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RESEARCH ON THE GENERATION OF INTERPOLATED MOVEMENTS IN THE CASE OF A ROBOTIC MECHANISM WITH ANTHROPOMORPHIC STRUCTURE

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ABSTRACT

The implementation of robotic system commands, along with the design of the component mechanisms, contributes to their correct functioning while performing various tasks. In this sense, the precise generation of interpolated movements at the level of the end effectors from the component of robotic mechanisms is particularly important in the optimal performance of tasks in many industrial applications. Compared to the point-to-point commands, the interpolated commands are intended to pilot the robotic mechanisms so that their final effectors follows an imposed trajectory in the operational space of the robot with an imposed hourly law. The paper presents a method for generating interpolated movements in the case of a robotic system whose active mechanism has an anthropomorphic structure. The presented method uses the differential model of the analyzed robotic system. The introduced interpolation is linear, and the hourly law used is in the form of a polynomial of the fifth degree. Within the simulations performed, the four possible configurations of the anthropomorphic robotic mechanism that allow the achievement of the imposed task were highlighted. Finally, for one of these configurations, the variation curves of the coordinates corresponding to the actuation motors for a certain task are established.

Keywords: robotic mechanism, anthropomorphic structure, operational space, interpolated commands, linear movement interpolation

INTRODUCTION

The creation of high-performance robotic systems requires, in addition to knowledge related to the analysis and synthesis of mechanisms, and especially active mechanisms, knowledge related to the implementation of their control and commands [1-10]. In this sense, the problem of generating of interpolated movements at the level of the end effectors from the component of robotic mechanisms is particularly important in the optimal performance of tasks in many industrial applications. Compared to the point-to-point commands, the interpolated commands are intended to pilot the robotic mechanisms so that their final effectors follows an imposed trajectory in the operational space of the robot with an imposed hourly law [11-25].

The main objective of this paper is to develop a method that allow generating interpolated movements in the case of a robotic system whose active mechanism has an anthropomorphic structure. The method uses the differential model of the robotic system. It is analyzed the case of a linear interpolation and the hourly law used is in the form of a polynomial of the fifth degree. The simulator developed with the Maple program allows highlighting all configurations of the analyzed robotic system in order to generate the desired trajectory, as well as the positioning errors at the level of the end effector of the analyzed robot relative to the trajectory imposed by the task. The method used for generating linear interpolated movements and the operating simulator of the analyzed robotic system has a novelty character, offering the possibility to include and analyze others types of interpolated movements.

MATERIALS AND METHODS

In figure 1 is presented an active robotic mechanism with an anthropomorphic structure. The coordinate systems $(O_i x_i y_i z_i), i = 0,1,2,3$, are attached to the base of the robotic mechanism and to the three component modules. The rotation matrices ${}^{i-1}R_i, i = 1,2,3$, corresponding to relative orientation between modules are as follows:

$$ {}^{0}R_1 = R(z, q_1) = \begin{bmatrix} \cos q_1 & -\sin q_1 & 0 \\ \sin q_1 & \cos q_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{1} $$

$$ {}^{1}R_2 = R(x, q_2) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos q_2 & -\sin q_2 \\ 0 & \sin q_2 & \cos q_2 \end{bmatrix} \tag{2} $$

$$ {}^{2}R_3 = R(x, q_3) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos q_3 & -\sin q_3 \\ 0 & \sin q_3 & \cos q_3 \end{bmatrix} \tag{3} $$

where: q_1, q_2, q_3 are the coordinates corresponding to the actuation motors.

The position of the origin of the tool frame $(O_T x_T y_T z_T)$ relative to the fixed coordinate system $(O_0 x_0 y_0 z_0)$ is given by the following equation:

$$ {}^{(0)}O_0O_T = {}^{(0)}O_0O_1 + {}^{0}R_1 \cdot {}^{(1)}O_1O_2 + {}^{0}R_2 \cdot {}^{(2)}O_2O_3 + {}^{0}R_3 \cdot {}^{(3)}O_3O_T \tag{4} $$

where: ${}^{(0)}O_0O_1 = 0$; ${}^{(1)}O_1O_2 = [0 \quad 0 \quad l_1]^T$; ${}^{(2)}O_2O_3 = [0 \quad l_2 \quad 0]^T$; ${}^{(3)}O_3O_T = [0 \quad l_3 \quad 0]^T$;

${}^{0}R_2 = {}^{0}R_1 \cdot {}^{1}R_2$; ${}^{0}R_3 = {}^{0}R_2 \cdot {}^{2}R_3$.

