BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LXVI No. 1/2014	73 – 78	Seria Tehnică

On the Establishment and Visualization of the Multiple Configurations of the Mitsubishi RV-1A Robot System

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Abstract

The paper presents a method that permits the establishment and the visualization of the multiple configurations of the Mitsubishi RV-1A robot system. The positional analysis is realized with the rotation matrices methodology. The expressions of the generalized coordinates of the mechanism of the Mitsubishi RV-1A robot for obtaining an imposed position and orientation between its tool frame and the base frame are derived. A computer program that permits the calculus of the generalized coordinates of all possible configurations of the Mitsubishi RV-1A robot mechanism has been developed. Some interesting simulation results are presented. Finally, these configurations are visualized using Ciros Studio program.

Key words: *robot, multiple configurations, position, orientation*

Introduction

Many times the tasks realized by the industrial robots are very complicated. These tasks demand an optimum choice of the robot configuration for many reasons: to avoid different obstacles or to avoid singular configurations during the movement of the robotic mechanism, for an optimum energy consumption etc. In all these cases those who operate industrial robots must to be capable to calculate the values of the robot generalized coordinates for obtaining a position and orientation between the robot tool frame and its base that are necessary to carry out the task. Always there are multiple solutions to this problem due to the versatility of robotic mechanisms. So, for a correct choice of the robot configuration it is absolutely necessary to visualize them.

In this paper a method that permits the establishment and the visualization of the multiple configurations of the Mitsubishi RV-1A robot system is presented. The positional analysis is realized with the rotation matrices methodology. On the basis of the expressions of the generalized coordinates of the robot mechanism necessary for obtaining a demanded position and orientation between the tool frame and the base of the robot a computer program that permits the calculus of the generalized coordinates of all possible configurations of the Mitsubishi RV-1A robot mechanism has been developed. Some interesting simulation results are presented. Then, these configurations are visualized using Ciros Studio program.

Theoretical Considerations and Simulation Results

The positional analysis of the mechanism of the Mitsubishi RV-1A robot system (fig. 1) has been realized using the rotation matrices methodology [1, 2]. The rotation matrices corresponding to the relative orientation between the component modules have the following expressions:

$$
\begin{aligned}
&{}^0R_1 = R(z,q_1) = \begin{bmatrix} c1 & -s1 & 0 \\ s1 & c1 & 0 \\ 0 & 0 & 1 \end{bmatrix};\ {}^1R_2 = R(x,q_2) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c2 & -s2 \\ 0 & s2 & c2 \end{bmatrix} \\
&{}^2R_3 = R(x,q_3) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c3 & -s3 \\ 0 & s3 & c3 \end{bmatrix};\ {}^3R_4 = R(y,q_4) = \begin{bmatrix} c4 & 0 & s4 \\ 0 & 1 & 0 \\ -s4 & 0 & c4 \end{bmatrix} \\
&{}^4R_5 = R(x,q_5) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c5 & -s5 \\ 0 & s5 & c5 \end{bmatrix};\ {}^5R_6 = R(y,q_6) = \begin{bmatrix} c6 & 0 & s6 \\ 0 & 1 & 0 \\ -s6 & 0 & c6 \end{bmatrix}
\end{aligned}
\tag{1}
$$

where:

$$
\begin{cases} si = \sin q_i \\ ci = \cos q_i \end{cases} \quad i = \overline{1,6} \tag{2}
$$

