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On an Optimal Choice of the Configurations for the Mechanism of the Mitsubishi RV-2AJ Robot

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Abstract

The paper presents a method that permits the calculus of the generalized coordinates of the Mitsubishi RV-2AJ robot mechanism for an imposed position of the tool frame when an optimization criterion is adopted. The optimization criterion imposes that the angular displacements of the motor axes for achieving an imposed position of the tool frame of the robot mechanism are minimal compared to a start configuration. The equations system that is obtained by applying the optimization criterion is numerically solved. Finally, some simulation results are presented.

Key words: *robot, position, characteristic point, optimization*

Introduction

In different industrial operations the robots may have more degrees of freedom than are necessary to accomplish the task, so they are redundant in relation to the task to be performed and there are an infinite number of solutions for the inverse geometric model [1] of these robot mechanisms. Sometimes in these cases certain performance criteria [2] (minimum energy consumption or minimal displacements of the motor axes, the fulfillment of some conditions for avoiding obstacles or singular configurations of the robot mechanism) are considered.

In this paper a method that allows the calculus of the generalized coordinates of the Mitsubishi RV-2AJ robot mechanism for an imposed position of the tool frame when an optimization criterion is adopted is presented. The optimization criterion imposes that the angular displacements of the motor axes for achieving an imposed position of the tool frame of the robot mechanism are minimal compared to a start configuration (fig.1).

Theoretical Considerations and Verification Results

In Figure 1, the cinematic scheme of the mechanism of the Mitsubishi RV-2AJ robot system is presented. The systems of coordinates $(O_i x_i y_i z_i), i = \overline{0,5}$, have been attached to each component module *i*, $i = \overline{0,5}$, using the Khalil-Kleinfinger method [1].

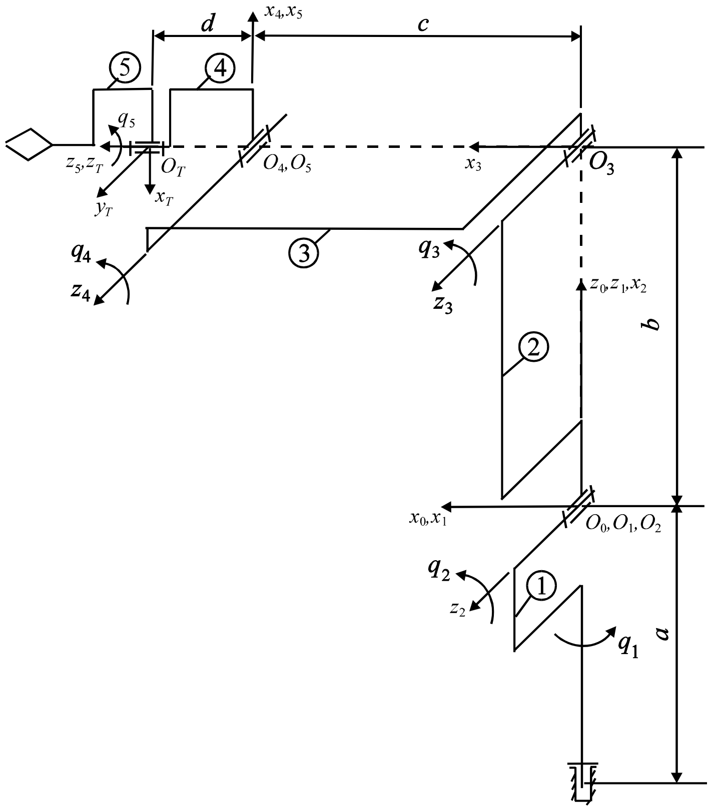

Fig. 1. Mitsubishi Melfa RV-2AJ robot mechanism

The values corresponding to the Khalil-Kleinfinger parameters are given in table 1.

Table 1. The values of the Khalil-Kleinfinger parameters

i	α_i	d_i	θ_i	r_i
1	0	0	q_1	0
2	-90°	0	q_2	0
3	0	b	q_3	0
4	0	c	q_4	0
5	-90°	0	q_5	0

The homogeneous matrix corresponding to the relative position and orientation of two consecutive modules i and $i+1$ has the following general form [1]:

$$
{}^{i}T_{i+1} = \begin{bmatrix} {}^{i}R_{i+1} & {}^{(i)}O_iO_{i+1} \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} \cos\theta_{i+1} & -\sin\theta_{i+1} & 0 & d_{i+1} \\ \cos\alpha_{i+1}\cdot\sin\theta_{i+1} & \cos\alpha_{i+1}\cdot\cos\theta_{i+1} & -\sin\alpha_{i+1} & -r_{i+1}\cdot\sin\alpha_{i+1} \\ \sin\alpha_{i+1}\cdot\sin\theta_{i+1} & \sin\alpha_{i+1}\cdot\cos\theta_{i+1} & \cos\alpha_{i+1} & r_{i+1}\cdot\cos\alpha_{i+1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)
$$

where: ${}^{i}R_{i+1}$ is the rotation matrix corresponding to the relative orientation of the modules.