The following notations are introduced:

$$ {}^{(0)}O_0O_T = x = \begin{bmatrix} {}^{(0)}x_{O_T} \\ {}^{(0)}y_{O_T} \\ {}^{(0)}z_{O_T} \end{bmatrix} \tag{5} $$

$$q = \begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix} \tag{6}$$

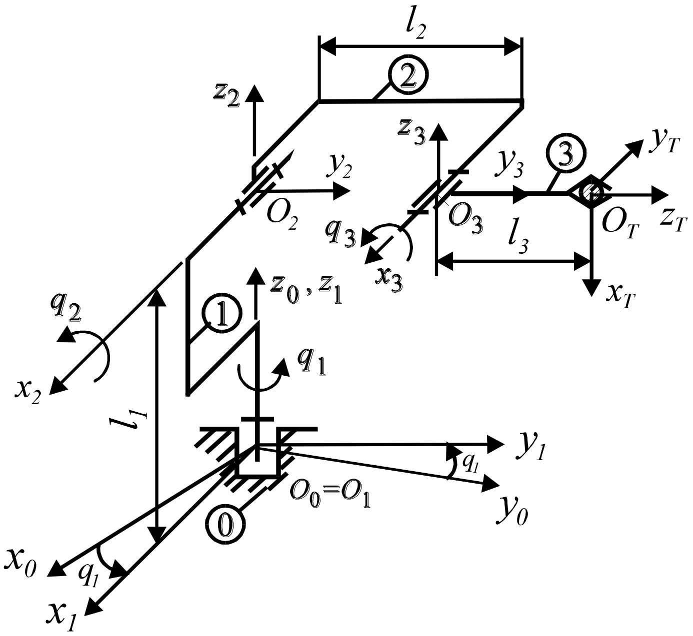

Figure 1. *Robotic mechanism with anthropomorphic structure*

The differential model of the analyzed robotic system is:

$$dx = J \cdot dq \tag{7}$$

where:

$$J = \begin{bmatrix} \frac{d\,^{(0)}x_{O_T}}{dq_1} & \frac{d\,^{(0)}x_{O_T}}{dq_2} & \frac{d\,^{(0)}x_{O_T}}{dq_3} \\ \frac{d\,^{(0)}y_{O_T}}{dq_1} & \frac{d\,^{(0)}y_{O_T}}{dq_2} & \frac{d\,^{(0)}y_{O_T}}{dq_3} \\ \frac{d\,^{(0)}z_{O_T}}{dq_1} & \frac{d\,^{(0)}z_{O_T}}{dq_2} & \frac{d\,^{(0)}z_{O_T}}{dq_3} \end{bmatrix} \tag{8}$$

Generating a linearly interpolated movement of the origin O_T is achieved with the following equation:

$$^{(0)}O_0O_T(t) = {}^{(0)}O_0O_{T_i} + g(t) \cdot {}^{(0)}O_{T_i}O_{T_f} \tag{9}$$

where: O_{T_i} and O_{T_f} are the initial position and the final position, respectively, of the origin O_T;

$$g(t) = 10 \cdot \left(\frac{t}{t_f}\right)^3 - 15 \cdot \left(\frac{t}{t_f}\right)^4 + 6 \cdot \left(\frac{t}{t_f}\right)^5 \tag{10}$$

where: t_f represents the time interval in which the robot's movement takes place.

The analysis was performed by discretizing the time interval t_f : $t_0 = 0, t_1, \ldots t_i, \ldots t_n = t_f$, into a number n of subintervals equal to t_f / n.

The variation of the motor coordinates is determined iteratively, using the differential model, with the following equation:

$$q(t_{k+1}) - q(t_k) = J^{-1}(t_k) \cdot \left({}^{(0)}O_0O_T(t_{k+1}) - {}^{(0)}O_0O_T(t_k) \right) \tag{11}$$

where:

$${}^{(0)}O_0O_T(t_{k+1}) - {}^{(0)}O_0O_T(t_k) = \left(g(t_{k+1}) - g(t_k) \right) \cdot {}^{(0)}O_{T_i}O_{T_f} \tag{12}$$

$q(t_0)$ was determined by numerically solving the resulting system of equations obtained by imposing in equation (4) that: ${}^{(0)}O_0O_T = {}^{(0)}O_0O_{T_i}$.