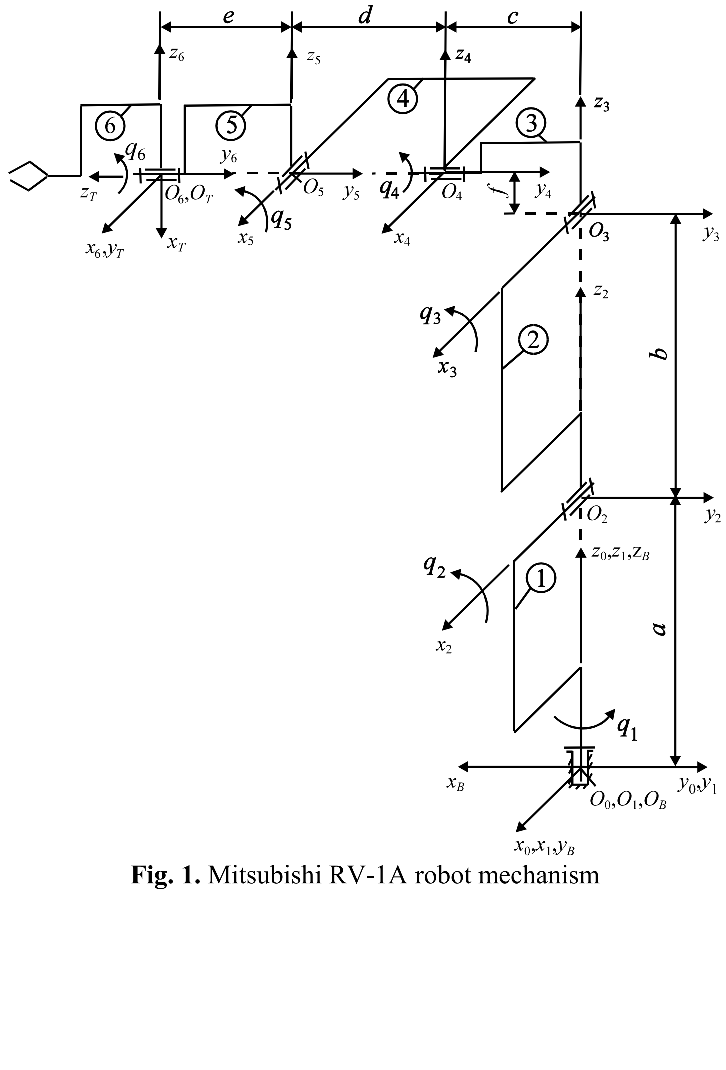

Fig. 1. Mitsubishi RV-1A robot mechanism

The position of the origin O_T (fig. 1) can be determined with the following relation:

$$\begin{aligned} {}^{(0)}O_0O_T &= [{}^{(0)}x_{O_T} \; {}^{(0)}y_{O_T} \; {}^{(0)}z_{O_T}]^T = {}^{(0)}O_0O_5 + {}^{(0)}O_5O_T = {}^{(0)}O_0O_1 + {}^0R_1 \cdot {}^{(1)}O_1O_2 + \\ &+ {}^0R_2 \cdot {}^{(2)}O_2O_3 + {}^0R_3 \cdot {}^{(3)}O_3O_4 + {}^0R_4 \cdot {}^{(4)}O_4O_5 + {}^0R_T \cdot {}^{(T)}O_5O_T \end{aligned} \tag{3}$$

where:

$${}^0R_2 = {}^0R_1 \cdot {}^1R_2;\; {}^0R_3 = {}^0R_2 \cdot {}^2R_3;\; {}^0R_4 = {}^0R_3 \cdot {}^3R_4 \tag{4}$$

$$\begin{aligned} &{}^{(0)}O_0O_1 = 0;\; {}^{(1)}O_1O_2 = [0\;0\;a]^T;\; {}^{(2)}O_2O_3 = [0\;0\;b]^T \\ &{}^{(3)}O_3O_4 = [0 - c\; f]^T;\; {}^{(4)}O_4O_5 = [0 - d\;0]^T;\; {}^{(T)}O_5O_T = [0\;0\;e]^T \end{aligned} \tag{5}$$

After performing the calculations, the following system of equations is obtained:

$$\begin{cases} {}^{(0)}x_{O_T} = s1 \cdot (s2 \cdot b + c23 \cdot (c+d) + s23 \cdot f) + r_{13} \cdot e \\ {}^{(0)}y_{O_T} = -c1 \cdot (s2 \cdot b + c23 \cdot (c+d) + s23 \cdot f) + r_{23} \cdot e \\ {}^{(0)}z_{O_T} = a + c2 \cdot b - s23 \cdot (c+d) + c23 \cdot f + r_{33} \cdot e \end{cases} \tag{6}$$

where: ${}^0R_T = \{r_{ij}\}_{1 \le i,j \le 3}$, $c23 = \cos(q_2 + q_3)$ and $s23 = \sin(q_2 + q_3)$.

Assuming that the position and the orientation between the tool frame $(O_T x_T y_T z_T)$ and the fixed frame $(O_0 x_0 y_0 z_0)$ are imposed by the values of the components of the vector ${}^{(0)}O_0O_T = [{}^{(0)}x_{O_T} \; {}^{(0)}y_{O_T} \; {}^{(0)}z_{O_T}]^T$ and of the rotation matrix ${}^0R_T$, after the completion of the calculus, the following expressions for the generalized coordinates $q_i, 1 = \overline{1,3}$, were obtained:

$$\begin{cases} q_1 = \text{arctg}\left(-\dfrac{{}^{(0)}x_{O_T} - r_{13} \cdot e}{{}^{(0)}y_{O_T} - r_{23} \cdot e} \right) + k\pi; \quad k \in Z \\ q_3 = (-1)^k \arcsin\left(\dfrac{C_3}{\sqrt{A_3^2 + B_3^2}} \right) + k\pi - \gamma; \quad k \in Z \\ q_2 = \text{ATAN2}\left(\dfrac{A_2 \cdot C_{21} - B_2 \cdot C_{22}}{\Delta}, \dfrac{A_2 \cdot C_{22} + B_2 \cdot C_{21}}{\Delta} \right) \end{cases} \tag{7}$$

