

Preface

St. Augustine of Hippo in *De Civitate Dei* writes
‘Si [...] fallor, sum’ (‘If I am mistaken, I am’)
(book XI, 26)

‘I can therefore gladly admit that falsificationists
like myself much prefer an attempt to solve
an interesting problem by a bold conjecture,
even (and especially) if it soon turns out
to be false, to any recital of a sequence
of irrelevant truisms. We prefer this
because we believe that in this way
we learn from our mistakes; and
that in finding that our
conjecture was false, we
shall have learnt much
about the truth, and
shall have got
nearer to the
truth.’

POPPER, K. 1962
Conjectures and Refutations,
New York: Basic Books, p. 231

Learning from mistakes, that according to Karl Popper brings us closer to the truth and, if prediction errors are interpreted as “mistakes”, it is the basic principle underlying the majority of system identification methods. System identification aims at the construction of mathematical models from prior knowledge of the system under study and noisy time series data. Essentially, system identification is an art of modeling, where appropriate choices have to be made concerning the level of approximation given the final modeling objective and given noisy data. The scientific methods described in this book and obtained from statistics and system theory may help to solve the system identification problem in a systematic way. In general, system identification consists of three basic steps: experiment design and data acquisition, model structure selection and parameter estimation, and model validation. In the past, many methods have been developed to support each of these steps. Initially, these methods were developed for each specific case. In the seventies, a more systematic approach to system identification arose with the start of the IFAC Symposia on Identification and System Parameter Estimation and the appearance of the books of Box and Jenkins on Time Series Analysis (1970), of Schweppe on Uncertain Dynamic Systems (1973) and Eykhoff’s book on System Identification (1974). Since then some ten books and many, most technical, papers have appeared on identification. Especially, the books of Norton entitled ‘An Introduction to Identification’ (1986) and Ljung’s ‘System Identification—Theory for the User’ (1987, 1999) became widely used introductory text books for students, at several levels. However, still the problem of system identification has not been completely solved. Consequently, nowadays new ideas and methods to solve the system identification problem or parts of it are introduced.

This book is designed to help students and practitioners to understand the system identification process, to read the identification literature and to make appropriate choices in this process. As such the identified mathematical model will help to gain insight into processes, to effectively design experiments, to make better predictions or to improve the performance of a control system.

In this book the starting point for identification is the prior system knowledge, preferably in terms of a set of algebraic or differential equations. This prior knowledge can often be found in text books or articles related to the process phenomena under study. In particular, one may think of constitutive laws from physics, chemistry, biology and economics together with conservation laws, like material and population balances. Hence, the focus of this book is basically on ‘semi-physical’ or ‘grey-box’ modeling approaches, although data-based modeling approaches using transfer function descriptions of the system are treated at an introductory level, as well. However, the reader will not find any data-based methods related to fuzzy models, neural nets, support vector machines and the like, as these require detailed specialist knowledge and as such can be seen as special nonlinear regression structures.

The methods described in this book are not treated at a thoroughly advanced mathematical level, and thus no attention will be paid to asymptotic theory; the book is essentially problem oriented using finite input–output data. As such, the contents of the book range from classical (frequency domain) to modern (time domain) identification, from static to dynamic, from linear to nonlinear and from time-invariant

to time-varying systems. Hence, for reading this book, an elementary knowledge of matrix algebra and statistics suffices. For more technical identification books, which focus on, for instance, asymptotic theory, nonlinear regression, time series analysis, frequency domain techniques, subspace identification, H_∞ -approaches, infinite-dimensional systems and the increasing popularity of Bayesian estimation methods, we refer to the literature, as indicated at the end of each chapter. In this book these subjects are covered at an elementary level and basically illustrated by simple examples, so that every reader is able to redo the estimation or identification step. Some examples are more complex, but these have been introduced to demonstrate the practical applicability of the methods. All the more complex examples have been derived from ‘real-world’ physical/chemical applications with, in most cases, a biological component. Moreover, in all these applications heat, mass (in particular, water vapor, carbon, nitrogen and oxygen concentration) or momentum transfer processes play a key role. A list of all examples can be found in the subject index. Some of the sections and subsections have been marked with an asterisk (*) in the title, indicating useful background material related to special topics. This material, presented at a more advanced level, can be easily skipped without losing sight of the main stream of system identification methods for practical use.

The book is structured as follows. First, some introduction into system theory, and in particular on model representations and model properties, is given. Then, in Part I the focus is on data-based identification, also known as the non-parametric methods. These methods are especially useful when the prior system knowledge is very limited and only good data sets are available. Essentially, the basic assumptions are that the dynamic system is linear and time-invariant, properties that are further explained in the Introduction. Part II focuses on time-invariant system identification methods, assuming constant parameters. We start with classical linear regression related to static, time-invariant systems and end this part with the identification of nonlinear dynamic systems. In Part III, the emphasis is on time-varying system identification methods, which basically rely on recursive estimation techniques. Again, the approach is from linear to nonlinear and from static to dynamic. In Part IV, model validation techniques are discussed using both the prior knowledge and the noisy time series data. Finally, the book contains appendices with background material on matrix algebra, statistics, integral transforms, Bode diagrams, shift operator calculus and the derivation of the recursive least-squares method. In addition to this, Appendix G contains hourly measurements of the dissolved oxygen (DO) concentration in g/m^3 , the saturated dissolved oxygen concentration (C_S) in g/m^3 and the radiation (I) in W/m^2 , from the lake ‘De Poel en ’t Zwet’, situated in the western part of the Netherlands, for the period 21–30 April 1983.

Solutions to the first problems of each chapter are presented in a password-protected online solutions manual, for the convenience of both the student and the tutor. Each solution, as a supplement to the many examples, is extensively described to give further insight into the problems that may appear in the identification of uncertain static or dynamic systems. For those who are starting at a very elementary level, it is recommended to study the many examples given in this book for a thorough grounding in the subject.

Finally, I would like to end this preface with a suggestion to the reader. Try to read the book as a road map for anybody who wants to wander through the diverse system identification landscape. No cycle path, let alone bush tracks, only the main roads are indicated with some nice, almost picturesque stops, which are the many simple examples that brighten up the material. Enjoy your trip!

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