Research on Algebraic Configuration Description Method and kinematical modeling for Modular Robot

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Abstract. We propose a new algebraic configuration description method (ACDM) for the modular robot. The ACDM can describe each mechanical configuration in the robotic configuration parameters, and make up for the inadequacy of D-H method in multiple configuration. The algebraic configuration description method support complicated calculation about the parameters in joint level. The configuration algebraic expression and kinematic model are established in this paper for the modular robot. And kinematical modeling and simulation results show that the algebraic configuration description method is effective.

Introduction

Modular robot has short time and high efficient in development. The design of robot can be de divided into the design of modules and the design of robot's configuration, the former is much easier than the latter so that it needs less time. When the configuration of robot needs to change, our main task is to do the configuration design and some special modules design, which greatly improves the efficient of design. Many institutions have made research about modular robot, such as the RMMS in Carnegie Mellon University[1,2], the modular robot system MRS in university of Toronto[3], the PowerCube series module products in the AMTEC company of Germany[4-6] .

Reconfigurable modular robot system(RMRS) consists of a series of different functions, characteristics and assembly function of the standard size of joint or link modules, the way to the building blocks of robotic systems that have been assembled[7]. This combination is not a simple mechanical restructuring, including control system, electronic hardware, control algorithm, software, such as restructuring. Because the modular joint itself is a set of drive, driving, control, communication as a whole unit[8].

The D-H method has been widely applied in kinematic model. But the D-H method is inefficient when modeling in multiple configuration. So the new algebraic configuration description method (ACDM) is proposed for the modular robot in this paper.

The modular robot parameters

The design configuration of 6-DOF modular reconfigurable robot is shown in Figure 1. And it has 6 DOF. The joint weight(m1~m6) is 13.00kg, 13.0kg, 8.5kg, 8.5kg, 5.5kg,5.5kg. The effective length of link module is 100mm, and its weight is 0.8kg. Because of the symmetrical design, barycentric position of the joints are all in the geometric center.

The basic module consists of three kinds of joints: Type 1, Type 2 and Type 3. The joints can also be designed in accordance with the requirements into larger or smaller Type. The appearance size of Type1 is 146*146*293mm, the appearance size of Type 2 is 110*110*221mm, and the appearance size of Type 3 is 90*90*181mm. Among them Joint 1 and Joint 2 are Type1, Joint 3 and Joint are Type2, Joint 5 and Joint 6 are Type3. The configuration of joints module are shown in Figure 2.

The Joints design parameters are shown in Table 1. We can see the Joints support flexible way of refactoring.
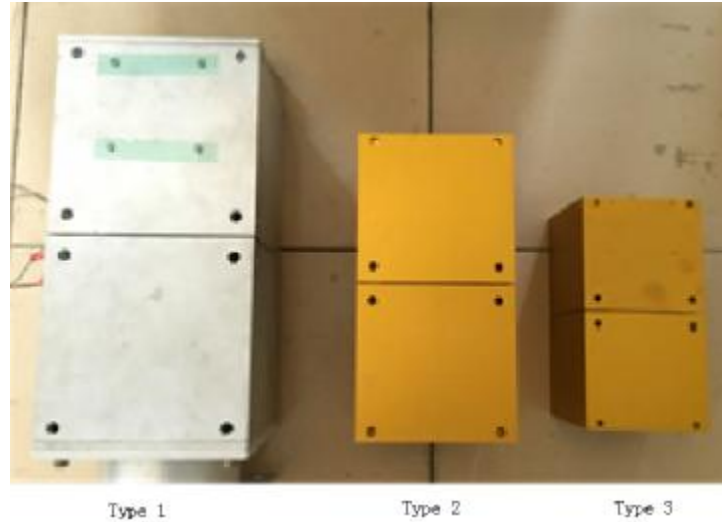
Figure 1 The 6-DOF modular robot

Figure 2 The Type of modular joints

Table 1 Joint design parameters

Designation	Unit	Type 1	Type 2	Type 3
Rated torque	Nm	580	220	100
Peak torque	Nm	1300	750	420
Rotation angle	°	>360	>360	>360
Weight	kg	13	8.5	5.5
Repeated accuracy	°	≤0.002	≤0.002	≤0.002
maximum angular velocity	rpm	35	70	80
reduction ratio	1	160/120	160/120	160/120/100
nominal voltage	VDC	48	48	48
electrical interface		RS232;CAN-Open; USB	RS232;CAN-Open; USB	RS232;CAN-Open; USB

The Algebraic Configuration Description Method

The Joint can combination the type of serial robots, parallel robot, mixed type and complex robot for the Reconfigurable modular robot. According to the connection mode, the configuration described in the following definition:

Common base model: the rotary joints is defined as R_y^x, the displacement of the joint is defined as D_y^x, the connecting rod is described as L_y^x.

