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Data driven discrete-time parsimonious identification of a nonlinear state-space model for a weakly nonlinear system with short data record ☆

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ABSTRACT

Many real world systems exhibit a quasi linear or weakly nonlinear behavior during normal operation, and a hard saturation effect for high peaks of the input signal. In this paper, a methodology to identify a parsimonious discrete-time nonlinear state space model (NLSS) for the nonlinear dynamical system with relatively short data record is proposed. The capability of the NLSS model structure is demonstrated by introducing two different initialisation schemes, one of them using multivariate polynomials. In addition, a method using first-order information of the multivariate polynomials and tensor decomposition is employed to obtain the parsimonious decoupled representation of the set of multivariate real polynomials estimated during the identification of NLSS model. Finally, the experimental verification of the model structure is done on the cascaded water-benchmark identification problem.

1. Introduction

There is an evident need of good system modelling techniques in many branches of engineering. Mathematical (linear or nonlinear) models are needed in various applications, for example, to understand and analyse the system under test, to simulate or predict the behavior of the system during the design phase or to design and implement a controller. System identification provides us with a variety of methods to derive accurate mathematical descriptions of the underlying system, based on a set of input/output measurements. Amount and quality of data plays an important role in any system identification framework. In some cases, increasing the measurement time is either not possible for example, when the input cannot be chosen and the system is unstable, the output can be exponentially growing. This essentially restricts the measurement time. Similarly, a major challenge is present in the study of systems whose behavior varies nonlinearly with time or task, resulting in small data records, or data that can be considered stationary for only short periods of time.

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1.1. Nonlinear system identification

The recent years have witnessed the shift from linear system identification [1–3] to nonlinear system identification methods, driven by the need to capture the inherent nonlinear effects of real-life systems [4–8]. Nonlinear system identification constantly faces the challenge of deciding between the complexity of the fitted model and its parsimony. Flexibility refers to the ability of the model to capture complex nonlinearities, while parsimony is its ability to possess a low number of parameters.

A general framework for nonlinear system identification does not exist [9], however, modeling nonlinear systems is covered in different fields like statistical learning and machine learning [10–14], but most of these methods are typically not specifically developed to deal with dynamics and often have limited means for dealing with noise. Within the system identification community two major approaches to nonlinear system identification can be distinguished: black-box nonlinear system identification [15–17] and block-oriented system identification [18,19].

State-space models are general representations that allow one to describe a variety of systems. In particular, nonlinear state-space modeling represents a promising, and at the same time challenging, class of techniques. In this paper, we focus mainly on black-box identification of nonlinear state space model (NLSS) structures [20,21].

The main contribution of this paper is the proposal of a data-driven nonlinear modelling methodology based on the initialisation methods proposed by [20,22] and the decoupling method proposed by [23], for the identification of nonlinear state-space models for the cascaded water-tanks benchmark problem [24]. The effect of various factors affecting the suitability and the performance of these methods to capture the dynamical behaviour of the cascaded water-tanks benchmark problem is also discussed.

This paper is organised in the following Sections: Section 2 describes an example of weakly nonlinear system i.e. cascaded water-tanks benchmark, identification challenges associated with this benchmark problem. Section 2.1 gives an introduction to the experimental set-up. Thereafter the measurement methodology used for the acquisition of the signals is discussed. Section 3 describes the nonlinear modelling approach using the NLSS model structures used in this paper. The identification of NLSS model along with two different initialisation schemes is described Section 4. Section 5 provides an overview of the final objective functions, which are minimised using two different initialisation schemes. The method to obtain the parsimonious representation of Polynomial Nonlinear State Space model is presented in Section 6. Results are presented in Section 7, and finally, the conclusions are given in Section 8.

2. Cascaded water tanks system

The cascaded tanks system is a liquid level control system consisting of two tanks with free outlets fed by a pump (see Fig 1). The input signal controls a water pump that pumps the water from a reservoir into the upper water tank. The water of the upper water tank flows through a small opening into the lower water tank, and finally through a small opening

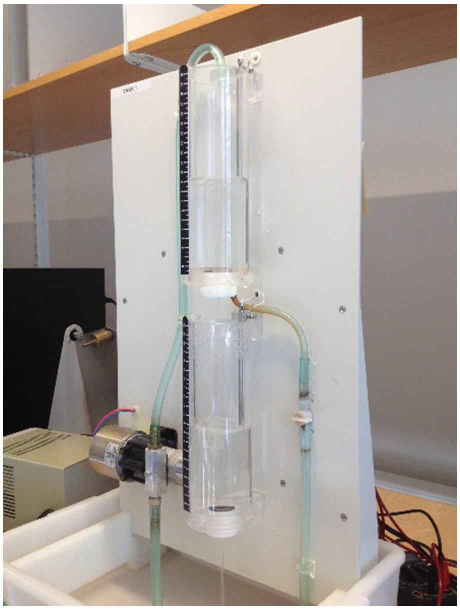

Fig. 1. The water is pumped from a reservoir in the upper tank, flows to the lower tank and finally flows back into the reservoir. The input is the pump voltage, the output is the water level of the lower tank.

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