By applying the relation (1) and by taking into account the values of the Khalil-Kleinfinger parameters in table 1, the following expressions for the homogeneous matrices ${}^{i}T_{i+1}, i=\overline{0,4}$, are obtained:

$$
{}^{0}T_1=\begin{bmatrix} c1 & -s1 & 0 & 0\\ s1 & c1 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix};\ {}^{1}T_2=\begin{bmatrix} c2 & -s2 & 0 & 0\\ 0 & 0 & 1 & 0\\ -s2 & -c2 & 0 & 0\\ 0 & 0 & 0 & 1\end{bmatrix};\ {}^{2}T_3=\begin{bmatrix} c3 & -s3 & 0 & b\\ s3 & c3 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix};
$$

$$
{}^{3}T_4=\begin{bmatrix} c4 & -s4 & 0 & c\\ s4 & c4 & 1 & 0\\ 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 1\end{bmatrix};\ {}^{4}T_5=\begin{bmatrix} c5 & -s5 & 0 & 0\\ 0 & 0 & 1 & 0\\ -s5 & -c5 & 0 & 0\\ 0 & 0 & 0 & 1\end{bmatrix} \tag{2}
$$

where:

$$
\begin{cases} si=\sin q_i \\ ci=\cos q_i \end{cases} i=\overline{1,5} \tag{3}
$$

The values of the geometric parameters: *a, b, c* and *d* (fig.1) are: $a=300\,\text{mm}$; $b=250\,\text{mm}$; $c=160\,\text{mm}$; $d=72\,\text{mm}$.

The position of the tool frame (fig. 1) relative to the system of coordinates $(O_0x_0y_0z_0)$ can be determined with the following relation:

$$
{}^{(0)}O_0O_T=[{}^{(0)}x_{O_T}\ \ {}^{(0)}y_{O_T}\ \ {}^{(0)}z_{O_T}]^T={}^{0}T_5\cdot{}^{(5)}O_5O_T \tag{4}
$$

where:

$$
{}^{0}T_5={}^{0}T_1\cdot{}^{1}T_2\cdot{}^{2}T_3\cdot{}^{3}T_4\cdot{}^{4}T_5 \tag{5}
$$

$$
{}^{(5)}O_5O_T=[0\ 0\ d\ 1]^T \tag{6}
$$

The coordinates of the point O_T relative to the system of coordinates $(O_0x_0y_0z_0)$ depend only on the generalized coordinates $q_i, i=\overline{1,4}$ (fig. 1). The position of the point O_T is imposed and it is considered an optimization criterion so that the displacements of the motor axes of the robot system are minimal as against the start configuration of the robot (the configuration in figure 1). The generalized coordinates $q_i, i=\overline{1,4}$, have the following values in the case of the configuration in Figure 1: $q_1=0$; $q_2=-90^\circ$; $q_3=90^\circ$; $q_4=-90^\circ$. The optimization criterion imposes that the following function must take a minimum value:

$$
F=\frac{1}{2}\cdot[q_1^2+(q_2+90)^2+(q_3-90)^2+(q_4+90)^2] \tag{7}
$$

The following function is introduced [2]:

$$
L=F+\lambda^T\cdot\left({}^{(0)}O_0O_T-[x_{im}\ y_{im}\ z_{im}]^T\right) \tag{8}
$$

where: x_{im}, y_{im} and z_{im} are the imposed values of the coordinates of the point O_T relative to the fixed system of coordinates $(O_0x_0y_0z_0)$ and $\lambda=[\lambda_1\ \ \lambda_2\ \ \lambda_3]^T$, where $\lambda_i, i=\overline{1,3}$, are three unknown parameters (Lagrange's parameters).

So, it is necessary to find the values of the coordinates $q_i, i=\overline{1,4}$, for which the function L is minimum and the coordinates of the point O_T: ${}^{(0)}x_{O_T}, {}^{(0)}y_{O_T}$ and ${}^{(0)}z_{O_T}$, given by the relation (4), take the imposed values: x_{im}, y_{im} and z_{im}, from the following system of equations that can be then solved numerically:

$$\begin{cases} {}^{(0)}x_{O_T} - x_{im} = 0;\ {}^{(0)}y_{O_T} - y_{im} = 0;\ {}^{(0)}z_{O_T} - z_{im} = 0 \\ q_i + \dfrac{\partial f_1}{\partial q_i}\cdot\lambda_1 + \dfrac{\partial f_2}{\partial q_i}\cdot\lambda_2 + \dfrac{\partial f_3}{\partial q_i}\cdot\lambda_3 = 0;\ \mathrm{i}=\overline{1,4} \end{cases} \tag{9}$$

The method has been transposed into a computer program. As a numerical example, by considering: $x_{im} = 210\,\mathrm{mm}$; $y_{im} = 170\,\mathrm{mm}$; $z_{im} = 100\,\mathrm{mm}$, the following values for the coordinates $q_i, i=\overline{1,4}$, have been obtained: $q_1 = 38.99^\circ$; $q_2 = -70.75^\circ$; $q_3 = 105.25^\circ$; $q_4 = -85.42^\circ$.

Conclusions

The paper presents a method that allows the calculus of the generalized coordinates of the Mitsubishi RV-2AJ robot mechanism for an imposed position of the tool frame when an optimization criterion is adopted. The optimization criterion imposes that the angular displacements of the motor axes for achieving an imposed position of the tool frame of the robot mechanism are minimal compared to a start configuration. The method is very useful to be applied for robotic operations, when the robot mechanism is redundant in relation to the task to be performed.

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Asupra alegerii optime a configurațiilor mecanismului robotului Mitsubishi RV-2AJ

Rezumat

Articolul prezintă o metodă care permite calculul coordonatelor generalizate ale mecanismului robotului Mitsubishi RV-2AJ pentru o poziție impusă a reperului sculei atunci când se adoptă un criteriu de optimizare. Criteriul de optimizare impune ca deplasările axelor motoare pentru atingerea unei poziții impuse a reperului sculei să fie minime în raport cu o configurație de start. Sistemul de ecuații care se obține prin aplicarea criteriului de optimizare este rezolvat numeric. In final, sunt prezentate o serie de rezultate ale simulărilor.