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Development of a 9 DoF Articulated Manipulator for Maintenance*

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Key words: 9 DoF articulated manipulator, maintenance, metamorphism, joint configuration, structure strategy, workspace.

1. Introduction

In recent years maintenance works involving inspection, diagnosis, and repairing, have greater importance socially. On the other hand, most of maintenance works are done by human in unfavorable working environment such as in nuclear plants. For the purpose of automation of such works we are developing an intelligent mobile robot system named "A MOOTY"[1] cooperating with other research groups, and our group designed and manufactured a 9 DoF articulated manipulator loaded on the mobile robot.

2. Specifications of the 9 DoF Manipulator

Joint configuration and technical data of the manipulator are shown below.

Base-S-R-P-R-P-P-R-P-R-Gripper

Total Weight	61Kg
Total Length	1513mm
Load Capacity	6Kg
Grasping Force Capacity	2Kg

The control unit is constituted as Fig.1. The controller is DENSAN DSC-86SF(CPU : 8086+8087, OS : CP/M86).

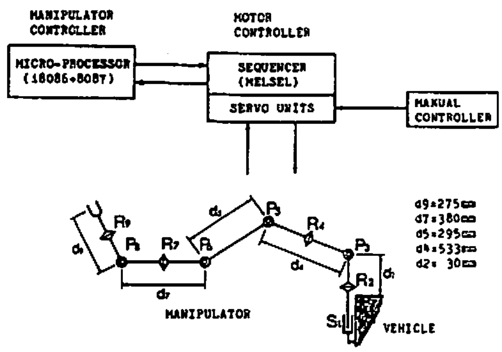

Fig.1 Control Unit

Table 1 Moving Statements

	Moving Joints	Interpolation	Destination
REVOLVE	9	angles	angles
MOVE(ANGLE)	free-side 6	angles	position
MOVE(LINE)	free-side 6	position	position
TRANSFORM	base-side 3	angles	angles

Each movement is programmed previously in sequential data and locational data. The controller reads a sequence of statements written by the first parameters in the sequential data. Four kinds of moving statements are prepaired (Table 1). Statements move joints concurrently to the destination given in angles or positions, interpolating the difference of angles or positions. MOVE(LINE) indicates linear motion with a uniform orientation. These statements are characterized by dividing 9 DoF into base-side 3 DoF and free-side 6 DoF. When MOVE statement is excuted, this program checks the referred destination position whether it is included in the workspace or not, and this program creates a new statement to move base-side 3 joints of the manipulator as to make the position include in its workspace.

3. An Approach to Control a Redundant Manipulator

A redundant manipulator has more degrees of freedom than 6 that is the number required to approach the spatial destination with the orientation. Its dexterity enables to avoid obstacles, to widen the work space, and to solve special-configuration-point problems. We propose, therefore, a new control method for the redundant manipulator. In this method, the redundant manipulator is considered as a metamorphic one with 6 mechanical DoF, and it can transform its own geometric structure by fixing proper three joints according to the given task. This approach unites the advantages of dexterity of a redundant manipulator and simplicity of algorythm to control a 6 DoF manipulator. When introducing this approach, the geometric structure of the manipulator as a working subject must be analyzed and classified.

4. Geometric Structure of Manipulator

The kinematic characteristics of the manipulator are determined by geometric structure which denotes the joint types,

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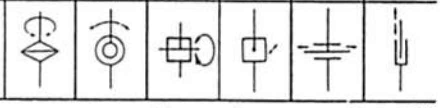
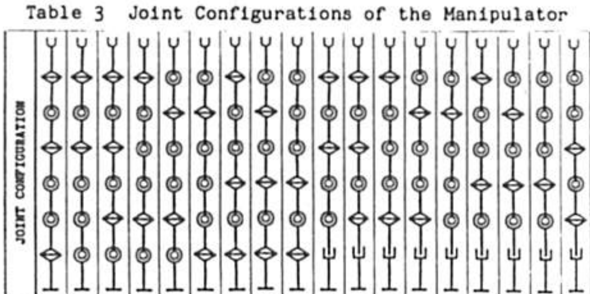
Table 2 Joint Types

