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Dynamic accuracy of robotic mechanisms. Part 1: Parametric sensitivity analysis

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Abstract

The paper is organized in two parts. Part 1 treats the problem of robot dynamic accuracy which has been scarcely elaborated in the literature. In this paper the error model of control by means of local feedback loops is given, which represents the initial research results in that field (N. Vešović, M. Vukobratović, Mech. Mach. Theory 29 (1994) 415–425). In this paper the error model of tracking trajectories using a dynamic control law, was developed and presented in detail. By using the inverse dynamics method (IDM) a control law was formed, into which the robot dynamics model was included and the sensitivity functions, which have served as the basis for the analysis of the variations influence on the dynamic robot parameters of the trajectory tracking accuracy were given.

1. Introduction

Low accuracy is still one of the important obstacles to a wider utilization of robots in industry and, especially, a considerable impediment to a more extensive use of advanced robot programming techniques which incorporate off-line simulation and CAD-based systems. The definition of the robot accuracy is usually related to robot positioning, so that the accuracy is defined as a measure of robot ability to attain a required position with respect to a fixed absolute reference coordinate frame. Such a definition is easily extended to trajectory tracking. Then, accuracy can be defined as a measure of robot ability to track the prescribed trajectory with respect to the absolute coordinate frame.

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Robot accuracy is correlated with repeatability, which is a measure of robot ability to return to a previously reached and memorized position (or ability to track the memorized trajectory repeatedly).

Although they express different things, robot accuracy and repeatability are sometimes intermixed: it is not uncommon that robot manufacturers state the value of the repeatability in the performance data sheets as the robot accuracy. Obviously, it is desirable that both accuracy and repeatability reach high standards. However, due to the fact that the absolute positioning accuracy is frequently greater than the repeatability by an order-of-magnitude, low accuracy of a robot is often regarded as a more serious problem, because it practically restricts such robot to the applications which can be satisfactorily programmed by 'teaching by showing' methods.

Robot accuracy is influenced by a number of factors. Kochekali et al. [2] classify them into six categories: environmental (for example, temperature changes), parametric (variation of kinematic parameters, influence of dynamic parameters, friction and other nonlinearities, including hysteresis and backlash), measurement (resolution and nonlinearity of joint position sensors), computational (computer round-off and steady-state servo errors), and application (installation errors and workpiece position and geometry errors). Analysis of their influence and its elimination is a subject of intensive research aimed at the improvement of both accuracy and repeatability.

Robots employ position sensors to obtain information on their current position. The position sensors can be external or internal. The external sensors are capable of giving the position and orientation of the robot gripper with respect to some absolute coordinate frame directly. However, such sensors are rarely applied because of their high cost and technical problems linked with their installation. On the other side, internal position sensors render the position of internal coordinates (joint displacements) of the robot. Position and orientation of the gripper are then calculated a posteriori, using the robot kinematic model. Thus, a difference can be made between the 'internal' and 'external' accuracy.

Internal accuracy is the accuracy of attaining the prescribed set actuator position (or the accuracy of tracking the prescribed trajectory given in joint coordinates). Important factors influencing the internal positioning accuracy are steady-state servosystem errors, nonlinearities in the transmission from the actuator drive to the actuator output shaft, and imprecisely known gravitational moments loading the actuators. By a suitable selection of the servosystem, the influence of the steady-state error and load can be practically eliminated. Influence of deformation and backlashes in the transmission can be eliminated by measuring the position on the output actuator shaft, although such a solution is rarely encountered in industrial robots due to high price.

Industrial robots usually exhibit large external positioning errors compared to the internal ones. Important sources of the difference between the internal and the external accuracy are off-sets between zero-reference readings of position sensors with respect to the actual zero positions of adjacent links, deviations of kinematic parameters from nominal values, and link deformations due to static load [3,1]. These factors contribute to the inaccuracy in mapping of the internal coordinates into the external ones, i.e. they influence the accuracy of the kinematic robot model that can be spoken as the 'kinematic accuracy' [4,5].

When considering the case of trajectory tracking, new factors, influencing primarily the internal trajectory tracking accuracy, appear. An important source of the internal tracking