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The sensitivities of industrial robot manipulators to errors of motion models' parameters

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Abstract

In this paper it is focused on sensitivity analyses of position and orientation coordinates of manipulator gripper to errors of kinematics' parameters. Also it is focused on sensitivity analyses of mass forces to errors of dynamics' parameters. In these models the transform graphs are used. These graphs were presented by the author of this paper in The First Int. Conf. Graphs & Mechanics. Practical methods of kinematics' calibration make use of the linear differential error of the kinematics' model. This model is based on the Jacobian of the direct kinematics' model with respect to parameters of this model. These methods use the theory of minimum-square identification of kinematics' parameters too. Practical methods of dynamics' calibration make use of the dynamics models, which are in a linear form in relation to dynamics' parameters. These methods use the theory of minimum-square identification of dynamics' parameters. Measurements are one of the steps of calibration. These measurements should be carried out in the manipulator's states in which the errors of kinematics' parameters cause the largest errors of the gripper's positioning or errors of dynamics' parameters cause the largest errors of the mass forces. These states are named as the most sensitive to errors of kinematics' parameters or as the most sensitive to errors of dynamics' parameters. In this paper measures of sensitivity of the gripper's positioning to errors of kinematics' parameters, and measures of sensitivity of the mass forces to errors of dynamics' parameters are proposed. The example for the calculation of sensitivity of the gripper's positioning for IRb-6 manipulator is presented too. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Modelling of manipulator positioning and mass force errors; Sensitivities of manipulator positioning and mass force; Calibration of manipulator parameters.

1. Introduction

Applying of industrial robots is connected with difficulties in their use. One of the factors which helps us in their use are systems of autonomous programming of robots named off-line [3]. These systems are important in the programming of contemporary industrial tools as well as are the

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basis of research into robotics area [3]. Systems of autonomous programming make robots user-friendly because they allow illustrating by means of computer graphics the planned operations.

Models of manipulators' motion, which are used in system off-line, have to assure appropriate compatibility between real manipulator. Manipulators are complex mechanical systems and therefore modelling of these is difficult. The number of parameters of models of manipulators' motion is large. The problems connected with this modelling were presented by the author of this paper in The First Int. Conf. Graphs & Mechanics and in papers [10,11]. For example the models of manipulators' motion of IRb-6 possess 38 kinematics' parameters and 110 dynamics' parameters [10,11]. In order to assure compatibility it is necessary to lead to the calibration of models' parameters which is based on the measurements of real characteristics of manipulators. Calibration can be carried out when the nominal values of parameters of model are obtained earlier. It is possible to obtain the nominal values of kinematics' parameters through measurement or reading the ones from technical documentation [17]. The nominal value of dynamics' parameters can be calculated from sizes and mass distribution [2,3,12]. These values of parameters are essential for sensitivity analyses of the most important parameters of manipulators' characteristics to individual parameters of model.

In this paper it will be focused on sensitivity analyses of position and orientation coordinates of gripper to errors of kinematics' parameters. Also it will be focused on sensitivity analyses of mass forces to errors of dynamics' parameters. Practical methods of kinematics' calibration make use of the linear differential error of model, which is based on the Jacobian of direct kinematics' model with respect to geometrical parameters [1,2,4–7,13,21]. These methods use the theory of minimum-square identification of kinematics' parameters too [2,4,8,9,14]. Practical methods of dynamics' calibration make use of the dynamics models. These models are in a linear form in relation to dynamics' parameters. Elements of pseudoinertia matrices of manipulator are dynamics' parameters [22]. These methods use the theory of minimum-square identification of dynamics' parameters. Measurements are one of the steps of calibration [18–20]. These measurements should be carried out in the manipulators' states in which the errors of kinematics' parameters cause the largest errors of the gripper's positioning or errors of dynamics' parameters cause the largest errors of the mass forces. These states will be named as the most sensitive to errors of kinematics' parameters or as the most sensitive to errors of dynamics' parameters.

In Section 2 measures of sensitivity of the gripper's positioning to errors of kinematics' parameters, and measures of sensitivity of the mass forces to errors of dynamics' parameters are proposed. In Section 3 the example of calculation of sensitivity of the gripper's positioning for IRb-6 manipulator is presented. Section 4 contains the conclusions.

2. The measures of sensitivity

Coordinates of position d_x, d_y, d_z and coordinates of orientation Φ, Θ, Ψ of the gripper are functions of natural coordinates and kinematics' parameters. Φ, Θ, Ψ are Z–Y–Z Euler angles [3]. The coordinates of position and orientation we can obtain by means of optical measurements [17]. These measurements should be carried out for the motionless manipulator.

The mass forces F_{a1}–F_{aN} of actuators are functions of natural coordinates, their velocities and accelerations, and dynamics' parameters [15,16]. The index N is a number of manipulator