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RESEARCH ON THE SIMULATION OF THE OPERATION OF ROBOTIC MECHANISMS

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ABSTRACT

The optimal design of the structures from the component of the robotic mechanisms requires a good knowledge of the various parameters during their operation. Among them are mentioned the working parameters that give the position, speed and acceleration at the operational level of the robots, as well as at the level of the active joints from the component of the robotic mechanisms. This paper presents how a functional simulator of robotic active mechanisms called *RobSim* was created. The simulator allows the positional and kinematic analysis of active robotic mechanisms, regardless of their configuration and the number of component modules. The positional analysis is performed parametrically. A polynomial variation of the fifth degree was considered for the position parameters at the level of active joints. The simulator allows establishing the position and orientation at the operational level of the analyzed robotic mechanism, as well as the trajectory followed by the robot during operation. Also, the simulator allows establishing the speeds and accelerations both at the operational level of the robotic mechanisms, as well as at the level of the active joints in their component.

Keywords*:* industrial robots, mechanism, active joints, position parameters, kinematics

INTRODUCTION

The simulation of the operation of robotic mechanisms represents an always current field of study due to the results offered, absolutely necessary in the correct evaluation of the operation of robots in the performance of various tasks [1-10]. In this context, the precise establishment of the position at the operational level of the industrial robots during the performance of tasks and the distribution of speeds and accelerations at this level is very important in the optimization of work cycles [11-23]. Likewise, simulating the operation of robots at the level of active joints considering different variation functions for the motor coordinates is equally important.

The scope of this paper is to present how a functional simulator of robotic active mechanisms can be created. The method chosen in the realization of the simulator, by using the special symbolic calculation capabilities of the Maple program [24, 25], introduces a novelty character and offers it multiple possibilities of obtaining results in numerical and symbolic form. The simulator called *RobSim* allows the positional and kinematic analysis of active robotic mechanisms, regardless of their configuration and the number of component modules. It allows establishing the position and orientation at the operational level of the analyzed robotic mechanism, as well as the trajectory followed by the robot during operation. Also, the simulator allows establishing the speeds and accelerations both at the operational level of the robotic mechanisms, as well as at the level of the active joints in their component.

THEORETICAL CONSIDERATIONS AND RESULTS OF THE SIMULATIONS

Within the positional analysis of the active robotic mechanisms, the determination of the relative position and orientation between the component modules during operation, as well as the position and orientation of the final effector in relation to the base system of coordinates of the robotic mechanism is performed parametrically [8,11]. Figure 1 shows the four parameters (the angle $\boldsymbol{\alpha}_{i+1}$, the distance d_{i+1}, the angle $\boldsymbol{\theta}_{i+1}$ and the distance r_{i+1}) that define the relative position and orientation between two consecutive modules from the component of an active robotic mechanism.

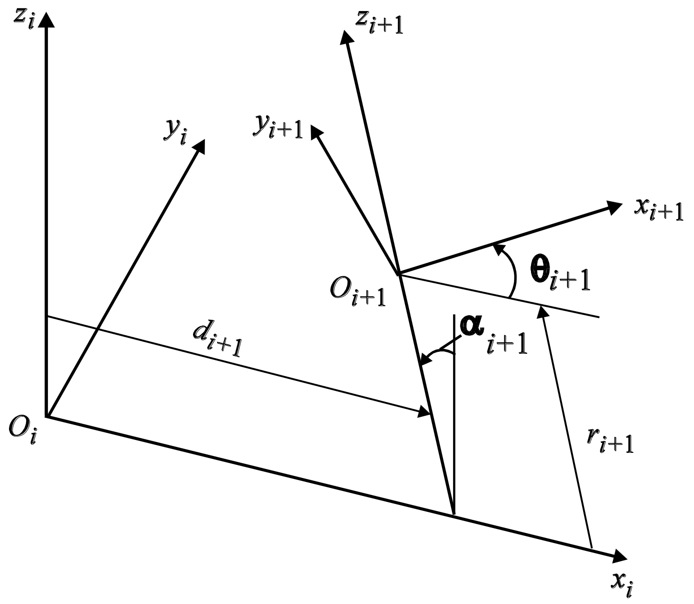

Figure 1. *The systems of coordinates attached to two consecutive modules*

The homogeneous transformation that establishes the relative position and orientation between consecutive modules *i* and *i+1* has the following expression [8]:

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

The *RobSim* simulator demands the number of component modules of the analyzed robot must to be entered first, and then are required the parameters corresponding to the relative position and orientation between the consecutive modules.

