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Closed-loop identification of an industrial robot containing flexibilities

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Abstract

Closed-loop identification of an industrial robot of the type ABB IRB 1400 is considered. Data are collected when the robot is subject to feedback control and moving around axis one. Both black-box and physically parameterized models are identified. A main purpose is to model the mechanical flexibilities. It is found that a model consisting of three-masses connected by springs and dampers gives a good description of the dynamics of the robot.

Keywords: Identification; Robotics; Flexible arms

1. Introduction

System identification is an established modeling tool in engineering and numerous successful applications have been reported. The theory is well developed, see e.g., Ljung (1999) or Söderström and Stoica (1989), and there are powerful software tools available, e.g., the System Identification Toolbox for Matlab (Ljung, 2000). Industrial robots represent an interesting challenge for system identification methods, and an overview of identification in robotics can be found in Kozlowski (1998).

One application area for system identification within robotics is identification of the parameters in the kinematic description of the robot, while a second area deals with the problem of identifying the parameters in the dynamical model of the robot. A third area is to determine the parameters on the joint level including, for example, friction, motor characteristics, etc. Recent results from the latter two areas may be found in, e.g., Wang, Bi, and Zou (1996), Grotjahn, Daemi, and Heimann (2001) and Gautier and Poignet (2001). In these papers it is assumed that the robot is rigid.

In the work presented here, the results of a study of the identification of robots, including flexibilities are presented. This topic has been addressed in, e.g., Dépincé (1998), ElMaraghy, ElMaraghy, Zaki, and Massoud (1994), Nissing and Polzer (2000), Albu-Schäffer and Hirzinger (2001), Berglund and Hovland (2000), Johansson, Robertsson, Nilsson, and Verhaegen (2000), Pham, Gautier, and Poignet (2001) and Östring, Gunnarsson, and Norrlöf (2001). The problem considered in Berglund and Hovland (2000) is closely related to the work reported below, but the proposed solution is based on frequency domain identification in combination with the solution of an eigenvalue problem. In Johansson et al. (2000), time domain identification methods of the black-box type are applied, which means that no physical parameters are obtained directly from the identification. The work presented in Albu-Schäffer and Hirzinger (2001) deals with the identification of a lightweight robot with seven degrees of freedom, and the results involve identification of joint elasticity and damping parameters. These are found by applying external excitation on one axis at a time. Also, in Pham et al. (2001) the identification experiments are carried out by moving one axis at a time. The physical parameters sought are obtained as nonlinear functions of the estimates obtained using a model structure that is linear in the parameters.

In the results of the work presented below, which is an extension of the work reported in Östring et al. (2001), a method is proposed in which inertial parameters and parameters describing flexibility, can be identified directly in the time domain. This is done by utilizing a user-defined model structure in the System Identification Toolbox. As far as the authors know, this approach has

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not been reported previously within the area of robot identification. The work presented is carried out under simplifying conditions. First, only movements around axis one are considered. Second, all experiments are carried out with the other axes in one position. Third, only a linear model structure is considered, which means that, for example, only viscous friction is included in the model. It should be noted that although the model is linear in the states it is not linear in the parameters. The simplifying assumptions can be motivated in different ways. First, the work presented can be seen as a feasibility study carried out in order to see whether or not this is a possible approach, and to try to go as far as possible with linear models. In some of the references cited above, the identification experiments are carried out on one axis at a time. The importance of the restriction that the identification is carried out on only one operating point is related to the intended use of the model. From the authors viewpoint there are at least two possible uses of the identified model. The first is to use the model for control design on joint level, and the second is to use the model for diagnostic purposes. In both cases, two ways to extend the approach can be considered. One way is to identify linear time-invariant models in a number of operating points and use gain scheduling in the control or diagnostic functions. A second alternative is to move to a nonlinear model, where nonlinearity due to variations in operating point is captured. These extensions are left for future work.

The paper is organized as follows. In Section 2, the robot system under consideration is described briefly, and in Section 3 generation and pre-processing of data before identification, are discussed. In Section 4, a linear three-mass model is derived, and in Section 5 the results from identification using physically parameterized models are presented. For comparison, the system is also identified using black-box model structures, and the results of which are presented in Section 6. Finally, Section 7 contains some conclusions.

2. The robot system

The industrial robot studied is of the type ABB IRB 1400, as shown in Fig. 1. As discussed above the study in this paper is restricted to movements around axis one, since this movement is to a large extent decoupled from the other axes.

The IRB 1400, which is one of the smaller members in the ABB family, is a six-degrees-of-freedom robot and carries a load of approximately 5 kg. The maximum speed for the TCP (tool center point) is 2.1 m/s and the maximum acceleration is 15 m/s^2. The robot is equipped with the control system S4C. In addition to the conventional control system, an interface between S4C and Matlab has been used. The interface used to inject and record signals in the robot control system is described in Norrlöf (2000).

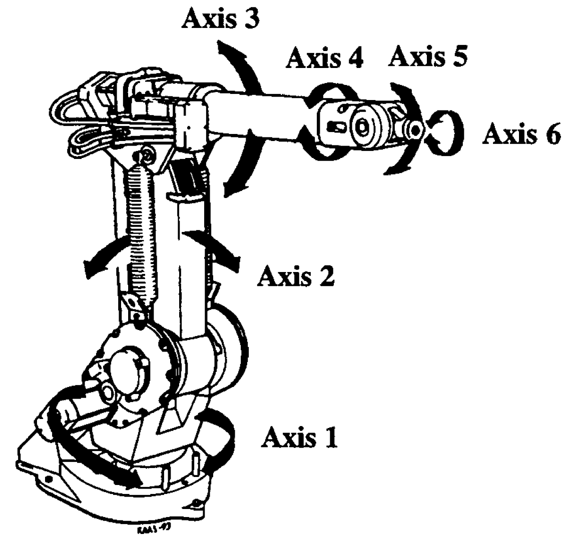

Fig. 1. ABB IRB 1400.

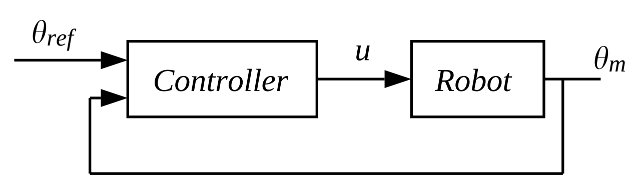

Fig. 2. Block diagram of the robot control system.

3. Data collection and pre-processing

3.1. Implementation issues

The data are collected while the control system is in operation, which means that the identification will be carried out using closed-loop data. The situation is schematically depicted in Fig. 2.

During conventional operation, the desired path is specified using a high level programming language RAPID. In the control system, the desired path and the actual position are used to compute a desired torque, which is sent to the motor drive system. The torque results in a movement of the robot arm via the gear box and the links. Measurements of the actual torque are not available, but, instead, the torque reference of an inner loop, controlling the motor current, is used. Since the inner control loop has high bandwidth, the relationship between torque reference and generated torque can be approximated by a constant. Hence, the signals available for measurement for each joint are the torque (reference) and the motor angle. The data are collected and sent to a PC using the interface between S4C and Matlab.