where: ATAN*2(y,x)* calculates arctg*(y/x)* by taking into account the sign of the parameters *y* and *x,* and:

$$\begin{cases} A_3 = 2 \cdot b \cdot f;\; B_3 = -2 \cdot b \cdot (d+c); \\ C_3 = \left(\dfrac{{}^{(0)}x_{O_T} - r_{13} \cdot e}{s1} \right)^2 + \left({}^{(0)}z_{O_T} - a - r_{33} \cdot e \right)^2 - b^2 - f^2 - (c+d)^2 \\ \gamma = \text{ATAN2}(A_3, B_3) \end{cases} \tag{8}$$

$$\begin{cases} A_2 = b - s3 \cdot (c+d) + c3 \cdot f;\; B_2 = s3 \cdot f + c3 \cdot (c+d) \\ C_{21} = \dfrac{{}^{(0)}x_{O_T} - r_{13} \cdot e}{s1};\; C_{22} = {}^{(0)}z_{O_T} - a - r_{33} \cdot e;\; \Delta = A_2^2 + B_2^2 \end{cases} \tag{9}$$

The rotation matrix ${}^{0}R_{T}$ verifies the following relation:

$$ {}^{0}R_{T} = {}^{0}R_{6} \cdot {}^{6}R_{T} = {}^{0}R_{3} \cdot {}^{3}R_{4} \cdot {}^{4}R_{5} \cdot {}^{5}R_{6} \cdot {}^{6}R_{T} \quad \Rightarrow \quad {}^{3}R_{4} \cdot {}^{4}R_{5} \cdot {}^{5}R_{6} = {}^{0}R_{3}^{T} \cdot {}^{0}R_{T} \cdot {}^{6}R_{T}^{T} \tag{10} $$

where: ${}^{6}R_{T}$ has the following expression:

$$ {}^{6}R_{T} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & -1 \\ -1 & 0 & 0 \end{bmatrix} \tag{11} $$

We consider that:

$$ E = {}^{0}R_{3}^{T} \cdot {}^{0}R_{T} \cdot {}^{6}R_{T}^{T} \tag{12} $$

where: the matrix $E = \{e_{ij}\}_{1 \le i,j \le 3}$ has all its elements known at this moment.

By solving the matrix equation (10), after performing the calculations, the generalized coordinates q_4, q_5 and q_6 can be determined with the following relations:

$$ \begin{cases} q_5 = \pm \arccos(e_{22}) + 2k\pi; \quad k \in Z \\ q_4 = \mathrm{ATAN2}(e_{12}/s5, e_{32}/s5) \\ q_6 = \mathrm{ATAN2}(e_{21}/s5, -e_{23}/s5) \end{cases} \tag{13} $$

The orientation between the tool frame $(O_T x_T y_T z_T)$ and the base frame $(O_B x_B y_B z_B)$ (fig. 1) is imposed by the values of the roll-pitch-yaw angles: α, β and γ. The rotation matrix ${}^{B}R_{T}$ can be calculated with the following relation [4]:

$$ {}^{B}R_{T} = \begin{bmatrix} \cos\alpha \cdot \cos\beta & \cos\alpha \cdot \sin\beta \cdot \sin\gamma - \sin\alpha \cdot \cos\gamma & \cos\alpha \cdot \sin\beta \cdot \cos\gamma + \sin\alpha \cdot \sin\gamma \\ \sin\alpha \cdot \sin\beta & \sin\alpha \cdot \sin\beta \cdot \sin\gamma + \cos\alpha \cdot \cos\gamma & \sin\alpha \cdot \sin\beta \cdot \cos\gamma - \cos\alpha \cdot \sin\gamma \\ -\sin\beta & \cos\beta \cdot \sin\gamma & \cos\beta \cdot \cos\gamma \end{bmatrix} \tag{14} $$

Then, the rotation matrix ${}^{0}R_{T}$ can be determined with the following relation:

$$ {}^{0}R_{T} = {}^{0}R_{B} \cdot {}^{B}R_{T} \tag{15} $$

where:

$$ {}^{0}R_{B} = \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{16} $$

The relations above have been transposed in a computer program which allows calculating the generalized coordinates of the Mitsubishi RV-1A robot mechanism necessary for obtaining a demanded position and orientation between the tool frame and the base of the robot mechanism.

