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Dynamic Model of the PUMA-like Manipulator with a Hybrid Position/Force Control in Operation with a Compliant Environment

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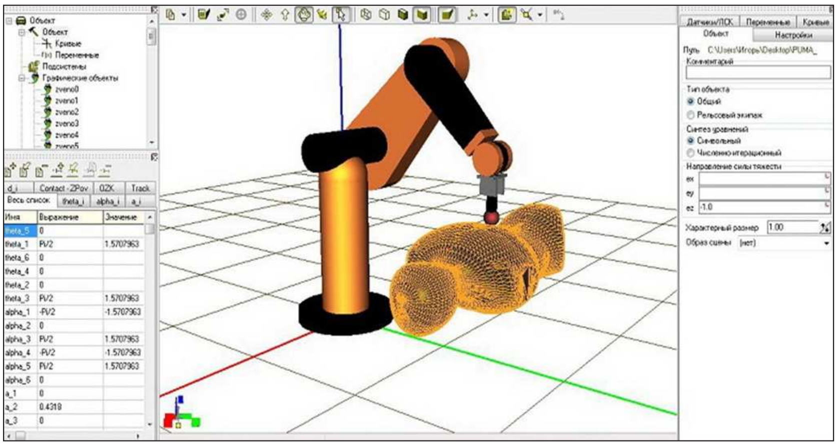
Abstract

The paper deals with the multibody dynamic model of the system robot–tool to work with a compliant environment. Manipulator with the PUMA-like kinematics is used, as a model of the robot [1] (Fig. 1). The tool has a translational degree of freedom and is firmly fixed to grab of the robot, so its degree of freedom can be treated as a fictitious joint. This system will be used for regenerative medicine, such as massage [2]. Particular attention is paid to the safety performance of procedures when working with a patient, provided by inclusion in the control loop model of the robot. The purpose of this paper is to construct a model, that has characteristics close to real. And further, to build a model of a hybrid position-force control system to work with visco-elastic surface and study the following parameters: the deviation of the tool axis from the surface normal, the deviation of effort when passing through the nodal point of the trajectory.



Имя	Выражение	Значение
theta_5	0	
theta_1	PI/2	1.5707963
theta_6	0	
theta_4	0	
theta_2	0	
theta_3	PI/2	1.5707963
alpha_1	-PI/2	-1.5707963
alpha_2	0	
alpha_3	PI/2	1.5707963
alpha_4	-PI/2	-1.5707963
alpha_5	PI/2	1.5707963
alpha_6	0	
a_1	0	
a_2	0.4318	
a_3	0	

Путь C:\Users\Игорь\Desktop\PUMA_
Комментарий
Тип объекта
● Общий
○ Рельсовый экипаж
Синтез уравнений
● Символьный
○ Численно итерационный
Направление силы тяжести
ex
ey
ez -1.0
Характерный размер 1.00
Образ сцены (нет)

Figure 1: Model of the PUMA-like robot.

To describe the mechanical system, the following model used (1)– (5):

1. DC motor mathematical model:

$$\begin{cases} u = iR + C_\omega \dot{\theta}, \\ M = C_m i, \end{cases} \tag{1}$$

where i – armature current, C_m – torque constant, C_ω – speed constant, R - armature resistance, M – motor torque, u – voltage, $\dot{\theta}$ – an angular velocity of rotor.

2. System of dynamic equation to describe the manipulator with drives:

$$\begin{cases} \mathbf{A}(\boldsymbol{\theta})\,\ddot{\boldsymbol{\theta}} + \mathbf{B}\left(\dot{\boldsymbol{\theta}}, \boldsymbol{\theta}\right) + \mathbf{C}(\boldsymbol{\theta}) = \mathbf{M} - \mathbf{Q_e}, \\ \mathbf{M} = \mathbf{b_1 u} - \mathbf{b_2}\dot{\boldsymbol{\theta}}, \end{cases} \tag{2}$$

3. Contact model:

$$\mathbf{N} = -(c\Delta z + k\Delta\dot{z})\boldsymbol{\nu}, \tag{3}$$

$$\mathbf{F} = \begin{cases} -fN\mathbf{v}/|\mathbf{v}|, |\mathbf{v}| > v_f, \\ -fN\mathbf{v}/v_f, |\mathbf{v}| \leq v_f, \end{cases} \tag{4}$$

where **N** – normal reaction force, **F** – dry friction force, $\boldsymbol{\nu}$ – surface normal, Δz – immersion depth of work tool, c, k – surface parameters, $\mathbf{v}$ – slip velocity, f – friction constant, v_f — sufficiently small.

4. Force control law tool with a translational degree of freedom [3]:

$$f = m\left[\frac{k_{pf}}{k_p}e_f - k_{vf}\dot{x}\right] + f_e. \tag{5}$$

Here $e_f = f_d - f_e$ – the difference between the desired force f_d and measured force f_e, k_{pf}, k_{vf} – PD controller gains.

Model of the robot and the working surface is created in the software package "Universal Mechanism" (UM), control model – in MATLAB Simulink (Fig. 2).

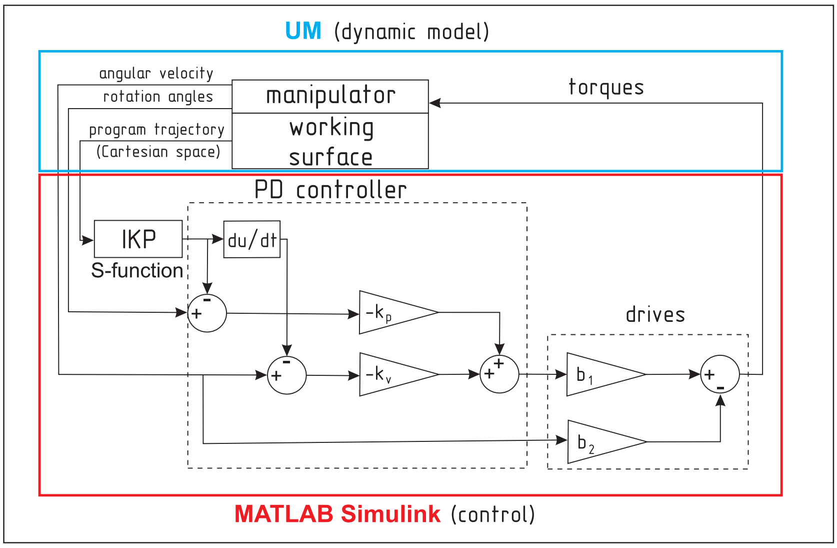


Figure 2: UM – MATLAB Simulink.

Path planning algorithm is constructed for linear motion trajectories in Cartesian space. Law between the number of nodal points of the trajectory and force error is constructed. Coefficients of PD controller was so selected, that the force error did not exceed 1% of the given force by the hybrid position-force control.

References

[1] B. Armstrong, O. Khatib, J. Burdick. The explicit dynamic model and inertial parameters of the PUMA 560 arm Proc. IEEE Int. Conf. Robotics and Automation. Proceedings. Vol. 3. P. 510 – 518. 1986.

[2] V.F. Golovin, V.V. Zhuravlev, M.V. Arkhipov, V.E. Pavlovsky, I.A. Orlov. Features of Mathematical Modeling of the Polyarticular Robot Interacting with an Elastic Dynamic Environment. Scientific and Technical Information. Series 2. "Information Processes and Systems". (2012). No. 12. pp. 16–27. [In Russian].

[3] J.J. Craig. Introduction to Robotics: Mechanics and Control. Addison-Wesley series in electrical and computer engineering: control engineering, Pearson/Prentice Hall. 2005.