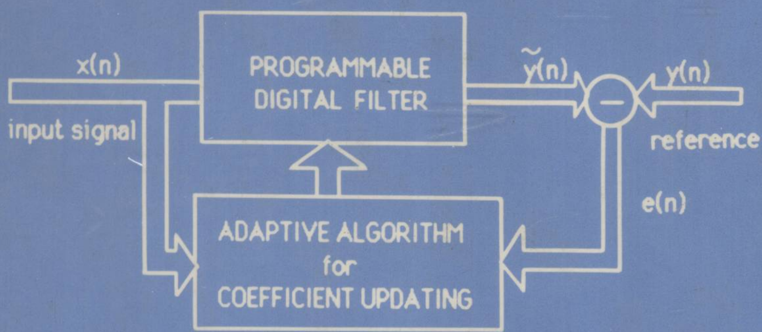
Adaptive Digital Filters and Signal Analysis



Maurice G. Bellanger

Adaptive Digital Filters and Signal Analysis

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Adaptive Digital Filters and Signal Analysis

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To the many friends in industry and research who made it possible to write this book.

Preface

The main idea behind this book, and the incentive for writing it, is that strong connections exist between adaptive filtering and signal analysis, to the extent that it is not realistic—at least from an engineering point of view—to separate them. In order to understand adaptive filters well enough to design them properly and apply them successfully, a certain amount of knowledge of the analysis of the signals involved is indispensable. Conversely, several major analysis techniques can be made really efficient and useful in products only when designed and implemented in an adaptive fashion. It seemed worthwhile to dedicate a book to the intricate relationships between these two areas. Moreover, the approach can lead to new ideas and new techniques in either field.

The areas of adaptive filters and signal analysis use concepts from several different theories, among which are estimation, information, and circuit theories, in connection with sophisticated mathematical tools. As a consequence, they present a problem to the application-oriented reader. However, if these concepts and tools are introduced with adequate justification and illustration, and if their physical and practical meaning is emphasized, they become easier to understand, retain, and exploit. The work has therefore been made as complete and self-contained as possible, presuming a background in discrete time signal processing and stochastic processes.

The book is organized to provide a smooth evolution from a basic knowledge of signal representations and properties, to simple gradient algorithms, to more elaborate adaptive techniques, to spectral analysis methods, and finally to implementation aspects and applications. The characteristics of determinist, random, and natural signals are given in Chapter 2, and fundamental results for analysis are derived. Chapter 3 concentrates on the correlation matrix and spectrum and their relationships; it is intended to familiarize the reader with concepts and properties which have to be fully understood for an in-depth knowledge of necessary adaptive techniques in engineering. The gradient or least mean squares (LMS) adaptive filters are treated in Chapter 4. The theoretical aspects, engineering design options, finite word-length effects, and implementation structures are covered in turn. Chapter 5 is entirely devoted to linear prediction theory and techniques, which are crucial in deriving and understanding fast algorithms operations. Fast least squares (FLS) algorithms of the transversal type are derived and studied in Chapter 6, with emphasis on design aspects and performance. Several complementary algorithms of the same family are presented in Chapter 7 to cope with various practical situations and signal types. Time and order recursions which lead to FLS lattice algorithms are presented in Chapter 8, which ends with an introduction to the unified geometric approach for deriving all sorts of FLS algorithms. The major spectral analysis and estimation techniques are described in Chapter 9, and the connections with adaptive methods are emphasized. Chapter 10 discusses circuits and architecture issues, and a wide range of illustrative applications, taken from different technical fields, are briefly presented, to show the significance and versatility of adaptive techniques.

At the end of several chapters, FORTRAN listings of computer subroutines are given to help the reader start practicing and evaluating the major techniques.

The book has been written with engineering in mind, so that it should be most useful to practicing engineers and professional readers. However, it can also be used as a textbook and is suitable for use in a graduate course. It is worth pointing out that researchers should also be interested, as a number of new results and ideas have been included which may deserve further work.