The position and orientation at the operational level of the robot is established with the relation:

$$^{0}T_T = {}^{0}T_n \cdot {}^{n}T_T \tag{2}$$

where:

$$^{0}T_n = {}^{0}T_1 \cdot {}^{1}T_2 \cdot \ldots \cdot {}^{n-1}T_n \tag{3}$$

and then the elements of the homogeneous transformation $^{n}T_T$ must be introduced in the simulator according to the way in which the coordinates system attached to the terminal module and the one attached to the final effector of the robot were chosen.

The *RobSim* simulator allows obtaining results both in symbolic and numerical form. For the numerical simulations, it was considered that the coordinates at the motor axle level vary according to the following law:

$$q(t) = q_i + g(t) \cdot (q_f - q_i) \tag{4}$$

where: q_i and q_f represent the initial and the final value of the active joint coordinate q. q_i and q_f are demanded to be introduced for any active component joint.

$g(t)$ is a polynomial function of time of degree five:

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

In relation (5), t_f represents the time interval in which the simulation of the analyzed robot is carried out.

The *diff* function from the Maple program was used to determine the speed and acceleration variation both at the level of the motor axes and at the operational level of the analyzed robot.

A series of results obtained by running the *RobSim* simulator in the case of the robot with five rotation modules in Figure 2 are presented below.

In this case $\theta_i = q_i; i = \overline{1,5}$; the values for the angles $\alpha_i, i = \overline{1,5}$, are: $0, -\frac{\pi}{2}, 0, 0$ and $-\frac{\pi}{2}$; the distances $d_i, i = \overline{1,5}$, are as follows: $0, 0, l_2, l_3$ and 0 and the distances $r_i, i = \overline{1,5}$, are all equal to zero.

The expression of the homogeneous transformation $^{5}T_T$ is in this case:

$$^{5}T_T = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & l_4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}$$

The initial and the final values of the active joint coordinates, q_i and q_f, introduced in this simulation case are: $0,-\frac{\pi}{2},\frac{\pi}{2},-\frac{\pi}{2},0$ and $\frac{\pi}{3},-\frac{\pi}{6},\frac{\pi}{3},-\frac{\pi}{3},\frac{\pi}{4}$, respectively.

In the representation of the systems of coordinates attached to the component modules of the robot, the *y* axes were omitted because they do not intervene in the evaluation of the parameters.

