

Research Concerning the Differential Model of the Mitsubishi Melfa RV-1A Robot System

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Abstract

The paper presents a method that permits the deriving of the differential model of the Mitsubishi Melfa RV-1A robot system that contains six rotation modules. The differential model makes the connection between the incremental variations of the operational coordinates and the incremental variations of the motor coordinates of the robot. It allows, in an iterative way, the calculus of the motor coordinates of the robot when the operational coordinates are imposed. Finally, some simulation results obtained with the differential model have been verified using the robot arm controller.

Key words: robot, differential model, operational coordinates

Introduction

Frequently, the robots utilized in different operations of manipulation are controlled using their differential model. The differential model makes the connection between the incremental variations of the operational coordinates and the incremental variations of the motor coordinates of an industrial robot. It allows, in an iterative way, the calculus of the motor coordinates of the robot when the operational coordinates are imposed.

In this paper a method that allows the deriving of the differential model of the Mitsubishi Melfa RV-1A robot system (fig. 1) is presented. Finally, some simulation results obtained with the differential model have been verified using the robot arm controller.

Theoretical Considerations and Verification Results

In figure 1, the cinematic scheme of the mechanism of the Mitsubishi Melfa RV-1A robot system is presented. The differential model of the mechanism of this robot can be expressed in the following matrix form [4]:

$$\begin{bmatrix} {}^{(0)}d_T \\ {}^{(0)}\delta_T \end{bmatrix} = {}^{(0)}J_T \cdot dq \quad (1)$$

where: ${}^{(0)}d_T$ and ${}^{(0)}\delta_T$ are the vectors of the differential translation and rotation of the tool frame ($O_T x_T y_T z_T$) (fig. 1) projected on the axes of the fixed system of coordinates ($O_0 x_0 y_0 z_0$),

${}^{(0)}J_T$ is the Jacobean matrix which depends on the robot configuration, dq is the vector containing the differential variations of motor coordinates $q_i, i = \overline{1,6}$.

The systems of coordinates $(O_i x_i y_i z_i), i = \overline{0,6}$, have been attached to each component module $i, i = \overline{0,6}$, using the Khalil-Kleinfinger method [4].

The axes $(O_i z_i), i = \overline{1,6}$, have the direction of the joints (C_i) between the modules $i-1$ and i , the axes $(O_i x_i), i = \overline{1,5}$, have the direction of the common perpendicular between the axes $(O_i z_i)$ and $(O_{i+1} z_{i+1})$ and the axes $(O_i y_i), i = \overline{1,6}$, are chosen in such a way that $(O_i x_i y_i z_i), i = \overline{1,6}$, are right-orthogonal systems of coordinates. In order to simplify the presentation of the cinematic scheme, the $(O_i y_i)$ axes have not been represented.

The fixed system of coordinate (T_0) is chosen so that it coincides with (T_1) when $q_1 = 0$, q_1 being the generalized coordinate corresponding to the joint (C_1) .

The axis $(O_6 x_6)$ is chosen to be collinear with the axis $(O_5 x_5)$ when $q_6 = 0$ and the origin O_6 will be at the intersection of the axes $(O_5 x_5)$ and $(O_6 z_6)$.

