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THE NUMERICAL SIMULATION OF TRR SMALL-SIZED ROBOT

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Abstract: *the paper presents a numerical simulation model for the TRR small-sized robot, by using the program SimMecRob. Starting from the definition of the initial data, concerning the robot's geometry and from a set of positions specific to the technological process, which must be reached at certain time moments, the geometric, kinematic and dynamic parameters of the robot, characterizing its behavior, are determined, by following the imposed technological process restrictions.*
Key words: *robot, serial, numerical simulation, SimMecRob.*

1. INITIAL DATA

The mechanical structure of TRR small-sized robot, having three degrees of freedom, is considered. The equations of the geometric, kinematic and dynamic models of the robot were determined in [1], [5], [4]. The numerical simulation of the robot aims to obtain the geometric, kinematic and dynamic parameters, according to a set of data describing the mechanical structure of the robot (number of degrees of freedom, joints type, joints sequence and orientation, parameters of mass distribution etc.) and the technological process the robot is implemented in. This process involves displacements in the robot's joints, in a given time interval, yielding the variation of a certain kinematics and dynamics parameters, such as: linear and angular velocities and accelerations, generalized forces etc. This paper presents the numerical simulation of TRR small-sized robot, using SimMecRob program, developed in [3] and described in [1] also.

For the beginning, the following data are entered: the name of the robot (TRR), the joints number (3), the number of configurations: (5). The data regarding the robot's geometry is described by specifying the origin of each link, the intermediary points and by specifying a point on each joint axis (fig.1). The points can be introduced either in absolute coordinates or relative coordinates (preceded by @).

The parameters describing the robot's nominal geometry are shown in table 1. Table 2 specifies the data regarding the mass distribution: mass center position for each link (in absolute coordinates), the masses and the axial and centrifugal moments of inertia with respect to the GP (Generalized Parameters, [2]) frames, translated into the mass center of each link. For the numerical representation of the useful force (table 3), a metal cube manipulation was considered, having the mass of 0.122 kg, without any interaction with the environment, in order to generate supplementary forces and moments.

Table 1

The nominal geometry of TRR small-sized robot, in mm

Frame	x_i	y_i	z_i	x_{A_i}	y_{A_i}	z_{A_i}
0	0,000	0,000	0,000	0,000	0,000	0,000
1	0,000	70,000	0,000	0,000	71,000	0,000
2	0,000	70,000	130,000	0,000	70,000	131,000
3	0,000	170,000	200,000	0,000	171,000	200,000
4	0,000	270,000	200,000	1,000	270,000	200,000

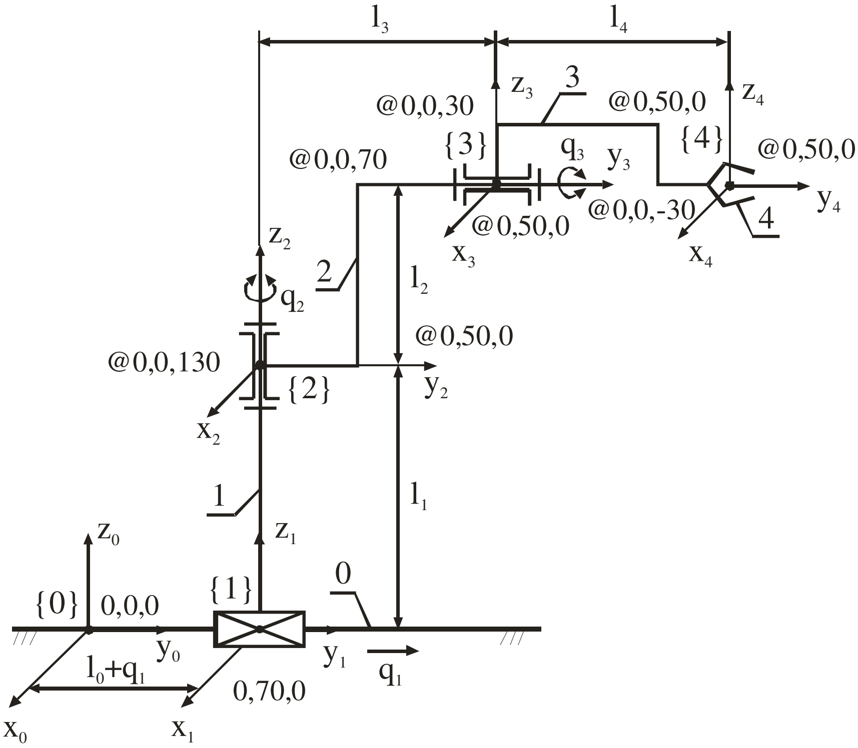

Fig. 1 The definition of the mechanical structure of TRR small-sized robot

Table 2

Mass distribution parameters corresponding to the links of TRR small-sized robot

{i}	M_i	x_{C_i}	y_{C_i}	z_{C_i}	${}^iJ_x$	${}^iJ_y$	${}^iJ_z$	${}^iJ_{xy}$	${}^iJ_{yz}$	${}^iJ_{zx}$
	<kg>	<mm>			<kg·mm²>					
1	2,009	0,00	70,000	65,000	627,800	3143,000	3143,000	0,00	0,00	0,00
2	1,680	0,00	120,000	165,000	2484,700	1760,000	1061,000	0,00	0,00	0,00
3	0,890	0,00	220,000	200,000	1281,320	949,740	431,720	0,00	0,00	0,00