The geometric parameters corresponding to the Mitsubishi RV-1A robot mechanism have the following values: $a = 300$ mm; $b = 250$ mm; $c = 43$ mm; $d = 117$ mm; $e = 72$ mm; $f = 90$ mm.

Some simulation results obtained with the computer program are presented. The following elements have been imposed: ${}^{(0)}x_{O_T} = 11.1$ mm; ${}^{(0)}y_{O_T} = 36.2$ mm; ${}^{(0)}z_{O_T} = 472.5$ mm; $\alpha = 132.5^\circ$; $\beta = 21.8^\circ$; $\gamma = 144.5^\circ$. The values obtained for the generalized coordinates for four configurations of the Mitsubishi RV-1A robot that fall into their admissible variation ranges imposed by the limiters are presented in table 1.

Table 1. The values of the generalized coordinates

	q_1	q_2	q_3	q_4	q_5	q_6
1	-34.88°	-55.151°	147.253°	34.08°	63.298°	-4.55°
2	145.12°	-34.19°	147.253°	-30.18°	95.29°	-166.639°
3	-34.88°	-55.151°	147.253°	-145.918°	-63.298°	175.448°
4	145.12°	-34.19°	147.253°	149.82°	-95.29°	13.36°

These four robot configurations can be visualized using Ciros Studio program (fig. 2).

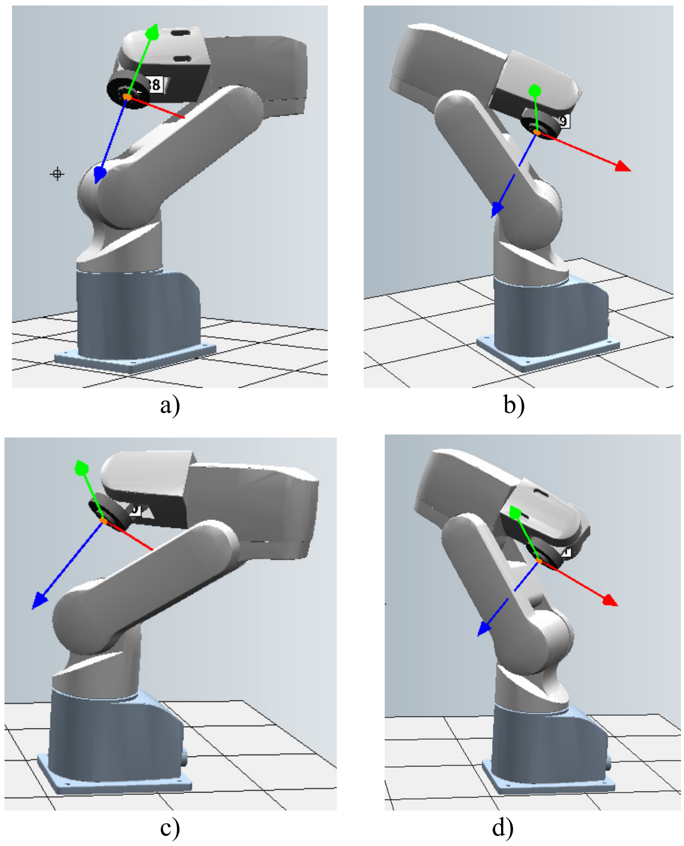

Fig. 2. Multiple configurations of the Mitsubishi RV-1A robot mechanism

Conclusions

In this paper a methodology that permits the establishment and the visualization of the multiple configurations of the Mitsubishi RV-1A robot system has been presented. On the basis of this methodology a computer program that permits the calculus of the generalized coordinates of all possible configurations of the Mitsubishi RV-1A robot mechanism has been developed. Some interesting simulation results have been presented and the corresponding robot configurations have been visualized using Ciros Studio program.

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Asupra stabilirii şi vizualizării configuraţiilor multiple ale sistemului robot Mitsubishi RV-1A

Rezumat

Articolul prezintă o metodă care permite stabilirea şi vizualizarea configuraţiilor multiple ale sistemului robot Mitsubishi RV-1A. Analiza poziţională este realizată cu metodologia matricilor de rotaţie. Sunt deduse expresiile coordonatelor generalizate ale mecanismului robotului Mitsubishi RV-1A pentru obţinerea unei poziţii şi orientări impuse între reperul sculei şi reperul de bază al acestuia. S-a realizat un program de calculator care permite calculul coordonatelor generalizate ale tuturor configuraţiilor posibile ale mecanismului robotului Mitsubishi RV-1A. O serie de rezultate interesante ale simulărilor sunt prezentate. In final, aceste configuraţii sunt vizualizate folosind programul Ciros Studio.