NAME	ROTATION	PIVOT	PIVOT	SLIDER	SLIDER	SLIDER
NOTATION	RO	PX	PY	SX	SY	SZ
ROTATING AXIS	Z-AXIS	X-AXIS	Y-AXIS	—	—	—
TRANSLATING AXIS	—	—	—	X-AXIS	Y-AXIS	Z-AXIS
JOINT SYMBOL						



their sequence, dimensions and offset directions of the links. In conventional transforming method, the four parameters are used to describe the relationship between the coordinate systems, which are θ_i, d_i, a_i, α_i. One of the four is a variable to be controlled (θ_i if the joint is rotational, d_i if prismatic), and the others are constants. In many cases of the industrial robots, these constants are simple values such as 0 or 90(deg) for the reason that on-line computational scheme demands short execution time to calculate the variables. Therefore we prescribe the six types of joints constructing the manipulator (Table 2), and links having offset only along z-axis. Total number of joint configurations is equal to that of combination of 6 types of joints, $6^6=46656$. But this number involves the number of joint configurations to be excluded. They are configurations degenerated by its own geometry, and configurations counted doubly, which are considered topologically identical by changing visual points or rotating revolute joints. Excluding the degenerated joint configurations, identifying the topologically equivalent ones, and assuming that three joint types of free-side are revolute ones by taking account of the fact that prismatic joints are not effective to turn its orientation, the total number 46656 reduces to 909.

Table 3 Joint Configurations of the Manipulator



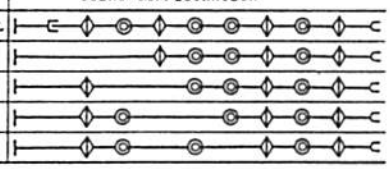
JOINT CONFIGURATION																		
No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
KINDS	4	1	2	1	1	1	4	2	1	3	10	6	4	1	4	1	2	3

Excluded Configurations 33
Total Number Of Kinds 84

In the case of this manipulator, if we assume to fix proper three joints as to make the variables zero, the total number of the joint configurations is ${}_9C_3=84$. In the same way as mentioned above, excluding invalid joint configurations we obtained 18 topologically distinguished ones as shown in Table 3. Moreover, in the topologically same joint configurations, we distinguish those structures (Metamorphoses-1,2,3,4) by the difference of link length (Table 4). Intelligent decision is necessary to determine the most suitable manipulator structure suited to the given task, which is called structure strategy. For example, the workspace of the structure should be evaluated to accomplish the task. In the case of Table 4, metamorphoses of the manipulator indicate different workspaces (Fig.2).

Table 4 Different Structures of R-P-P-R-P-R

No.	JOINT CONFIGURATION
ORIGINAL	
META-1	
META-2	
META-3	
META-4	



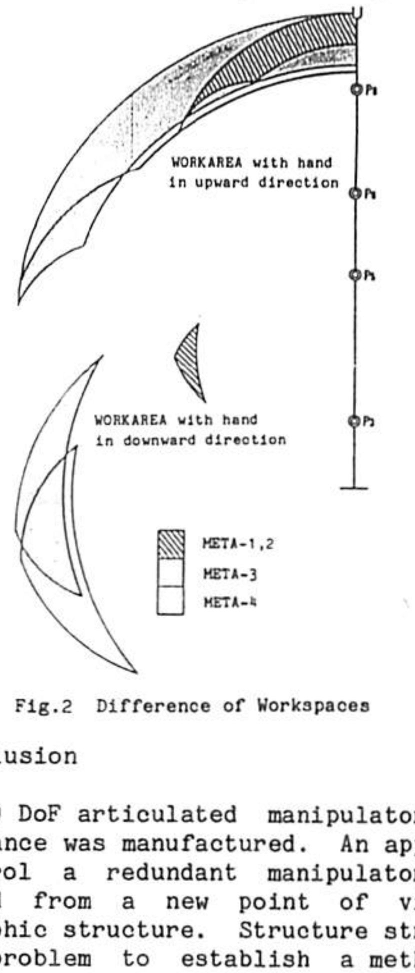


Fig.2 Difference of Workspaces

5. Conclusion

A 9 DoF articulated manipulator for maintenance was manufactured. An approach to control a redundant manipulator was proposed from a new point of view of metamorphic structure. Structure strategy is a problem to establish a method to select the most suitable structure by classified tasks. It is supposed to be efficient to apply knowledge engineering to this problem.

References

1) ARAI, T., et al.: Seminar on Remote Handling Equipment for Nuclear Fuel Cycle Facilities, IAEA, OECD Nuclear Energy Agency, Harwell, UK, Oct. 1984.