Table 3

Useful force and moment in the simulation of TRR small-sized robot

Frame type	${}^4\bar{f}_4$			${}^4\bar{n}_4$		
	<N>			<N·m>		
DH	0,000	-1,197	0,000	0,000	0,000	0,000
PG	-1,197	0,000	0,000	0,000	0,000	0,000

Table 4

Successive configurations time in the working cycle of TRR small-sized robot

τ_p <s>, $p=\overline{0,4}$	0	2	5	7	10

Table 5

Nominal configurations in the working cycle of TRR small-sized robot

Link	Joint type	q_1 <mm>	q_2, q_3 <°>	p
1	T	0		
2	R		0	0
3	R		0	
1	T	-70,00		
2	R		-180,00	1
3	R		-180,00	
1	T	45,00		
2	R		-90,00	2
3	R		-90,00	

1	T	90,00		3
2	R		90,00	
3	R		0,00	
1	T	130,00		4
2	R		45,00	
3	R		90,00	

The TRR robot was implemented in a virtual technological process, described by five successive configurations ($p = \overline{0,4}$), specified by displacements in joints (table 5). The time moments corresponding to these configurations are presented in table 4.

2. NUMERICAL RESULTS

By automated computation, the DH and GP-type frames are determined and graphically represented (fig. 2 and 3), the GP and DH matrices of parameters are established (table 6 and 7), as well as the operational parameters of position-orientation (table 8) and the generalized variables (velocities and accelerations, table 9). The data corresponding to the third configuration (p =3) is presented as follows.

Notice. By T_D and T_G, the DH and GP frames were denoted, corresponding to the origin (3) and the extremity (4) of the gripper.

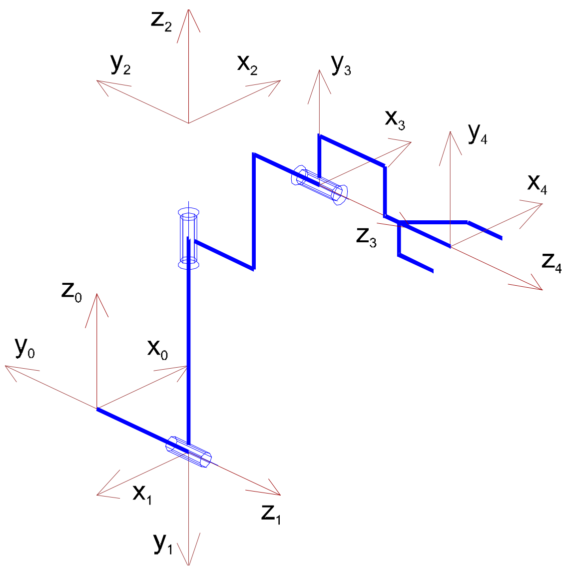

Fig. 2 TRR robot, DH frames

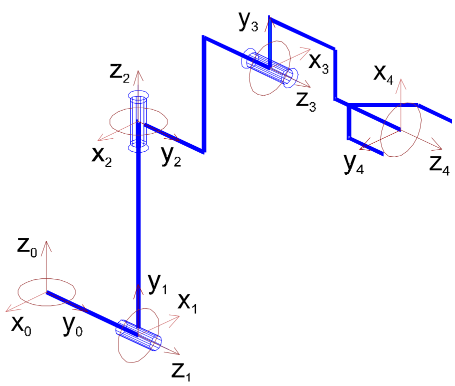

Fig. 3 TRR robot, PG frames

Table 6

GP parameters of TRR robot, in the configuration zero

Link	a_{i-1}	b_{i-1}	c_{i-1}	α_{i-1}	β_{i-1}	γ_{i-1}
	<mm>			<°>		
1	0,000	70,000	0,000	-90,000	0,000	-180,000
2	0,000	130,000	90,000	-90,000	0,000	-90,000
3	0,000	100,000	70,000	-90,000	0,000	-180,000
4	0,000	0,000	100,000	0,000	0,000	90,000

Table 7

DH parameters of TRR robot, in the configuration zero

Link	a_{i-1}	α_{i-1}	d_i	θ_i
	<mm>	<°>	<mm>	<°>
1	0,000	90,000	160,000	180,000
2	0,000	90,000	200,000	270,000
3	0,000	90,000	100,000	0,000
4	0,000	0,000	100,000	0,000

