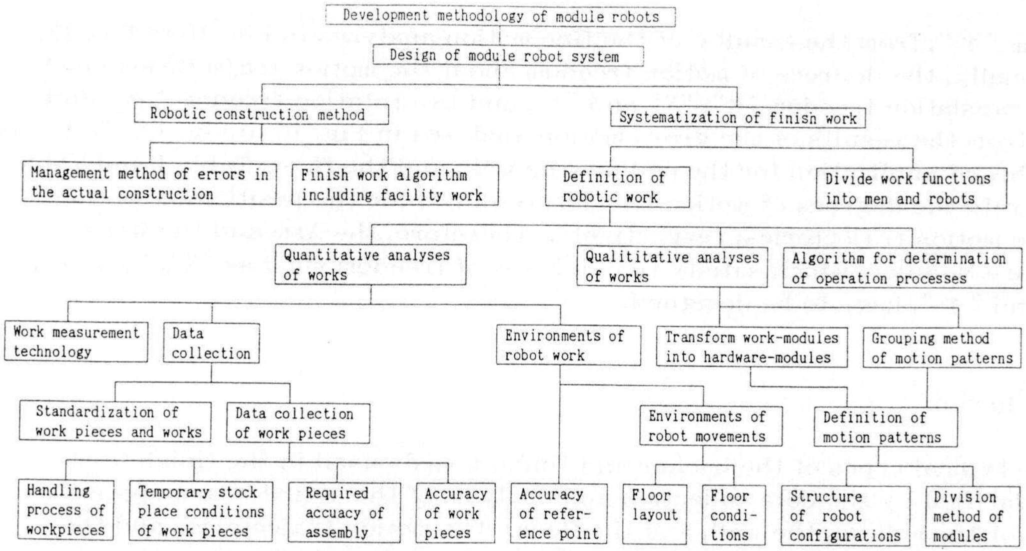


Fig.1 Technology Assignment of Systematic Design of Robotic Task Systems

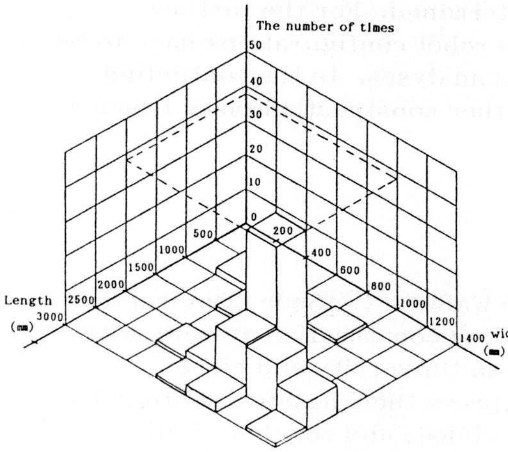


Fig.2 Distribution Map of Board Length (Backer Board)

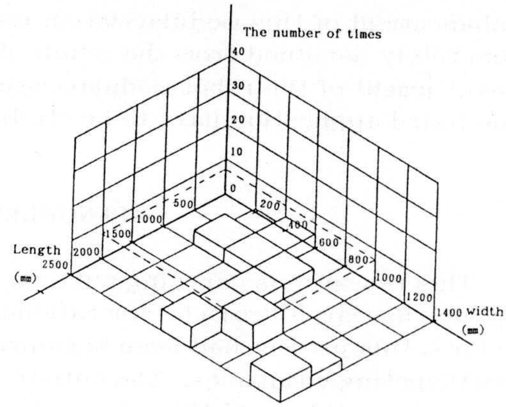


Fig.3 Distribution Map of Board Length (Finish Board)

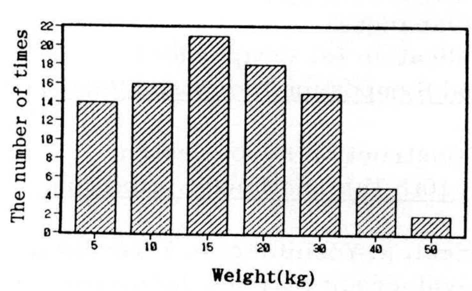


Fig.4 Distribution Map of Board Weight (Backer Board)

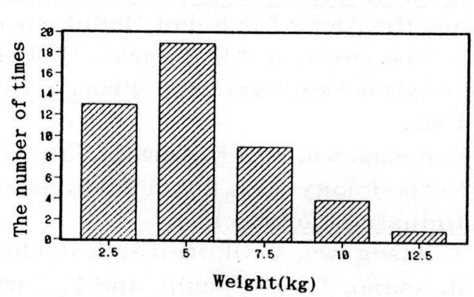


Fig.5 Distribution Map of Board Weight (Finish Board)