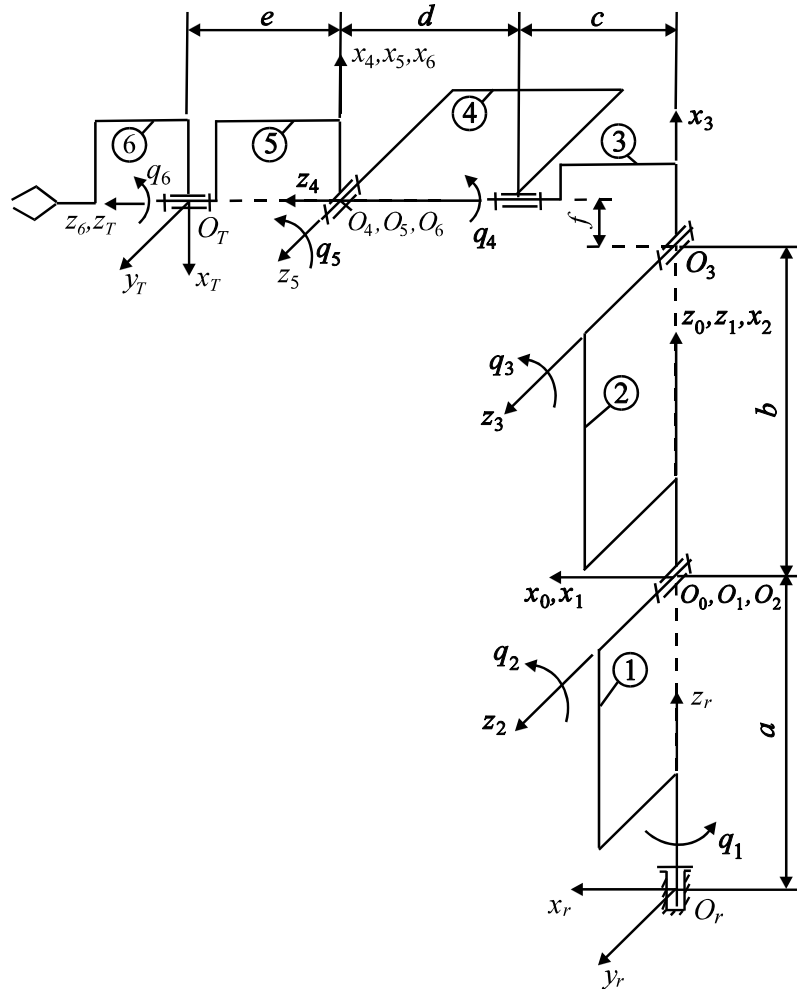


Fig. 1. Mitsubishi Melfa RV-1A robot mechanism

The systems of coordinates (T_{i+1}) and (T_i) , $i = \overline{0,5}$, are relatively positioned using four parameters (fig. 2): the angle α_{i+1} between the axes $(O_i z_i)$ and $(O_{i+1} z_{i+1})$, the distance d_{i+1} between the same axes, the angle θ_{i+1} between the axes $(O_i x_i)$ and $(O_{i+1} x_{i+1})$ and the distance r_{i+1} between $(O_i x_i)$ and $(O_{i+1} x_{i+1})$, measured on the positive direction of the axis $(O_{i+1} z_{i+1})$.

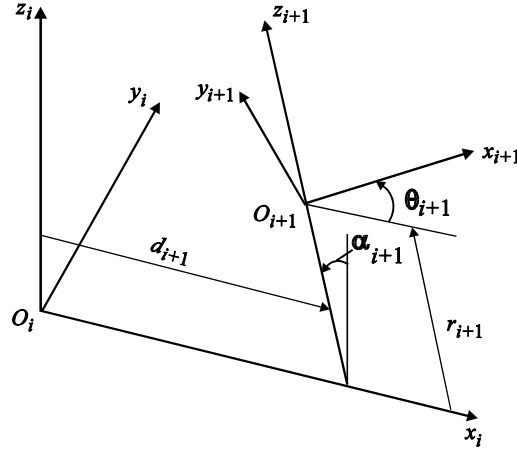


Fig. 2. Khalil-Kleinfinger parameters

In table 1 the values corresponding to the Khalil-Kleinfinger parameters are presented.

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	-90°	f	q_4	$d+c$
5	90°	0	q_5	0
6	-90°	0	q_6	0

The homogeneous matrix corresponding to the relative position and orientation of the systems of coordinates (T_{i+1}) and (T_i) , $i = \overline{0,5}$, has the following general form [1]:

$${}^i T_{i+1} = \begin{bmatrix} {}^i R_{i+1} & {}^{(i)}O_i O_{i+1} \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} \cos \theta_{i+1} & -\sin \theta_{i+1} & 0 & d_{i+1} \\ \cos \alpha_{i+1} \cdot \sin \theta_{i+1} & \cos \alpha_{i+1} \cdot \cos \theta_{i+1} & -\sin \alpha_{i+1} & -r_{i+1} \cdot \sin \alpha_{i+1} \\ \sin \alpha_{i+1} \cdot \sin \theta_{i+1} & \sin \alpha_{i+1} \cdot \cos \theta_{i+1} & \cos \alpha_{i+1} & r_{i+1} \cdot \cos \alpha_{i+1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

where: ${}^iR_{i+1}$ is the rotation matrix corresponding to the relative orientation of the systems of coordinates (T_{i+1}) and (T_i) .

The generalized coordinates $q_i, i = \overline{1,6}$, will be the angles θ_i because all the component modules are of rotation.

By applying the relation (2) and by taking into account the values of the Khalil-Kleinfinger parameters in the table 1, the following expressions for the homogeneous matrices ${}^iT_{i+1}, i = \overline{0,5}$, are obtained:

$$\begin{aligned} {}^0T_1 &= \begin{bmatrix} c1 & -s1 & 0 & 0 \\ s1 & c1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; {}^1T_2 = \begin{bmatrix} c2 & -s2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -s2 & -c2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; {}^2T_3 = \begin{bmatrix} c3 & -s3 & 0 & b \\ s3 & c3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \\ {}^3T_4 &= \begin{bmatrix} c4 & -s4 & 0 & g \\ 0 & 0 & 1 & d+c \\ -s4 & -c4 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; {}^4T_5 = \begin{bmatrix} c5 & -s5 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ s5 & c5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; {}^5T_6 = \begin{bmatrix} c6 & -s6 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -s6 & -c6 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \end{aligned} \quad (3)$$

where:

$$\begin{cases} si = \sin q_i \\ ci = \cos q_i \end{cases} \quad i = \overline{1,6} \quad (4)$$