RESULTS AND DISCUSSIONS

The simulations were performed with a program developed in Maple based on the method presented previously. The following values were considered for l_1, l_2 and l_3: $l_1 = 1.2$ m ; $l_2 = 0.65$ m ; $l_3 = 0.4$ m .

${}^{(0)}O_0O_{T_i} = \begin{bmatrix} 0.2 & 0.5 & 0.6 \end{bmatrix}^T$; ${}^{(0)}O_0O_{T_f} = \begin{bmatrix} 0.4 & 0.8 & 0.75 \end{bmatrix}^T$;

The solutions obtained for $q(t_0)$ with the program mentioned above when ${}^{(0)}O_0O_T = {}^{(0)}O_0O_{T_i}$ are as follow:

$$\left[\begin{bmatrix} 2.761086276 \\ -2.816561714 \\ 1.440621298 \end{bmatrix}, \begin{bmatrix} 2.761086276 \\ -1.787925702 \\ -1.440621298 \end{bmatrix}, \begin{bmatrix} -0.3805063771 \\ -0.3250309391 \\ -1.440621298 \end{bmatrix}, \begin{bmatrix} -0.3805063771 \\ -1.353666952 \\ 1.440621298 \end{bmatrix} \right] \tag{13}$$

The variation curves of the motor coordinates q_1, q_2, q_3 when:

$q(t_0) = \begin{bmatrix} 2.761086276 & -2.816561714 & 1.440621298 \end{bmatrix}^T$ are shown in figures 2, 3 and 4.

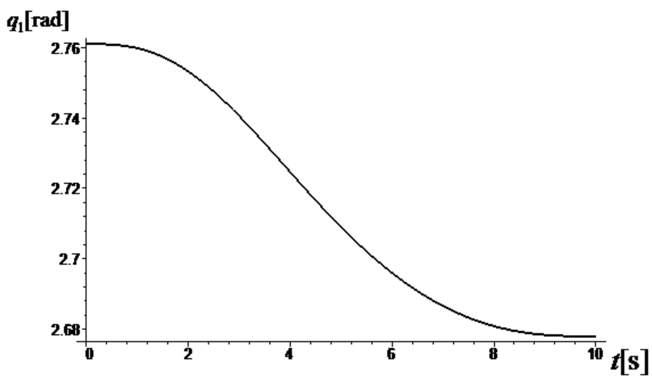

Figure 2. *The variation curve of the motor coordinate* q_1

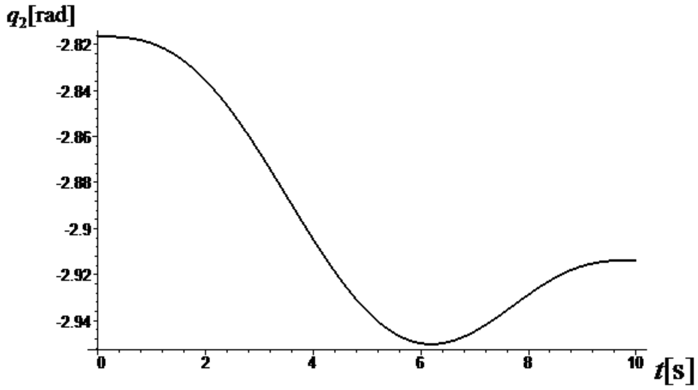

Figure 3. *The variation curve of the motor coordinate* q_2

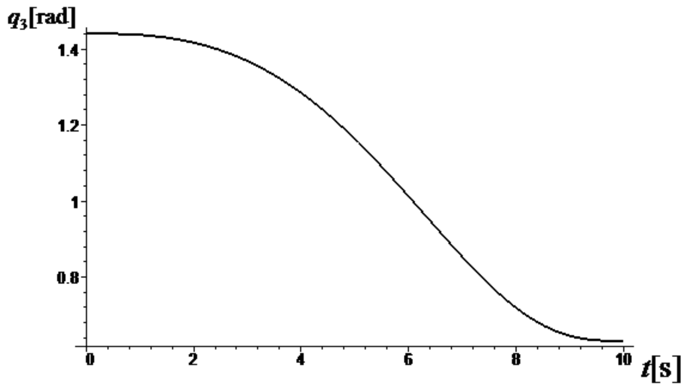

Figure 4. *The variation curve of the motor coordinate* q_3

In figures 5, 6 and 7 are represented the positioning errors at the level of the end effector of the analyzed robot relative to the trajectory imposed by the task: $err_x = x_{O_T,dif} - x_{O_T,task}$; $err_y = y_{O_T,dif} - y_{O_T,task}$ and $err_z = z_{O_T,dif} - z_{O_T,task}$, where: $x_{O_T,dif}$, $y_{O_T,dif}$ and $z_{O_T,dif}$ are the coordinates of the origin O_T obtained using the differential model and $x_{O_T,task}$, $y_{O_T,task}$ and $z_{O_T,task}$ are the values of these coordinates imposed by the linear interpolation used.

