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Journal of The Franklin Institute

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Data-driven model reference control design by prediction error identification ☆

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Received 18 December 2015; received in revised form 21 March 2016; accepted 8 August 2016

Abstract

This paper deals with Data-Driven (DD) control design in a Model Reference (MR) framework. We present a new DD method for tuning the parameters of a controller with a fixed structure. Because the method originates from embedding the control design problem in the Prediction Error identification of an optimal controller, it is baptized as Optimal Controller Identification (OCI). Incorporating different levels of prior information about the optimal controller leads to different design choices, which allows to shape the bias and variance errors in its estimation. It is shown that the limit case where all available prior information is incorporated is tantamount to model-based design. Thus, this methodology also provides a framework in which model-based design and DD design can be fairly and objectively compared. This comparison reveals that DD design essentially outperforms model-based design by providing better bias shaping, except in the full order controller case, in which there is no bias and model-based design provides smaller variance. The practical effectiveness of the design methodology is illustrated with experimental results.

☆The material in this paper was partially presented at the IFAC Symposium on System Identification 2012 – SYSID'12, July 11–13, 2012, Brussels, Belgium.

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http://dx.doi.org/10.1016/j.jfranklin.2016.08.006

1. Introduction

In the past two decades, a number of data-driven (DD) methods have been proposed for control design [1–4] and for fault diagnosis [5–7]. In DD control design, a parametrized controller structure is chosen *a priori*, and the controller tuning is based directly on input and output data collected on the plant without the use of a model of this plant. These methods are typically based on the Model Reference (MR) paradigm, in which the desired closed-loop performance is specified by means of a target closed-loop transfer function – the Reference Model. Some of these methods, like Iterative Feedback Tuning [1,2] and Correlation-based Tuning (CbT) [4] are iterative in nature: the optimal controller is obtained as a sequence of controllers that operate on the actual plant, and experimental data are collected on the corresponding sequence of closed-loop plants. Other methods are “one-shot” – that is, non-iterative: they directly estimate the controller parameters on the basis of only one batch of input–output data; Virtual Reference Feedback Tuning (VRFT) [3] and a non-iterative version of CbT [8] are representative of this class. A common theoretical framework for these data-driven methods is provided in [9].

In this paper we present a new “one-shot” DD control design methodology, which is also based on the Model Reference paradigm. In our method the input–output model of the system is replaced from the outset by an equivalent input–output description involving only parameters of the controller. With this new parametrization, the estimation of the controller parameters is embedded in a completely standard Prediction Error (PE) identification problem, in which the inverse of the controller is identified. As a consequence, a complete statistical analysis of the estimated controller can be provided. An immediate consequence of PE identification theory is that the ideal model reference controller can be identified without bias if the controller structure chosen for the controller is of full order,[1] provided that open-loop data are used. The same holds with closed-loop data provided that a full order noise model is also identified. In the non-ideal case where the controller structure is not of full order (that is, the specified performance can only be approximated with this controller structure), the standard results from PE identification can be used to characterize the bias of the resulting controller.

An inherent property of the MR framework is the existence of an a priori algebraic relationship between the unknown plant, the known reference model, and the ideal controller (the one that would provide exactly the desired closed-loop performance). A similar relationship exists between the known reference model, a parametric model of the plant, and the parametric controller that would provide the desired closed-loop performance with this model. A major contribution of this paper, in which the controller rather than the model is identified, is to show that the existence of this relationship and of the desired reference model allows us to propose a range of possible design choices for the parametrization of the controller. These different design choices consist of incorporating different levels of prior knowledge about the ideal controller in a fixed part of the controller structure, resulting in a parametric part of varying complexity. In other words, the parametric part of the controller, which needs to be estimated by prediction error identification, will have different numbers of parameters depending on the design choices. These design choices can then be made to shape the bias and variance of the controller estimate, since bias and variance error depend very much on the flexibility of the controller structure, i.e. on the number of its parameters. Exploring these design choices and the resulting statistical properties for each one also provides a framework that allows a meaningful comparison of DD design with

[1]That is, if it is possible to achieve exactly the specified performance with this structure.

Please cite this article as: L. Campestrini, et al., Data-driven model reference control design by prediction error identification, Journal of the Franklin Institute. (2016), http://dx.doi.org/10.1016/j.jfranklin.2016.08.006