Table 8

The position-orientation of the gripper

Frame $\{T_D;T_G\}$	x	y	z	α	β	γ
	<mm>			<°>		
$3T_D$	100,00	-160,000	200,000	90,000	90,000	0,000
$3T_G$	-100,00	160,000	200,000	-90,000	90,000	0,000
$4T_D$	200,00	-160,000	200,000	90,000	0,000	90,000
$4T_G$	-200,00	160,000	200,000	-90,000	0,000	-180,000

Table 9

The generalized velocities and accelerations of TRR robot

Link	$\dot{q}_1$	$\dot{q}_2, \dot{q}_3$	$\ddot{q}_1$	$\ddot{q}_2, \ddot{q}_3$
	<mm·s^{-1}>	<rad·s^{-1}>	<mm·s^{-2}>	<rad·s^{-2}>
1	25,277		43,600	
2		0,174		-1,946
3		0,959		1,210

Table 10

Operational velocities of the gripper, expressed in the frame {0}

Frame	Variant	${}^0\bar{v}_3$			v_3	${}^0\bar{\omega}_3$			ω_3
$\{T_D;T_G\}$	{1,2}	<mm·s^{-1}>				<rad·s^{-1}>			
T_D	1	0,000	-7,824	0,000	7,824	0,959	0,000	0,174	0,975
T_D	2	0,000	-7,824	0,000	7,824	0,959	0,000	0,174	0,975
T_G	1	0,000	7,824	0,000	7,824	-0,959	0,000	0,174	0,975
T_G	2	0,000	7,824	0,000	7,824	-0,959	0,000	0,174	0,975

Table 11

Operational velocities of the gripper, expressed in the frame {3}

Frame	Variant	${}^3\bar{v}_3$			v_3	${}^3\bar{\omega}_3$			ω_3
$\{T_D;T_G\}$	{1,2}	<mm·s^{-1}>				<rad·s^{-1}>			
T_D	1	-7,824	0,000	0,000	7,824	0,000	0,174	0,959	0,975
T_D	2	-7,824	0,000	0,000	7,824	0,000	0,174	0,959	0,975
T_G	1	-7,824	0,000	0,000	7,824	0,000	0,174	0,959	0,975
T_G	2	-7,824	0,000	0,000	7,824	0,000	0,174	0,959	0,975

Table 12

Operational accelerations of the gripper, expressed in the frame {0}

Frame	Variant	${}^0\dot{\bar{v}}_3$			$\dot{v}_3$	${}^0\dot{\bar{\omega}}_3$			$\dot{\omega}_3$
$\{T_D;T_G\}$	{1,2}	<mm·s^{-2}>				<rad·s^{-2}>			
T_D	1	-3,046	-238,221	0,000	238,240	1,210	0,167	-1,946	2,297
T_D	2	-3,046	-238,221	0,000	238,240	1,210	0,167	-1,946	2,297
T_G	1	3,046	238,221	0,000	238,240	-1,210	-0,167	-1,946	2,297
T_G	2	3,046	238,221	0,000	238,240	-1,210	-0,167	-1,946	2,297

Table 13

Operational accelerations of the gripper, expressed in the frame {3}

Frame	Variant	${}^3\dot{\bar{v}}_3$	$\dot{v}_3$	${}^3\dot{\bar{\omega}}_3$	$\dot{\omega}_3$
$\{T_D;T_G\}$	{1,2}	<mm·s^{-2}>		<rad·s^{-2}>	

T_D	1	-238,221	0,000	-3,046	238,240	0,167	-1,946	1,210	2,297
T_D	2	-238,221	0,000	-3,046	238,240	0,167	-1,946	1,210	2,297
T_G	1	-238,221	0,000	-3,046	238,240	0,167	-1,946	1,210	2,297
T_G	2	-238,221	0,000	-3,046	238,240	0,167	-1,946	1,210	2,297

Table 14

MD parameters corresponding to the TRR robot

Frame	$\{i\}$	M_i	x_{C_i}	y_{C_i}	z_{C_i}	${}^iJ_x$	${}^iJ_y$	${}^iJ_z$	${}^iJ_{xy}$	${}^iJ_{yz}$	${}^iJ_{zx}$
$\{T_D;T_G\}$		<kg>	<mm>			<kg·mm²>					
T_D	1	2,009	0,00	-65,00	0,000	9115,825	3143,000	11631,025	0,00	0,00	0,00
	2	1,680	0,00	-50,00	-35,000	8742,700	3818,000	5261,000	0,00	2940,00	0,00
	3	0,890	0,00	0,00	50,000	3506,320	3174,740	431,720	0,00	0,00	0,00
T_G	1	2,009	0,00	65,00	0,000	9115,825	3143,000	11631,025	0,00	0,00	0,00
	2	1,680	0,00	50,00	35,000	8742,700	3818,000	5261,000	0,00	2940,00	0,00
	3	0,890	0,00	0,00	50,000	3506,320	3174,740	431,720	0,00	0,00	0,00

The obtained data become input elements for the kinematic parameters computation. The following amounts will be determined, for every configuration ($m = 5$):

- the differential matrices;
- the Jacobi matrix and its inverse;
- the operational velocities and accelerations.

