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Kinematic and dynamic identification of parallel mechanisms☆

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Abstract

In this paper, we provide a comprehensive method to perform the physical model identification of parallel mechanisms. This includes both the kinematic identification using vision and the identification of the dynamic parameters. A careful attention is given to the issues of identifiability and excitation. Experimental results obtained on a H4 parallel robot show that kinematic identification yields an improvement in the static positioning accuracy from some 1 cm down to 1 mm, and that dynamic parameters are globally estimated with less than 10% relative error yielding a similar error on the control torque estimation.

Keywords: Physical model identification; Kinematic identification; Kinematic calibration; Inertial and friction parameters; Parallel mechanisms; Computer vision

1. Introduction

Parallel mechanisms are emerging in the industry (machine-tools, high-speed pick-and-place robots, flight simulators, medical robots, for instance). Indeed, these mechanisms have for main property their end-effector connected with several kinematic chains to their base, rather than one for the standard serial mechanisms. This allows parallel mechanisms to bear higher loads, at higher speed and often with a higher repeatability (Merlet, 2000). However, their large number of links and passive joints often limit their performance in terms of accuracy (Wang & Masory, 1993). Therefore, the kinematic parameters of such mechanisms have to be identified by the so-called kinematic identification (or kinematic calibration).

Moreover, in order to achieve high speed and acceleration for pick-and-place applications or precise motion in machining tasks, an accurate dynamic modeling is usually required. This will also increase the quality of their simulation in order to improve their design and/or to compute advanced model-based robust controllers such as moving horizon control schemes. After completing the kinematic calibration, the second difficulty is then to estimate the physical parameters including mass, inertia and frictions of the dynamic model.

1.1. State of the art

1.1.1. Kinematic identification

There exist several classes of methods to perform kinematic identification of parallel mechanisms (Fig. 1).

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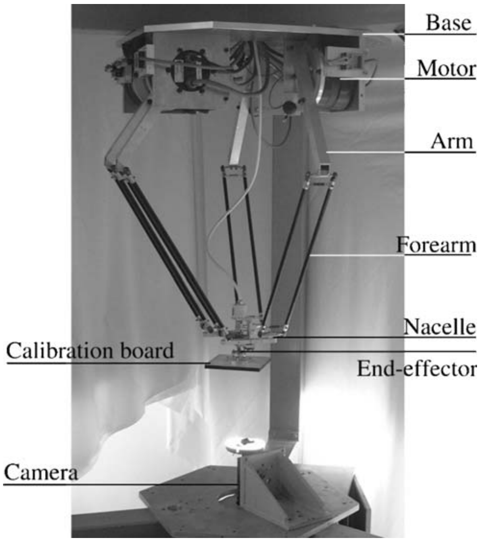

Fig. 1. A typical set-up for vision-based identification of a parallel mechanism: the H4 mechanism (Pierrot et al., 2001) and the vision-based measuring device.

The first one relies on the application of mechanical constraints on the end-effector or the mechanism legs (Daney, 1999; Khalil & Besnard, 1999). This class of methods only needs joint measurements, but is hard to use in practice since applying mechanical constraints requires an accurate extra mechanism. Moreover, such methods reduce the workspace size and therefore the identification efficiency (Besnard & Khalil, 2001). A second class of methods (Khalil & Murareci, 1997; Wampler & Arai, 1992; Zhuang, 1997), known as self-calibration, relies on the notion of redundant metrology: adding extra proprioceptive sensors at the usually uninstrumented joints of the mechanism allows for identification in the whole available workspace and only requires joint measurements. However, it is hard in practice to add these extra sensors on an existing mechanism and sometimes almost impossible (think of a spherical joint).

The third class of methods is based on the forward kinematic model and comes directly from the methods developed for serial mechanisms. Such methods minimize a non-linear error between a measure of the end-effector pose and its estimation from the measured joint values through the forward kinematic model (Masory et al., 1993; Visher, 1996). However, in general, parallel mechanisms only have a numerical evaluation of the latter, which may lead to numerical unstabilities of the identification (Daney, 1999).

On the opposite, for parallel mechanisms, the inverse kinematic model can usually be easily derived (Merlet, 2000). Therefore, the most natural method to perform identification of a parallel mechanism is to minimize an error between the measured joint variables and their corresponding values, estimated from the measured end-effector pose through the inverse kinematic model (Zhuang et al., 1995; Zhuang et al., 1998). This method seems indeed to be the most numerically efficient among the identification algorithms for parallel structures (Besnard & Khalil, 2001). Nevertheless, it is constrained by the need for accurate measurement of the full end-effector pose (i.e. both its position and its orientation). Some adapted measuring devices have been proposed (e.g. laser tracking systems (Koseki et al., 1998; Vincze et al., 1994) or mechanical devices, Geng & Haynes, 1994; Jeong et al., 1999) that are either expensive or limitative as workspace is concerned. Vision could constitute an adequate sensor (Zhuang & Roth, 1996; Zou & Notash, 2001), that we hence propose to use in this article.

1.1.2. Dynamic parameters identification

The experimental identification of serial mechanisms dynamic parameters has been extensively investigated within a statistical framework (Gautier & Poignet, 2001; Olsen & Petersen, 2001). Assuming random measurement errors with known statistical characteristics, the maximum likelihood (ML) estimator makes possible to derive reliable parameter estimates with confidence intervals. Usually the inverse model expressing the motor torque input as a function of the state variables is used to estimate the parameter vector through a weighted least squares (WLS) solution (Gautier & Poignet, 2001) since this model can be linearly written with respect to the parameters to be estimated.

Similarly, the dynamic model of parallel mechanisms can also be expressed in a linear relation with respect to the dynamic parameters. Therefore, in this paper, we focus on the estimation of the dynamic parameters of the rigid multibody closed loop structure: the parameters are estimated by a classical WLS technique. The main difficulty of approach lies in the estimation of the end-effector dynamics.

1.2. Contribution and outline

The main contribution of this paper is to provide the reader with a comprehensive method for identifying the complete physical model of a parallel robot. Hence, we identify the kinematic parameters, describing the geometry of the robot, and the dynamic physical parameters, describing the effects of masses, inertias and friction on the dynamical behavior of the robot.

Two algorithms are given for the vision-based kinematic identification, depending on which of the implicit or the inverse kinematic models is available for a given parallel robot. Using vision allows for unexpensive and accurate measurement of the end-effector position and orientation. A method is also provided for the identification of the dynamic physical