Chapter 4
State and Parametric Estimation of Nonlinear Systems Described by Wiener State-Space Mathematical Models

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ABSTRACT
This chapter deals with the description, the parametric estimation, the state estimation, and the parametric and state estimation conjointly of nonlinear systems. The focus is on the class of nonlinear systems, which are described by Wiener state-space discrete-time mathematical models. Thus, the authors develop a new recursive parametric estimation algorithm, which is based on least squares techniques. The stability conditions of the developed parametric estimation scheme are analyzed using the Lyapunov method. The state estimation problem of the considered nonlinear systems is formulated. Thus, the authors propose a recursive state estimation algorithm, which is based on Kalman Filter. A new recursive algorithm is proposed, which permits one to estimate conjointly the parameters and the state variables of nonlinear systems described by Wiener mathematical models, with unknown parameters and state variables. The efficiency and performance of the proposed recursive estimation algorithms are tested on numerical simulation examples.

1. INTRODUCTION
The development of a mathematical model (an equation or set of equations) to describe correctly a dynamical system is a crucial step before embarking the formulation of a control scheme (Kamoun, 2003). This step can present some difficulties when developing a good mathematical model, especially in the case of nonlinear systems. Indeed, the synthesis of a control law is generally based on the quality of the DOI: 10.4018/978-1-4666-7248-2.ch004
used mathematical model. More works on the description and the parametric estimation of nonlinear systems have been published in the literature (Haber & Keviczky, 1999; Kamoun, 2003; Billings, 2013).

During the past two decades, some approaches to describing the nonlinear systems have been developed, which are based mainly on the concepts of neural networks (Chen & Billings, 1992; Janczak, 2005) and fuzzy logic (Lee & Teng, 2000; Hong & Harris, 2001). In fact, the description of the nonlinear systems on the basis of these new approaches can be carried out by using learning algorithms (back-propagation algorithm, etc.) and from linguistic rules, which can be given by the experts from specific fields (Nelles, 2001).

Problems relating to the description and the estimation of nonlinear systems have preoccupied many researchers over the past three decades. Thus, extensive works have been published in the literature. In this sense, we can mention the works of Haber and Keviczky (1976) and Billings (1980), which are the oldest works dealing with the description and the identification of nonlinear systems.

Identification and control of nonlinear dynamic systems have been widely studied and different model structures and identification and control methods have been reported in the literature. Many models structure are used to describe the nonlinear systems. Several studies related to the estimation of nonlinear systems have been developed by considering different types of mathematical models on the basis of various analytical methods (Haber & Keviczky, 1999; Belforte & Gay, 2001; Vörös, 2002; Zhao & Kanellakopoulos, 2002a, 2002b; Kamoun, 2003). In parallel, other studies dealing with the identification of nonlinear dynamic systems are developed, and that, especially using the concepts of neural networks (Yingwei et al., 1997; Li et al., 2000).

The important developments in several fields of science and technology (information processing, microelectronics, computer engineering, etc.) and the availability of numerical components (DSP cards, calculation software, etc.) with moderate prices have permitted the study of discrete-time mathematical models. Computer systems may be connected, without any difficulty, to dynamic systems which are described by discrete-time mathematical models for the practical implementation (in real time) of estimation and control schemes. In this context, we can use interfacing cards, data acquisition and computer software (MATLAB, etc.), which are related to the estimation and control systems. For example, we can estimate the system parameters by implementation of a recursive parametric estimation algorithm on the basis of the computer software MATLAB. In this chapter, we will focus only on the description, the parametric estimation and the state estimation of nonlinear systems, which can be described by discrete-time mathematical models.

Four types of mathematical models can essentially describe nonlinear systems, namely: the functions series mathematical models, the state-space mathematical models, the input-output mathematical models and the block-oriented mathematical models. Note that the block-oriented mathematical models are widely used in industrial applications. The block-oriented models are often used to describe adequately nonlinear systems, over the entire range of operating conditions. This class of mathematical models is composed of linear dynamic parts and nonlinear static parts. The well-known models of the block-oriented models are the Hammerstein models and Wiener models, which correspond to processes with linear dynamic, but a nonlinear gain (Glaria Lopez & Sbarbaro, 2011).

The structure of Hammerstein mathematical models is consists of a nonlinear static part followed by a linear dynamic part. A Wiener mathematical model is defined as a linear dynamic part precedes a nonlinear static part. These two mathematical models are useful in representing the nonlinearity of a dynamic system without introducing the complications associated with general nonlinear operator (Norquay & Palazoglu, 1998). Hammerstein and Wiener mathematical models reveal the capability