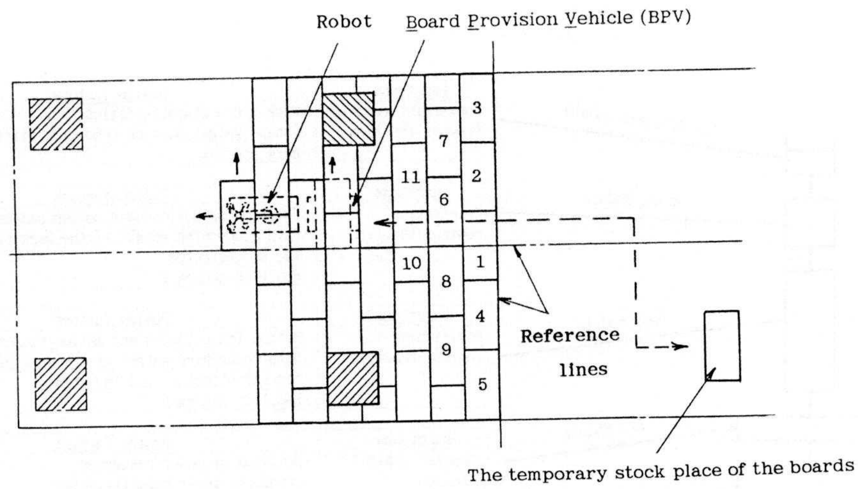


Fig.6 Task Processes of Robotic Board Application

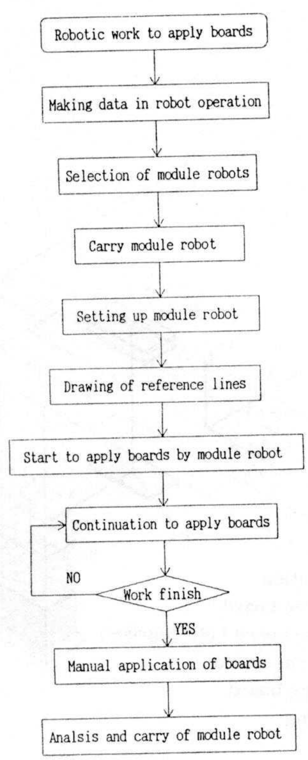


Fig.7 Flow Chart of Robtic Task Processes

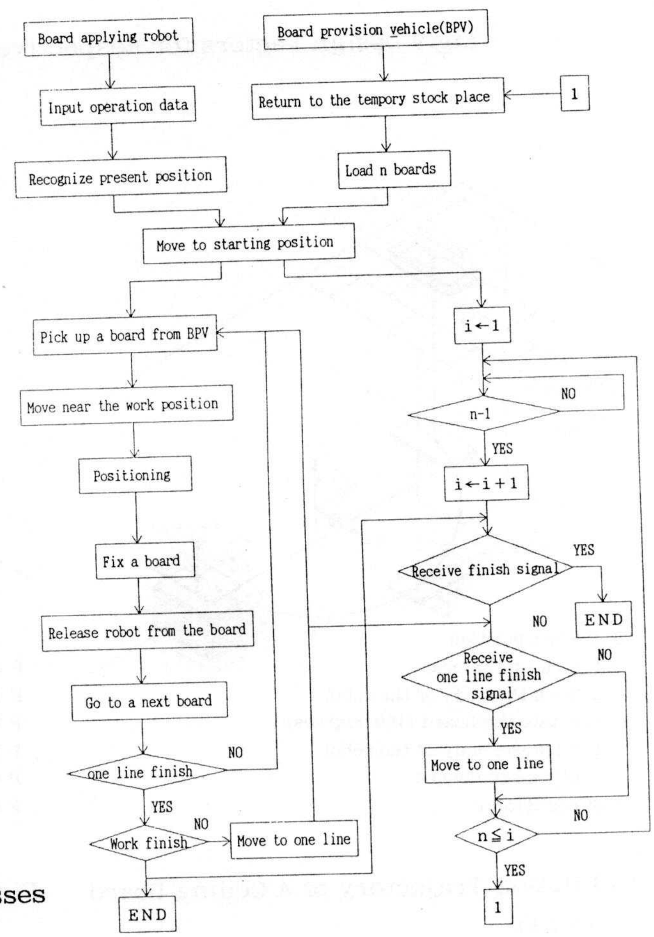
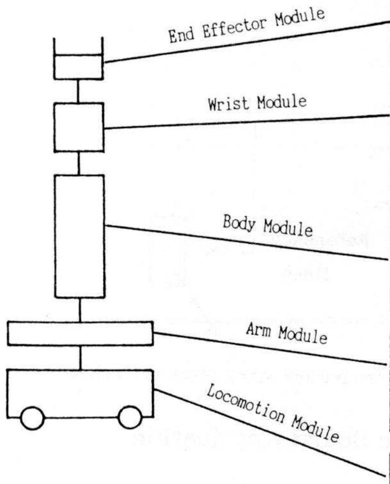