The Jacobean matrix ${}^{(0)}J_T$ can be calculated with the relation:

$${}^{(0)}J_T = \begin{bmatrix} {}^0R_T & 0 \\ 0 & {}^0R_T \end{bmatrix} \cdot {}^{(T)}J_T \quad (5)$$

where: ${}^{(T)}J_T$ is the Jacobean matrix which has the elements projected on the tool frame $(O_T x_T y_T z_T)$ and 0R_T is the rotation matrix corresponding to the relative orientation of the fixed and tool systems of coordinates:

$${}^0R_T = {}^0R_1 \cdot {}^1R_2 \cdot {}^2R_3 \cdot {}^3R_4 \cdot {}^4R_5 \cdot {}^5R_6 \cdot {}^6R_T \quad (6)$$

where: the rotation matrices ${}^iR_{i+1}, i = \overline{0,5}$, can be calculated by taking into account the relations (2) and (3) and the rotation matrix 6R_T has the following expression:

$${}^6R_T = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (7)$$

The columns of the Jacobean matrix ${}^{(T)}J_T$ can be calculated with the following relation [4]:

$$\begin{bmatrix} {}^T R_j \cdot {}^{(j)}k_j^v \cdot {}^{(j)}O_j O_T \\ {}^T R_j \cdot {}^{(j)}k_j \end{bmatrix}; \quad j = \overline{1,6} \quad (8)$$

where: ${}^T R_j = ({}^j R_T)^T$ and ${}^{(j)}O_j O_T$ are containing in the homogeneous matrices ${}^j T_T, j = \overline{1,6}$, that

can be calculated with the relation:

$${}^jT_T = \left(\prod_{i=j}^5 {}^iT_{i+1} \right) \cdot {}^6T_T \quad (9)$$

and:

$${}^6T_T = \begin{bmatrix} {}^6R_T & {}^{(6)}O_6O_T \\ 0 & 1 \end{bmatrix} \quad (10)$$

where: ${}^{(6)}O_6O_T = [0 \ 0 \ e]^T$; ${}^{(j)}k_j$ is the unit vector corresponding to the axis (O_jz_j) : ${}^{(j)}k_j = [0 \ 0 \ 1]^T$; ${}^{(j)}k_j^v$ is the matrix corresponding to the unit vector ${}^{(j)}k_j$ which has the following expression:

$${}^{(j)}k_j^v = \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad (11)$$

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

The relations above have been transposed in a computer program which allows calculating very easy and precisely the differential model of the Mitsubishi robot.

The results obtained with the computer program have been verified using the robot controller. The relations between the generalized coordinates $q_i, i = \overline{1,6}$, used in the analysis and those used by the controller and noted with $q_i^r, i = \overline{1,6}$, are the following:

$$\begin{cases} q_1 = q_1^r \\ q_2 = -90^\circ + q_2^r \\ q_3 = -90^\circ + q_3^r \\ q_4 = q_4^r \\ q_5 = q_5^r \\ q_6 = q_6^r \end{cases} \quad (12)$$

Some simulation results verified with the Mitsubishi robot controller are presented.

By considering the position of the Mitsubishi robot given by: $q_1^r = 21^\circ$; $q_2^r = 24^\circ$; $q_3^r = 96^\circ$; $q_4^r = 52^\circ$; $q_5^r = -42^\circ$; $q_6^r = 35^\circ$; and increasing each motor coordinate $q_i^r, i = \overline{1,6}$, with one degree, by applying the simulation program the following components of the translation of the origin O_T projected on the fixed system of coordinates $(O_0x_0y_0z_0)$ expressed in mm have been obtained: $[2.095 \ 7.514 \ -11.809]^T$.

For the chosen position of the Mitsubishi robot the controller gives the following values for the coordinates of the origin O_T on the fixed system of coordinates: 337 mm; 88.7 mm; 525.26 mm.

By increasing each motor coordinate $q_i^r, i = \overline{1,6}$, with one degree, the controller gives the following values for the coordinates of the origin O_T : 338.8 mm; 96.2 mm; 513.45 mm.

The components of the translation of the origin O_T projected on the fixed system of coordinates given by the controller are: 1.8 mm; 7.5 mm; -11.81 mm. It can be observed a very good accordance between the results obtained with the computer program and those given by the robot controller.

Conclusions

The paper presents a method that allows the calculus of the differential model of the Mitsubishi Melfa RV-1A robot system. The method presented has been transposed in a computer program which allows calculating very easy and precisely the differential model of the Mitsubishi robot. The verification of the results has been done using the robot arm controller. The results show a very good accordance between the results obtained with the computer program and those given by the robot controller.

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Cercetări privind modelul diferențial al sistemului robot Mitsubishi Melfa RV-1A

Rezumat

Articolul prezintă o metodă care permite calculul modelului diferențial al sistemului robot Mitsubishi Melfa RV-1A care conține șase module de rotație. Modelul diferențial realizează legătura dintre variațiile incrementale ale coordonatelor operaționale și variațiile incrementale ale coordonatelor motoare ale robotului. El permite într-un mod iterativ calculul coordonatelor motoare ale robotului când coordonatele operaționale sunt impuse. În final, o serie de rezultate ale simulărilor au fost verificate cu controlerul robotului.