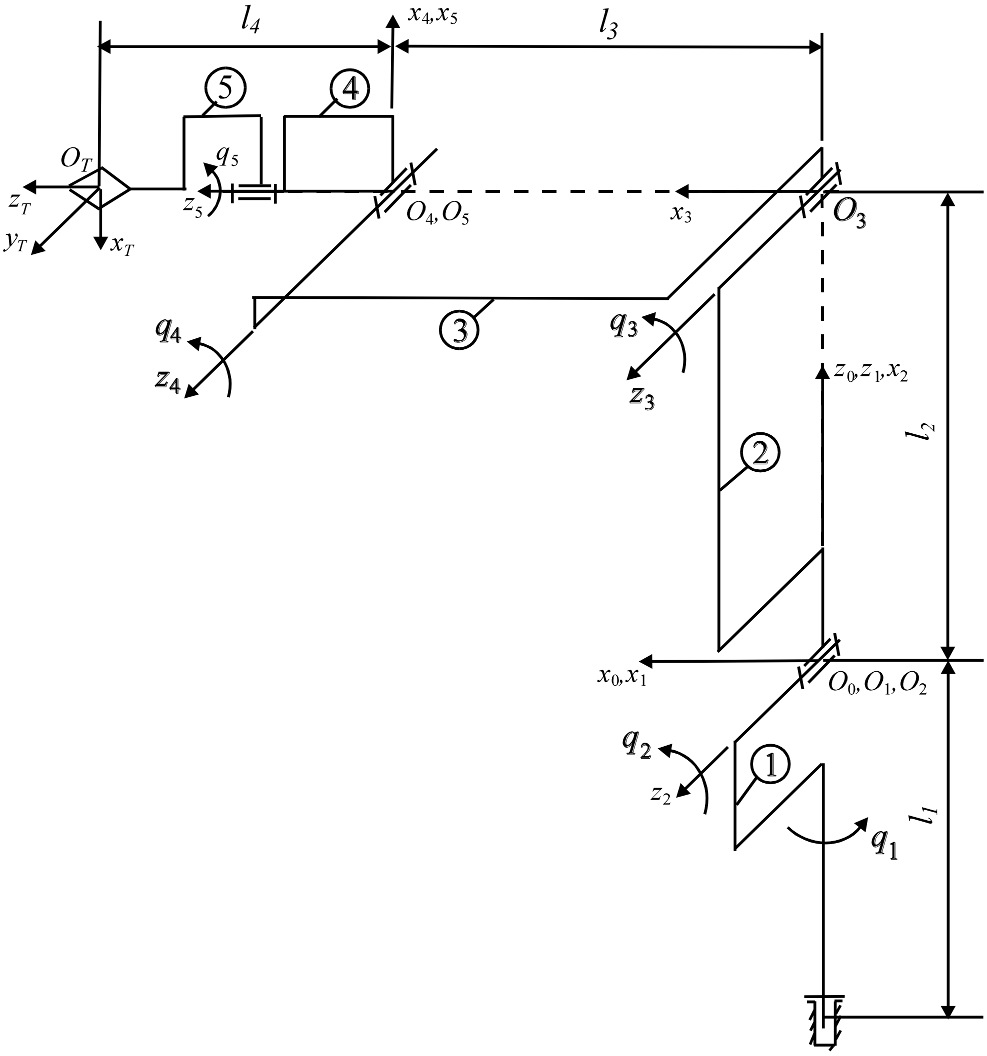

Figure 2. *Robot mechanism with five rotation modules*

The simulation was carried out for a time interval $t_f = 10\,s$. The following values were considered for the dimensions of the component modules: $l_1 = 0.55\,\text{m}$; $l_2 = 0.42\,\text{m}$; $l_3 = 0.34\,\text{m}$ and $l_4 = 0.15\,\text{m}$.

Figure 3 shows the variation curves of the coordinates of the characteristic point O_T in relation to the fixed system of coordinates $O_0x_0y_0z_0$.

Figure 4 shows the trajectory followed by the characteristic point O_T.

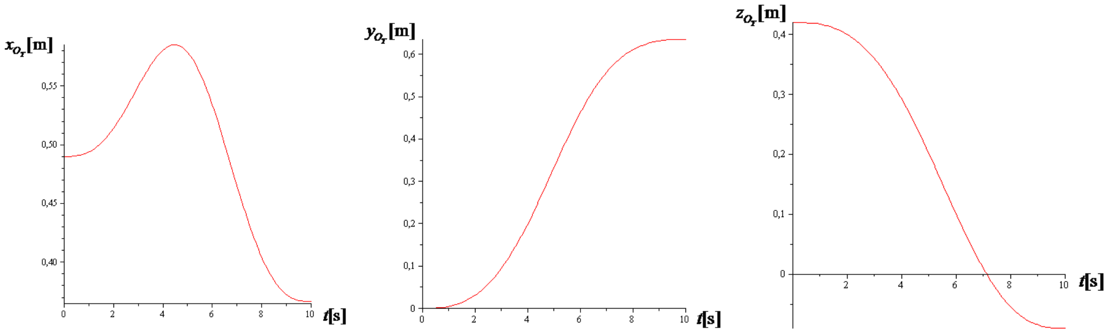

Figure 3. *The variation curves of the coordinates of the characteristic point* O_T

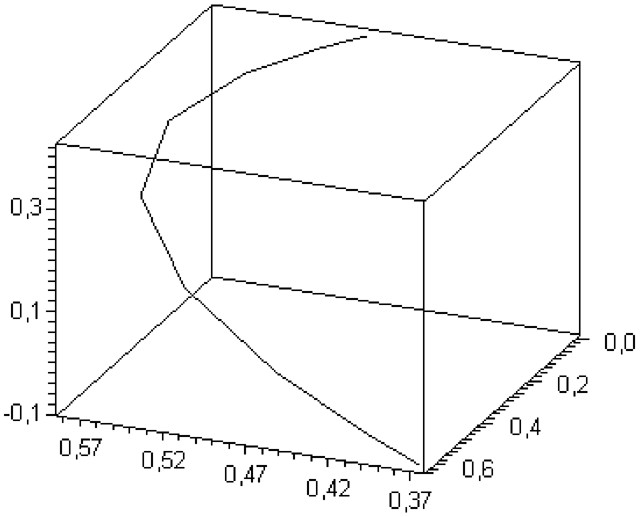

Figure 4. *The trajectory followed by the characteristic point* O_T

Figure 5 shows the variation curves of the derivatives in relation to time of the coordinates of the characteristic point O_T in relation to the fixed system of coordinates $O_0x_0y_0z_0$. Figure 6 shows the variation curve of the speed of characteristic point O_T.