Fig.8 Board Application by Using Module Robot



Functions	Design factors
·Constraint function ·Process function	·Work piece characteristics (shape,weight,surface condition,stiffness,etc.) ·Work process

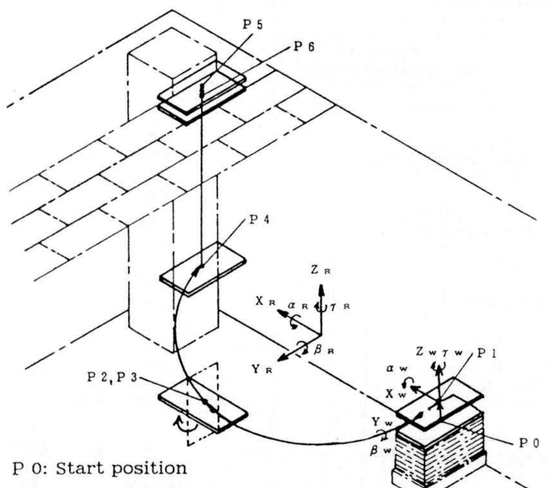
Functions	Design factors
·Orientation control function	·Positioning motions and motion ranges ·Data concerning weight of the work piece and the end effector ·Position accuracy

Functions	Design factors
·Positioning control function	·Motion trajectories and motion ranges ·Data concerning weight of the work piece, the end effector, and the wrist ·Position accuracy

Functions	Design factors
·Conputer control function ·Power resources function	·Decision of power resources (required power,capacity,weight) ·Motion trajectories and motion ranges ·Control algorithm

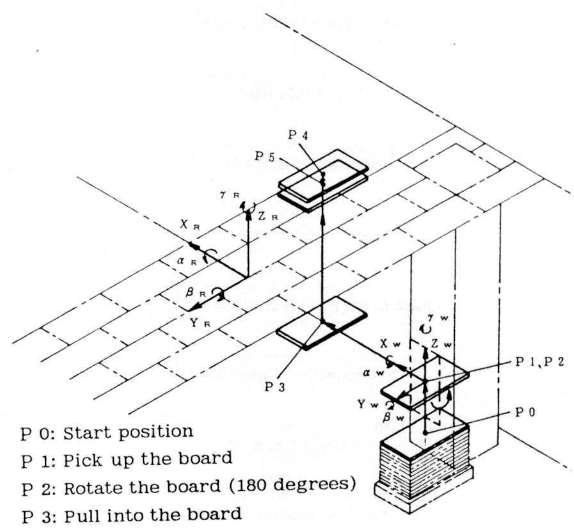
Functions	Design factors
·Travering function	·Weight of module robot ·Floor conditions

Fig.9 Design Factors for Respective Robot Hardware Modules



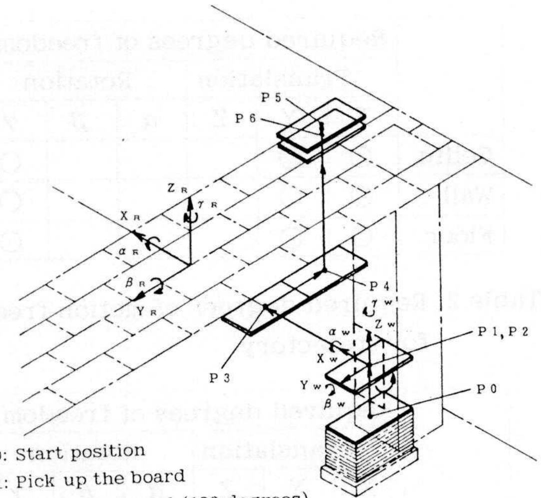
P 0: Start position
P 1: Pick up the board
P 2: Turn the body of the robot
P 3: Rotate the board (180 degrees)
P 4: Turn the body of the robot
P 5: Lift up the board
P 6: Positioning

