Structural parameter identification for 6 DOF industrial robots

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Abstract

To decrease the movement uncertainty of industrial robots, a parameter identification method based on the Denavit-Hartenberg (DH) model is presented in this paper, where the redundant parameters are particularly addressed in the identifier procedure. In order to be consistent with the kinematic model used in robot controllers, we use DH method to establish the kinematic model instead of the modified DH (MDH) method that was used in most identification schemes. The kinematic model of a 6 degree of freedom (DOF) industrial robot is first developed, which is linearized to obtain the parameter identification coefficient matrix. Further analysis shows that this matrix is not with full rank, which means some parameters in this matrix are linearly dependant. This fact makes the direct identification of unknown parameters in this matrix unfeasible. To solve this problem, singular value decomposition (SVD) is used to determine the redundant parameters, which are then removed from the matrix. Then, an alternative identification algorithm with a modified least-square scheme is suggested to estimate the structural parameters of the robot. For this purpose, an identification calculation scheme is designed to minimize the residual movement uncertainties. Experimental studies based on a 6 DOF industrial robot show that the proposed identification method, which detects and removes the redundant parameters, can greatly reduce the residual movement uncertainties and calculation costs. Thus, this newly proposed method can improve the movement accuracy of the industrial robot significantly.

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1. Introduction

Industrial robot is a typical mechanical and electrical equipment, which plays an important role in the industrial production and social development. In practical industrial robotic applications, the positioning accuracy is a critical performance index. Recently, with the development of automation and intelligent manufacturing technology, the requirements for the positioning and tracking accuracy of industrial robots are more demanding, especially in the field of welding, assembly, piping and so on. Specifically, the repeatability of industrial robots is very essential, because most industrial robots only perform repetitive motions in their work scenarios [1,2]. In fact, there are many factors which can influence the tracking accuracy of industrial robots, e.g. manufacturing errors of the linkages, assembling errors and fitting, environmental temperature change. All these effects can lead to inconsistence between the nominal structural parameters embedded in the controller and the actual ones. According to the research of [3,4], about 95% of the industrial robots’ end actuator error is due to the error of the structural parameters. Therefore, obtaining accurate parameters of the robotic systems is important for

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improving their operation precision. To obtain accurate parameters, calibration is an effective way, which has been widely used to improve the performance and reliability of industrial robots. There are two kinds of calibration methods for industrial robots: the first one is the calibration based on the structural parameter identification through mathematical calculations to improve the accuracy in the whole working space; the second approach is non-parametric calibration, which estimates and compensates the error of the positions without modeling, and poses in a partial working space [4–6]. Unlike the non-parametric calibration that can only improve the accuracy in a partial working space, the calibration scheme with the model based identification only changes the setting of the structural parameters in the controller rather than modifies the structure of the robot and the frame of the controller [7]. Therefore, it is easier and more convenient to be conducted in practice. Thus, the framework of modeling based method will be adopted in this paper.

To facilitate the calibration of industrial robots, four steps should be conducted: modeling, measurement, identification and compensation. Modeling is the premise and foundation of identification. Roth [8] pointed out that a perfect kinematic model of the robot requires three conditions: (1) completeness, there should be enough parameters to indicate the difference between the nominal value and actual value; (2) continuousness, the model should be a continuous function of structural parameters; (3) minimality, a minimal model should exclude the redundant parameters. For the precision modeling of robotic kinematics, the most influential method is the Denavit-Hartenberg (DH) model, which has been widely used owing to its clear physical meaning [9,10]. However, DH model is not continuous when the adjacent joints are parallel or nearly parallel. Therefore, many modified models were proposed to guarantee the continuousness, e.g. MDH model [11], S model [12], CPC model [13], POE model [14] and so on. It should be noted that there is still no perfect kinematic model for describing robot kinematics and dynamics, which can be used for parameter identification. Although the parameters in some of these modified kinematic models can be identified, the subsequent compensation is not trivial because the kinematic model used in the controller is based on DH model in general. Consequently, it is difficult to apply these models in the actual industrial robot [15]. In order to apply the identification results to industrial robots, the model for identification should be consistent with the model used in the controller of industrial robots. Hence, it is preferable to use DH model in the identification in this paper. On the other hand, some identification approaches have been adopted to obtain DH model parameters. Among them, Least squares (LS) method, particle swarm optimization (PSO) algorithm and genetic (GA) algorithm have been widely used in the identification calculation [4,15]. However, the direct application of LS method may suffer from the coupling effects between the redundant parameters. Moreover, the implementation of PSO and GA needs offline calculations, which also imposes heavy computation costs.

With the aim to develop a feasible and precise robotic model with accurate parameters, an efficient identification method based on the coefficient matrix analysis is proposed in this paper. A kinematic model is first developed based on DH method, which is further linearized to obtain the coefficient matrix of robotic parameters. We further analyze the property of this induced matrix, which shows that there are linearly dependent parameters. In this case, this matrix is not full rank, and some parameters in this matrix are redundant in the identification calculation. Based on this observation, the redundancies embedded in the coefficient matrix are analyzed and can be eliminated by removing these coupled parameters. By doing so, the coupling effects in this matrix are diminished and the identifiability of the modified coefficients can be retained. Finally, we propose a parameter identification scheme, which is designed based on the least-square algorithm. This method can estimate the structural parameters of the robot, and thus improve the accuracy and operation precision of the studied robot. Experiments based on a 6 DOF robot system are conducted to verify the identification method and to show the improved performance.

The main contribution of this paper can be briefly summarized as: (1) we determine the coupled parameters in the DH model, and then eliminate the embedded redundancies using the singular value decomposition. (2) By removing the coupled parameters, an iteration calculation is suggested, such that the identification procedure is with less iterations (i.e. only one time iteration calculation is needed), which is verified based on a 6 DOF industrial robot. (3) Different to other available results (e.g. [5]), we do not need to set precise initial parameters in the proposed identification method, e.g. we can set the initial parameters arbitrarily as long as they are not too exaggerated.

The paper is organized as follows. Section 2 presents the modeling of the studied 6 DOF industrial robot system, and the modified identification method. Section 3 gives the practical test results and comparisons based on the 6 DOF industrial robot. Conclusions are provided in Section 4.

2. Modeling and parameter identification

Industrial robots are usually in the form of an open series chain with joints connecting linkages, whose working space is orthogonal. The kinematic model is a mathematical description of the relation between the geometry and the end actuator of the robot in the coordinate system. It is the foundation of the robotic control system and the parameter identification [16]. Thus, we first present the kinematic model of a practical robot, analyze the redundancies in the coefficient matrix and then investigate a parameter identification scheme in this section.

2.1. Kinematic modeling

The structure of the studied industrial robot is shown in Fig. 1. For the ease of application of the results of proposed in this paper in the actual in potential industrial robots, we use DH model to describe the kinematic dynamics because this is the
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