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Black- and white-box approaches for cascaded tanks benchmark system identification

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ABSTRACT

This contribution consists of the identification and comparison of different models for a non-linear system: the Cascaded Tanks system. The identification of this system is challenging due to the combination of soft and hard non-linearities. Model structures with different levels of flexibility and prior knowledge are compared. The most simple ones are linear black-box models. They are extended to become non-linear black-box models, whose performances are compared with the linear ones. A second track is the investigation of a series of models with increasing complexity based on physical prior knowledge. Results show that while linear black-box models perform good in prediction, a fairly precise description of the non-linear effects is needed to achieve good performances in simulation. All models have been estimated and validated using benchmark data from a real cascaded tanks system. The contribution represents also an overview on how standard modelling techniques perform on a real identification problem.

1. Introduction

The system under study has been presented at the Workshop on Non-linear System Identification Benchmarks [1]. It is a fluid level control system consisting of two tanks with free outlets fed by a pump. 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 from the lower water tank back into the reservoir, see Fig. 1. The input–output relations of the system can be constructed based on Bernoulli's principle and conservation of mass [2] when no overflow occurs,

$$\dot{x}_1(t) = -k_1\sqrt{x_1(t)} + k_4u(t) \quad (1)$$

$$\dot{x}_2(t) = k_2\sqrt{x_1(t)} - k_3\sqrt{x_2(t)} \quad (2)$$

$$y(t) = x_2(t) \quad (3)$$

where $x_1(t)$ and $x_2(t)$ are the water level in the upper and lower tank (states of the system) respectively, $u(t)$ is the voltage of the pump (input signal), and $k_1,\ k_2,\ k_3,\ k_4$ are constants depending on the geometry of the system and on the Earth's gravitational acceleration.

Due to the presence of the square root operator, the relations describing the water flows are weakly non-linear functions. However, when the amplitude of the input signal is too large, an overflow can happen in the upper tank, and with a delay

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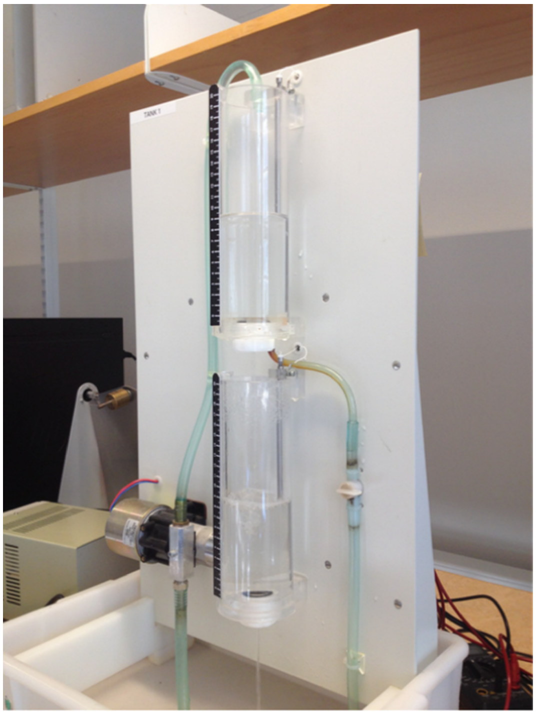

Fig. 1. The cascaded tanks system: the water is pumped from a reservoir in the upper tank, flows to the lower tank and finally flows back into the reservoir. The input is the pump voltage, the output is the water level of the lower tank.

also in the lower tank. When the upper tank overflows, part of the water goes into the lower tank, the rest flows directly into the reservoir. When the lower tank overflows, instead, the water flows directly in the reservoir. Therefore, in this situation, the system shows a hard non-linear behaviour.

In literature, many works deal with the control of cascaded tanks system [3–6], based on simple models build upon physical knowledge and where no identification is involved. In this work, instead, accurate models for the cascaded tanks are developed along two main system identification tracks. The first track is the black-box modelling where, with exception of the dynamic nature of the mathematical relations, both the structure of the model and the parameters of the structure are constructed from the observed data only [7–9]. The second track, instead, is the white-box modelling, where only the parameters are estimated from the data and the structure is found by using basic physical principles. Moreover, in this work, only a short data record is assumed available for identification and the initial conditions of the two water levels are unknown. The lack of big sets of data excludes the use of pure data-driven techniques, such as support vector machine or neural networks. However, simple neural networks are used in the black-box case, in combination with linear models describing the main dynamics of the system.

The aim of this work is also to provide an overview of how standard modelling techniques perform on a real identification problem. The main idea is to start from very simple structures and increase the complexity only if this leads to a clear improvement in the performance. However, all tested approaches assume the dynamical nature of the true system to describe, i.e. both black- and white-box models will be described by differential equations. In this way, the identification method is not pure data-driven and, even in the black-box case, the identified parameters have the potential to describe real physical quantities of the system.

All the derived models are compared on the same benchmark data and the results show that linear black-box models with simple noise models are good enough for prediction purposes, while, for simulation, an accurate description of the non-linearity is more important.

The paper is organized as follows: in Section 2 a description of the benchmark data is presented. In Sections 3 and 4 black- and white- box models are derived. Identification results are presented in Sections 5 and 6 concludes the paper.

2. Data and parameter estimation

The data available for estimation and validation are real experimental data provided by [1] and plotted in Figs. 2 and 3. The input signal consists of 1024 sampled values of a multisine signal containing 60 excited frequencies, in the range 0.0–0.0144 Hz. This holds for both estimation and validation data. The sample period is 4 s. Figs. 4 and 5 show the frequency content of the signals. The water level of the lower tank is measured using capacitive water level sensors. The measured out-

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