And the x is position number, the y is in combination with surface code.

And the x or y be omit when robot has one joint.

The expression of configuration: The Joints (Joint or link) is defined as N_x, the robot is defined as N_0. When it has child-robot, the child-robot is defined as N_{0x}.

The joint of multiple DOF is defined as multiplication cross: $N_x = N_1 \times N_2$.

The series robot is described as dot product: $N_x = N_1 \cdot N_2$.

The parallel robot is described as sum: $N_x = N_1 + N_2$

The connecting rod assignment for the joints when is has the function of special. The connecting

rod is is described as: $N_x = L_y^x$.

Configuration expression and kinematic model

The configuration expression of the modular robot in Figure 1 can be expressed as following Formula (1):

$$N_x = N_1 \cdot N_2 \cdot N_3 \cdot N_4 \cdot N_5 \cdot N_6 \tag{1}$$

The N_1 to N_6 is corresponding to Joint 1 to Joint 6. The kinematic model is corresponding to each matrix of the Joint.

The Joint transformation matrix is expressed in Equation (2).

$$^{i-1}_iT = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & a_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -d_i s\alpha_{i-1} \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1}0 & c\alpha_{i-1} & d_i c\alpha_{i-1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

The D-H parameters are shown in Table 2.

Table 2 The D-H parameters for 6-DOF robot

Link i	α_{i-1}	/mm	d_i	θ_i
1	0	0	420	0
2	pi/2	0	0	pi/2
3	pi	254	0	pi/2
4	pi/2	0	469	0
5	pi/2	0	111	0
6	-pi/2	0	251	0

The transformational matrix are expressed in Equation (3) to Equation (8)

$$A_1 = \begin{bmatrix} c\theta_1 & -s\theta_1 & 0 & 0 \\ s\theta_1 & c\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 420 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

$$A_2 = \begin{bmatrix} c\theta_2 & -s\theta_2 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ s\theta_2 & c\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

$$A_3 = \begin{bmatrix} c\theta_3 & -s\theta_3 & 0 & 254 \\ -s\theta_3 & -c\theta_3 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

$$A_4 = \begin{bmatrix} c\theta_4 & -s\theta_4 & 0 & 0 \\ 0 & 0 & -1 & -469 \\ s\theta_4 & c\theta_4 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}$$

$$A_5 = \begin{bmatrix} c\theta_5 & -s\theta_5 & 0 & 0 \\ 0 & 0 & -1 & -111 \\ s\theta_5 & c\theta_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{7}$$

$$A_6 = \begin{bmatrix} c\theta_6 & -s\theta_6 & 0 & 0 \\ 0 & 0 & 1 & 251 \\ -s\theta_6 & -c\theta_6 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{8}$$

So kinematic model of the 6-DOF robot is expressed in Equation (9) as following.

$$T = \begin{bmatrix} c\theta_1 & -s\theta_1 & 0 & 0 \\ s\theta_1 & c\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 420 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c\theta_2 & -s\theta_2 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ s\theta_2 & c\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c\theta_3 & -s\theta_3 & 0 & 254 \\ -s\theta_3 & -c\theta_3 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

$$
\begin{bmatrix} c\theta_4 & -s\theta_4 & 0 & 0 \\ 0 & 0 & -1 & -469 \\ s\theta_4 & c\theta_4 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\begin{bmatrix} c\theta_5 & -s\theta_5 & 0 & 0 \\ 0 & 0 & -1 & -111 \\ s\theta_5 & c\theta_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\begin{bmatrix} c\theta_6 & -s\theta_6 & 0 & 0 \\ 0 & 0 & 1 & 251 \\ -s\theta_6 & -c\theta_6 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{9}
$$

Thus the $N_1=A_1$, $N_2=A_2$, $N_3=A_3$, $N_4=A_4$, $N_5=A_5$, $N_6=A_6$. The kinematics parameters can be calculated directly in ACDM.

Conclusions

In this paper, we propose a new algebraic configuration description method for the modular robot. And the algebraic configuration description method (ACDM) can describe all mechanical configuration in the robot configuration parameters, and the ACDM make up for the inadequacy of D-H method in multiple configuration. The ACDM support complicated calculation about the parameters in joint level. The configuration algebraic expression and kinematic model are established in this paper for modular robot. And the kinematical modeling and simulation results show that the algebraic configuration description method is effective.

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