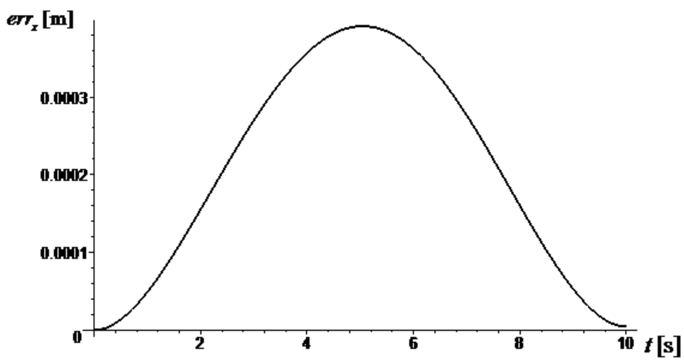

Figure 5. *The variation curve of the error* err_x

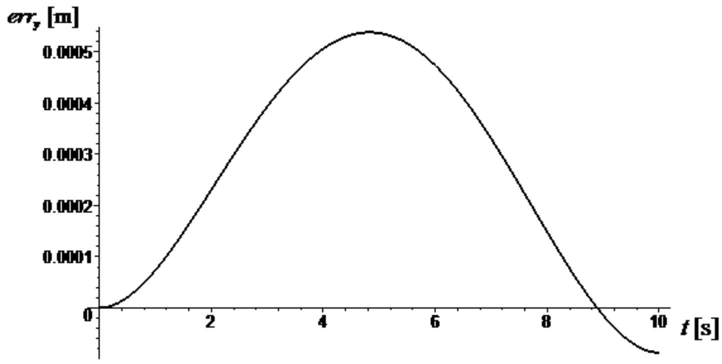

Figure 6. *The variation curve of the error* err_y

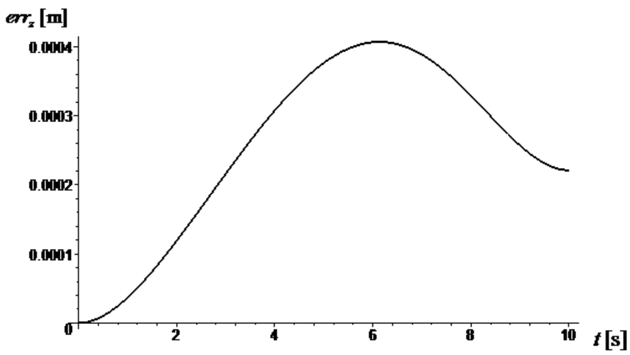

Figure 7. *The variation curve of the error* err_z

The variation curves of the motors coordinates q_1, q_2, q_3 and the positioning errors at the level of the end effector have been obtained by considering $n = 1000$ equal subintervals of the time interval $t_f = 10\, s$. So, the values for the mentioned parameters were obtained every $0.01\, s$ during the robot's movement.

The variation curves of the positioning errors during the robot's movement highlight their acceptable values and the fact that they do not show a continuous increase during the movement, on the contrary they decrease sharply towards the end of the trajectory traveled by the robot.

CONCLUSIONS

The problem of generating of interpolated movements at the level of the end effectors from the component of robotic mechanisms is particularly important in the optimal performance of tasks in many industrial applications such as: the realization of welding cords, laser cutting operations or handling of painting devices. In this paper was developed a method that allow generating interpolated movements in the case of a robotic system whose active mechanism has an anthropomorphic structure. The method used the differential model of the robotic system. The case analyzed was of a linear interpolation in which the hourly law used was in the form of a polynomial of the fifth degree. A simulator was realized using Maple program that allowed establishing all the configurations of the analyzed robotic system in order to generate the desired trajectory, as well as the positioning errors at the level of the end effector relative to the trajectory imposed by the task. It can be mentioned that the method used offer the possibility to include and analyze others types of interpolated movements. The values of the positioning errors during the robot's movement highlight that they do not show a continuous increase during the movement, on the contrary they decrease towards the end of the trajectory traveled by the robot, which demonstrates a good stability of the calculation algorithm used.

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