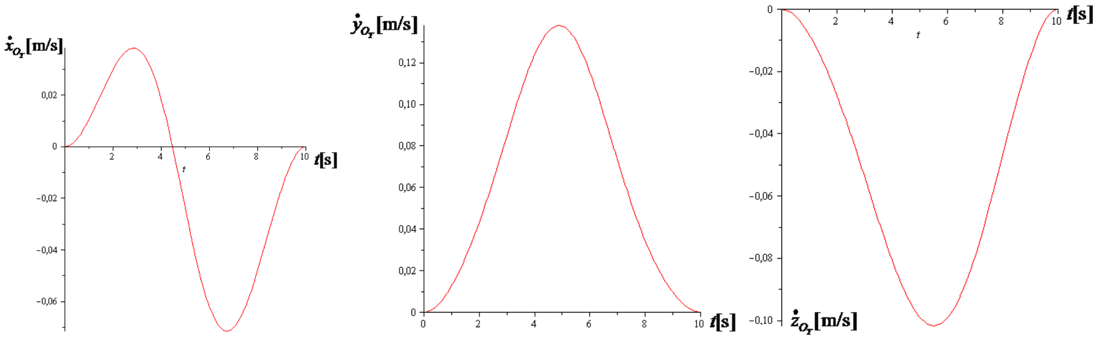

Figure 5. *The variation curves of the derivatives in relation to time of the coordinates of the characteristic point* O_T

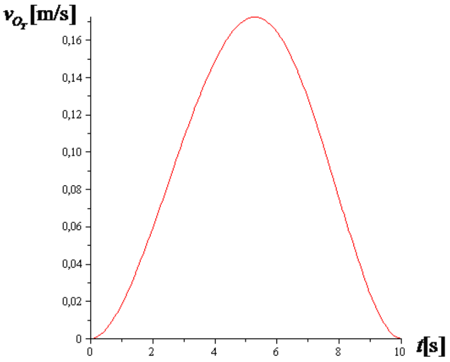

Figure 6. *The variation curve of the speed of characteristic point* O_T

In Figure 7 are represented the variation curves for $\ddot{x}_{O_T}, \ddot{y}_{O_T}$ and $\ddot{z}_{O_T}$ and Figure 8 shows the variation curve of the acceleration of characteristic point O_T.

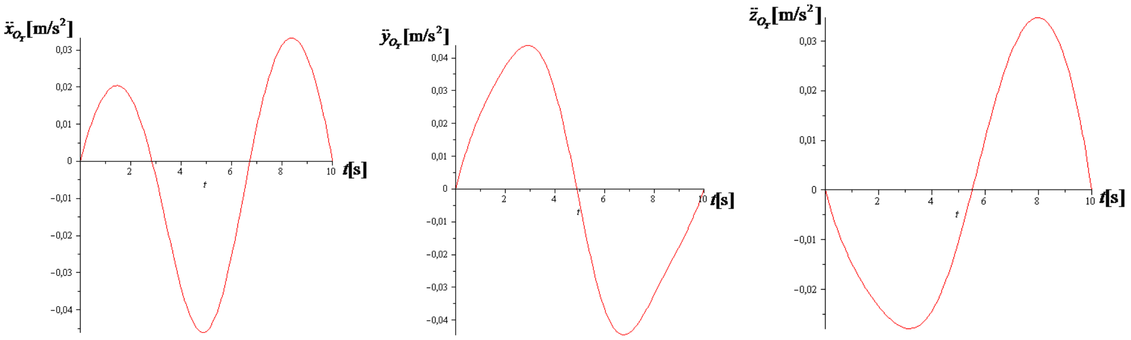

Figure 7. *The variation curves of* $\ddot{x}_{O_T}, \ddot{y}_{O_T}$ and $\ddot{z}_{O_T}$

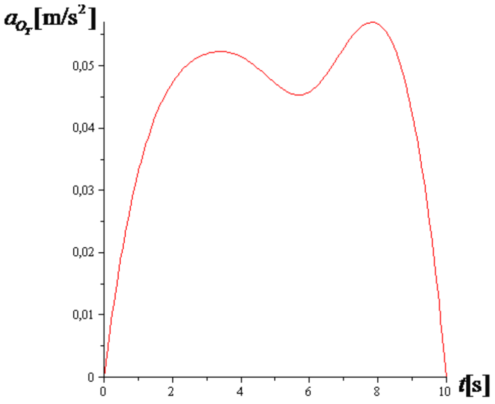

Figure 8. *The variation curve of the acceleration of characteristic point* O_T

CONCLUSIONS

In this article, the stages of creating a simulator with the help of which the active mechanisms of industrial robots can be analyzed positionally and kinematically were presented. The positional analysis was performed parametrically, and in the kinematic analysis it was considered that the positional parameters at the level of active joints have a polynomial variation of the fifth degree. In the realization of the simulator, called *RobSim*, the special symbolic calculation capabilities of the Maple program were used, so that the results can be obtained both in symbolic and numerical form. The simulator was run in the case of a robotic mechanism with five rotation modules. It was established the position and orientation at the operational level of the analyzed robotic mechanism, as well as the trajectory followed by the robot during operation. Also, it were determined the speeds and accelerations at the operational level of this robotic mechanism, as well as at the level of the active joints. Finally, it can be concluded that the *RobSim* simulator is useful to all those involved in the field of robotics, the results that can be obtained with it being necessary to establish optimal structures of robotic mechanisms.

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