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Generating initial estimates for Wiener-Hammerstein systems using phase coupled multisines☆

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Abstract: Block oriented nonlinear models capture the dynamics of a nonlinear system with linear dynamic sub-systems (L), the nonlinear behavior is modelled using static nonlinear sub-blocks (N). In this paper we study the generation of initial estimates for the linear dynamic blocks of a Wiener-Hammerstein system that has a cascaded LNL structure. While it is very easy to identify the product of the transfer functions of the first and last dynamic block using linear system identification methods, it turns out to be very difficult to split the global dynamics over these individual blocks. In this paper a method is proposed that allows the poles of the best linear approximation to be assigned to the first or second linear block. Once this split is made, it is shown in the literature that the remaining initialization problem can be solved much easier than the original one. The first step of the method is the design of a special random phase multisine excitation, using pair-wise coupled random phases. Next, a modfied best linear approximation will be estimated on a shifted frequency grid. It will be shown that this procedure shifts the poles and zeros of the first linear sub-block with a known frequency offset, while those of the second sub-block are not changed. The shifted poles and zeros result in a transfer function with complex coefficients that can be identified using a modified frequency domain estimation method. This results in a simple initialization method, based on a linear system identification step.

Keywords: block oriented nonlinear system, Wiener-Hammerstein model, system identification

1. INTRODUCTION

Nonlinear system identification is much more involved than linear system identification. One of the major issues is the selection of a good model structure. Typical examples are nonlinear state space models or nonlinear ARX (NARX) and ARMAX (NARMAX) models that are well suited to capture the behavior of a dynamic nonlinear systems (Billings, 2013). Many successful applications are described. However, none of the above mentioned methods do perfectly match the needs of the design- and control engineers: typically a (very) large number of model parameters is used, and the models provide very little structural insight into the system behavior, all delayed inputs and outputs are nonlinearly combined. Moreover, the number of possible combinations of parameters grows very fast with the degree of the nonlinearity and the number of taps in the filters. Alternatively, block oriented nonlinear models like those shown in Figure 1 can be used (see also Billings and Fakhouri, 1982). These capture the dynamics of the system using linear dynamic sub-systems (L), while the nonlinear behavior is modelled using static nonlinear sub-blocks (N). This idea matches also with the observation that in many systems, the nonlinearity is localised at a few places in the system, embedded in the remaining linear dynamics. Although the identification of block oriented model structures is a hot topic, the actual state of the art is still struggling with very simple structures: most ($> 90\%$) of the recent publications on block oriented systems still deal with single branch structures consisting of sandwich systems like Wiener (LN), Hammerstein (NL), Wiener-Hammerstein (LNL), and Hammerstein-Wiener (NLN) as shown in Figure 1: a,b,e,f. In the recent edited book of Giri and Bai (2010), none of the 24 contributions was considering more complex systems, while it is known for a long time that structures with parallel branches of LNL systems (see for example Figure 1 h) are strongly needed to approximate a wide class of real-life nonlinear systems with a small(er) number of branches [Pal1979]. Some early attempts to identify parallel structures are reported in Billings and Fakhouri (1982), Hunter and Korenberg (1986), Korenberg (1991). Recently, the effort to identify parallel Hammerstein or Wiener systems (Figure 1 c) is strongly increased because these model structures are nowadays popular in the telecommunication field to linearise power amplifiers. Little or no information is available to identify parallel Hammerstein-Wiener or parallel

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Wiener-Hammerstein, and nonlinear feedback structures as shown in Figure 1 g, h, i) (Schoukens and Rolain, 2012) are hardly discussed in the literature.

The major difficulty in block-oriented identification is the generation of good starting values for the dynamics of the linear blocks, even for the single branch WH-model. Early attemps were published by (Vandersteen and Schoukens, 1999) using a series of very specific experiments. Also in (Haber and Keviczky, 1999), a number of methods is presented to separate the dynamics of the linear blocks, but in each of these methods, a set of nonlinear equations need to be solved. This raises again the problem of finding good initial values to start a numerical search procedure. Recently, it was shown that WH-systems could be modelled as a cascade of well selected Hammerstein-Wiener systems (Wills and Ninness, 2012). Other attempts started from the best linear approximation (BLA) of the nonlinear system, and next the poles and zeros are assigned to the first or second dynamic block of the system using, for example, a brute force scanning method by trying all possible combinations (Sjöberg and Schoukens, 2012).