The results specific to the third configuration ($p = 3$) will be shown as follows, for the kinematic parameters expressing the motion of the gripper in the Cartesian space (tables 10-13).

The obtained results become input data in the automated computation of the mass distribution parameters. The MD (mass distribution) parameters matrix, corresponding to the third configuration ($p = 3$) is presented in table 14, as an example.

An essential aspect is the dynamic model of the considered structure. By automated computation, using the data previously generated, the generalized driving forces and the operational velocities and accelerations are determined. The results corresponding to the robot ($p = 3$) are presented below (tables 15-17). Within the tables, NE represents Newton-Euler's formulation and LE represents Lagrange-Euler's method. The dynamic functions corresponding to the transition from the first configuration, at the time $t = 2$ to the second configuration ($t = 5$), are in table 17.

Table 15

The generalized driving forces of the TRR robot

Frame	Method	Variant	Q_m^1	Q_m^2	Q_m^3
$\{T_D;T_G\}$	{NE; LE}	{1; 2}	<N·m>	<N>	<N>
T_D	NE	1	0,622	-60,543	0,522
	LE	2,1	0,622	-60,543	0,522
		2,2	0,622	-60,543	0,522
		2,3	0,622	-60,543	0,522
T_G	NE	1	0,622	-60,543	0,522
	LE	2,1	0,622	-60,543	0,522
		2,2	0,622	-60,543	0,522
		2,3	0,622	-60,543	0,522

Table 16

The operational accelerations corresponding to the TRR robot

Frame	${}^0\dot{\bar{v}}_{3d}$	$\dot{v}_{3d}$	${}^0\dot{\bar{\omega}}_{3d}$	$\dot{\omega}_{3d}$

{T_D;T_G}	<mm·s^{-2}>				<rad·s^{-2}>			
T_D	0,000	-0,2382	0,000	0,2382	0,0012	0,000	-0,0019	0,0023
T_G	0,000	0,2382	0,000	0,2382	-0,0012	0,000	-0,0019	0,0023

Table 17

Dynamic functions

$\ddot{X}(t)$	{T_D, T_G}	Function
$\dot{v}_{px}(t)$	T_D T_G	0.084*(5.000-t)+0.000*(t-2.000) -0.084*(5.000-t)+0.000*(t-2.000)
$\dot{v}_{py}(t)$	T_D T_G	0.207*(5.000-t)-0.036*(t-2.000) -0.207*(5.000-t)+0.036*(t-2.000)
$\dot{v}_{pz}(t)$	T_D T_G	0.000*(5.000-t)+0.000*(t-2.000) 0.000*(5.000-t)+0.000*(t-2.000)
$\dot{v}_{p}(t)$	T_D T_G	0.223*(5.000-t)+0.036*(t-2.000) 0.223*(5.000-t)+0.036*(t-2.000)
$\dot{\omega}_{4x}(t)$	T_D T_G	0.000*(5.000-t)-0.001*(t-2.000) 0.000*(5.000-t)+0.001*(t-2.000)
$\dot{\omega}_{4y}(t)$	T_D T_G	0.001*(5.000-t)+0.000*(t-2.000) 0.001*(5.000-t)+0.000*(t-2.000)
$\dot{\omega}_{4z}(t)$	T_D T_G	0.001*(5.000-t)+0.000*(t-2.000) 0.001*(5.000-t)+0.000*(t-2.000)
$\dot{\omega}_{4}(t)$	T_D T_G	0.001*(5.000-t)+0.001*(t-2.000) 0.001*(5.000-t)+0.001*(t-2.000)

As a conclusion, the obtained data are useful to study the behavior of the analyzed robot, ensuring the parameters of the technological process the robot is implemented in.

5. REFERENCES

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Simularea numerică a minirobotului TRR

Rezumat: Lucrarea prezintă un model de simulare numerică a minirobotului de tip TRR, utilizând programul SimMecRob. Pornind de la definirea datelor iniţiale, referitoare la geometria robotului şi de la un set de configuraţii specifice procesului tehnologic, care trebuie atinse la anumite momente de timp, sunt determinaţi parametrii geometrici, cinematici şi dinamici ai robotului, care caracterizează comportamentul acestuia, în urma respectării procesului tehnologic impus.

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