Fig.10 Motion Trajectory of A Ceiling Board (No.1)



P 0: Start position
P 1: Pick up the board
P 2: Rotate the board (180 degrees)
P 3: Pull into the board
P 4: Lift up the board
P 5: Positioning

Fig.11 Motion Trajectory of A Ceiling Board (No.2)



P 0: Start position
P 1: Pick up the board
P 2: Rotate the board (180 degrees)
P 3: Pull into the board
P 4: Lift up the board
P 5: The robot moves
P 6: Positioning

Fig.12 Motion Trajectory of A Ceiling Board (No.3)

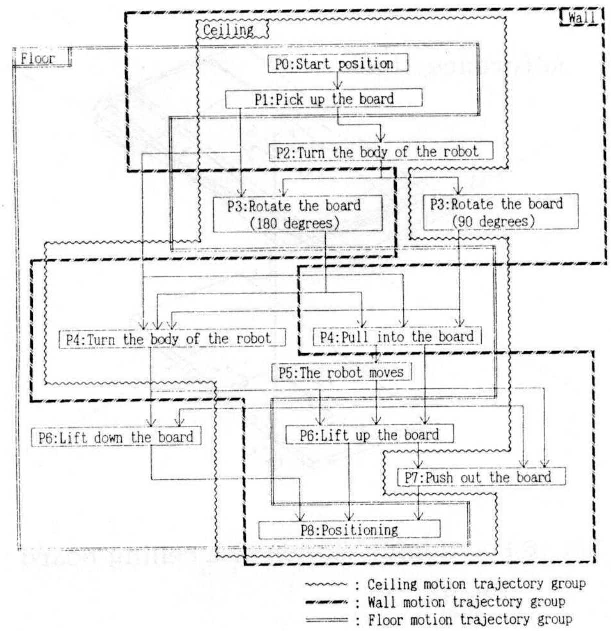


Fig.13 Unification of Motion Trajectory for Ceiling, Wall, Floor

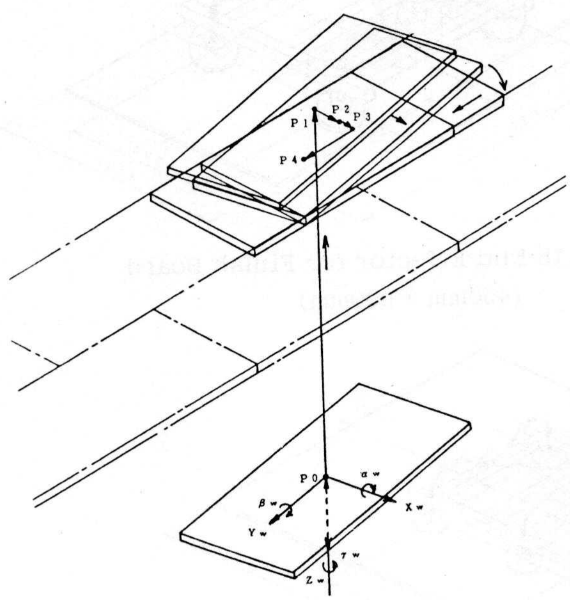


Fig.14 Positioning Motion of A Ceiling Board (No.1)

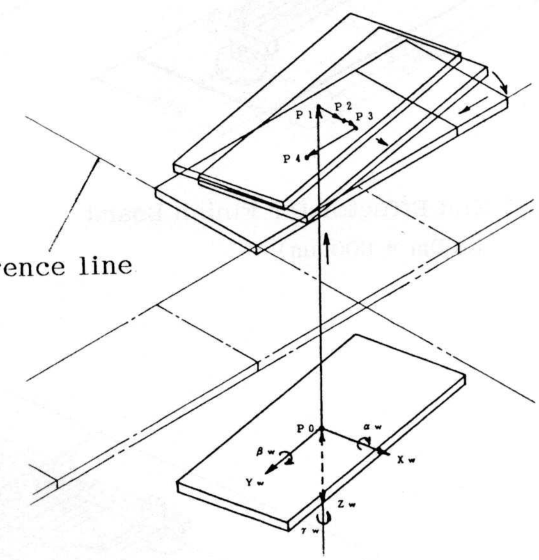


Fig.15 Positioning Motion of A Ceiling Board (No.2)