An attempt to split the poles, using a more systematic procedure is given by Westwick and Schoukens (2012), using a higher order BLA based on the squared or cubed input. It is shown that the poles p_i of the first linear system will shift in this step to $2p_i$ or $3p_i$, while those of the second system remain invariant. This provides a tool to separate both sets. However, due to the higher order nature of the BLA, very long measurements are needed in order to get a sufficient precision. In this paper we will develop a similar approach, but using again the first order BLA in stead of the higher order BLA. Using a well designed excitation signal, we create again a shift of the sytem poles. Because we make no use of higher order BLA's, we can avoid the use of extremely long experiments.

We first will give a formal setup of the problem, followed by an analysis of the best linear approximation for a WH-system using a newly proposed class of excitation signals: the phase coupled multisines. Eventually, some simulation results are shown, followed by experimental results.

2. THE BLA OF A WH-SYSTEM USING RANDOM PHASE MULTISINES

In this section we give a brief introduction to the theory of the best linear approximation of a nonlinear system. We first define the class of systems, the class of excitation signals, and introduce formally the concept of the best linear approximation. Next we deliver explicit expressions for G_{BLA} for a WH-system.

2.1. System

In this paper we focus on a Wiener-Hammerstein single branch block-oriented system as given in Figure 2. It consists of a static nonlinear function f , that is acting

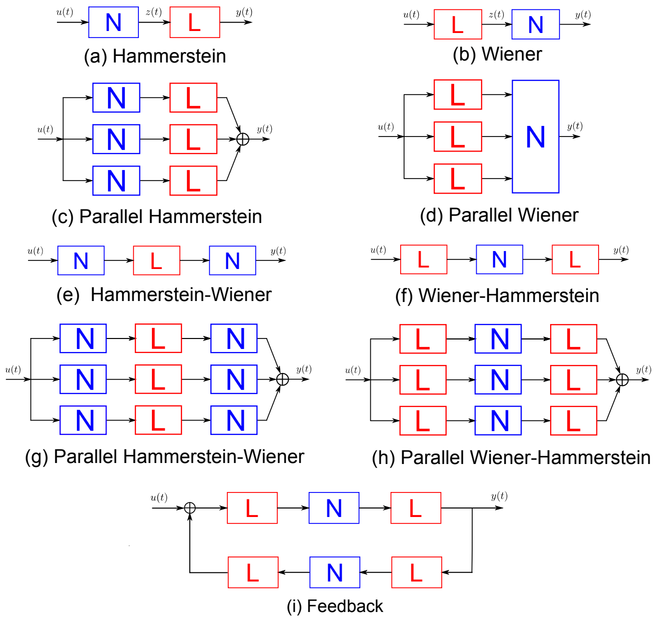

Figure 1: Examples of block-oriented nonlinear model structures.

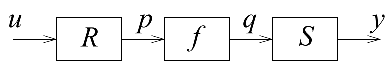

Figure 2: Wiener-Hammerstein system.

on the output of the linear dynamic system R. Its output is passed through the second linear dynamic system S.

In this paper, we consider, without loss of generality, discrete time systems. All results are also valid for continuous time systems. Starting from the measured input and output signal $u(t), y(t)$, with $t = 0, 1, \cdots, N-1$, we need to identify the linear dynamics R, S and the static nonlinearity f. The paper is completely focused on the generation of good initial estimates for R, S. For the moment we assume that there is no disturbing noise, all signals are exactly known. Adding disturbing noise to the output, that is independent of the input, will not change the conclusions of this paper since it is known that the classical least squares framework results in consistent estimates of the BLA under these conditions (Pintelon and Schoukens, 2012).

Define $Y(k), U(k)$ as the discrete Fourier transforms of $u(t), y(t)$, evaluated at the frequencies $k\frac{2\pi}{N}$. The analytic relation between Y, U for a Wiener-Hammerstein system is exactly known for polynomial nonlinearities, for example for a cubic system ($f(p) = p^3$), we have that (Pintelon and Schoukens, 2012):

$$Y(k) = \sum_{l_1=-N/2}^{N/2-1} \sum_{l_2=-N/2}^{N/2-1} \cdots \\ S(k)R(k-l_1-l_2)R(l_1)R(l_2)U(k-l_1-l_2)U(l_1)U(l_2) \quad (1)$$

In this expression we neglected the finite length effects (initial transient in the time domain, leakage in the frequency domain) without loss of generality. This will be done so in the rest of this paper. An alternative expres-