I am indebted to many friends and colleagues from industry and research for contributions in various forms and wish to thank them all for their help. For their direct contributions, special thanks are due to J. M. Travassos-Romano from the Laboratoire des Signaux et Systèmes (LSS/ESE), to R. Lamberti from the Institut National des Télécommunications (INT) and to S. Hethuin and C. Evci from the Télécommunications Radioélectriques et Téléphoniques Company (TRT). Stimulating interaction with O. Macchi, M. Benidir and B. Picinbono (LSS/ESE) is also gratefully acknowledged.

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Contents

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Adaptive Filtering and Signal Analysis

Digital techniques are characterized by flexibility and accuracy, two properties which are best exploited in the rapidly growing technical field of adaptive signal processing.

Among the processing operations, linear filtering is probably the most common and important. It is made adaptive if its parameters, the coefficients, are varied according to a specified criterion as new information becomes available. That updating has to follow the evolution of the system environment as fast and accurately as possible, and, in general, it is associated with real-time operation. Applications can be found in any technical field as soon as data series and particularly time series are available; they are remarkably well developed in communications and control.

Adaptive filtering techniques have been successfully used for many years. As users gain more experience from applications and as signal processing theory matures, these techniques become more and more refined and sophisticated. But to make the best use of the improved potential of these techniques, users must reach an in-depth understanding of how they really work, rather than simply applying algorithms. Moreover, the number of algorithms suitable for adaptive filtering has grown enormously. It is not unusual to find more than a dozen algorithms to complete a given task. Finding the best algorithm is a crucial engineering problem. The key to properly using adaptive techniques is an intimate knowledge of signal makeup. That is why signal analysis is so tightly connected to adaptive processing. In reality, the class of the most performant algorithms rests on a real-time analysis of the signals to be processed.

Conversely, adaptive techniques can be efficient instruments for performing signal analysis: For example, an adaptive filter can be designed as an intelligent spectrum analyzer.

So, for all these reasons, it appears that learning adaptive filtering goes with learning signal analysis, and both topics are jointly treated in this book.

First, the signal analysis problem is stated in very general terms.

1.1 SIGNAL ANALYSIS

By definition a signal carries information from a source to a receiver. In the real world, several signals, wanted or not, are transmitted and processed together, and the signal analysis problem may be stated as follows.

Let us consider a set of N sources which produce N variables $x_0, x_1, \dots, x_{N-1}$ and a set of N corresponding receivers which give N variables $y_0, y_1, \dots, y_{N-1}$, as shown in Figure 1.1. The transmission medium is assumed to be linear, and every receiver variable is a linear combination of

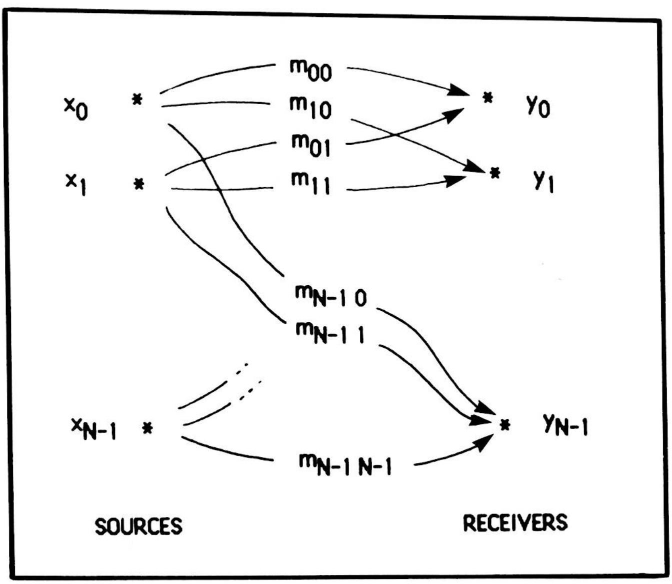

Figure 1.1 A transmission system of order N.