Table 1. Required degrees of motion freedom for positioning

	Required degrees of freedom					
	Translation			Rotation		
	X	Y	Z	α	β	γ
Ceilin	○	○				○
Wall	○	○				○
Floor	○	○				○

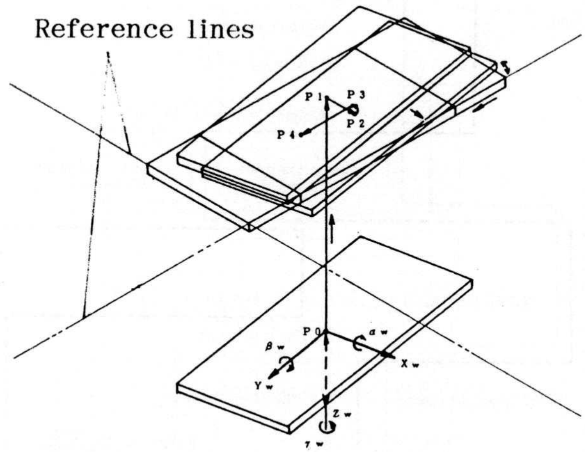


Fig.16 Positioning motion of a ceiling board (No.3)

Table 2. Required degrees of motion freedom for trajectory

	Required degrees of freedom					
	translation			Rotation		
	X	Y	Z	α	β	γ
Ceilin	○	○		○		○
Wall	○	○		○		○
Floor	○	○				○

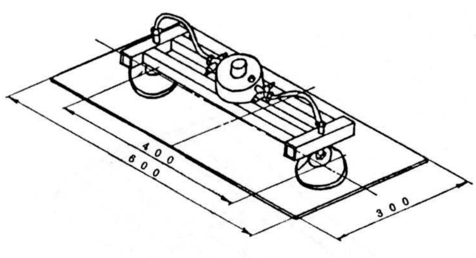


Fig.17 End Effector for Finish Board (300m * 600mm)

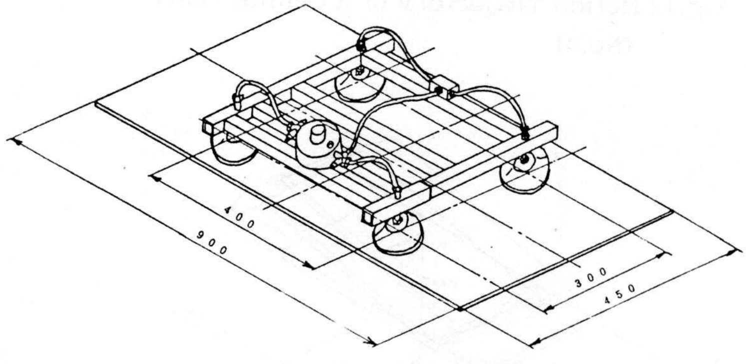


Fig.18 End Effector for Finish Board (450mm * 900mm)

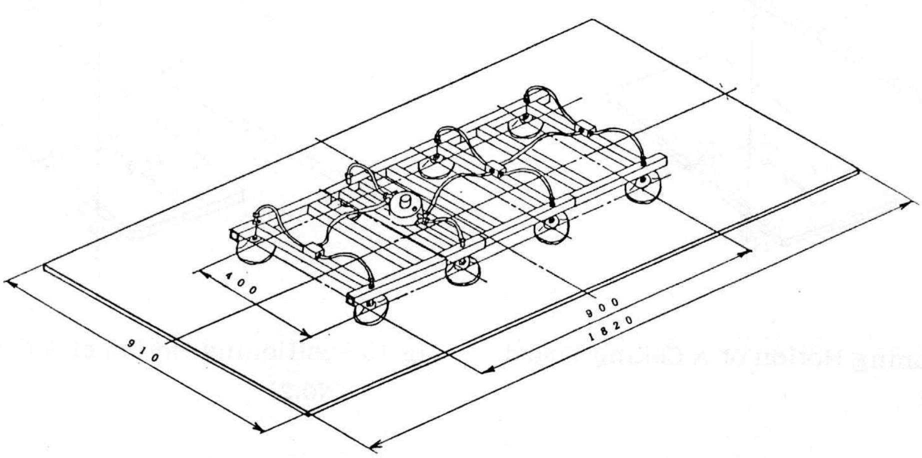


Fig.19 End Effector for Backer Board (910mm * 1820mm)