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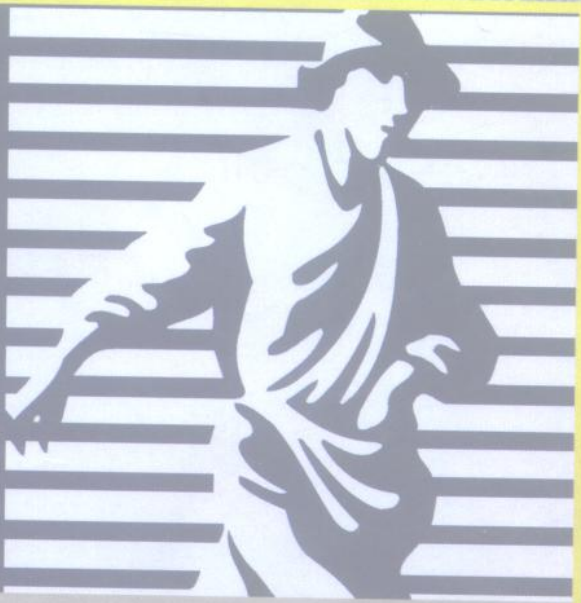

# ADAPTIVE FILTER THEORY

THIRD EDITION

# 自适应滤波器原理（第三版）

〔美〕Simon Haykin 著

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## 内 容 简 介

本书全面系统地论述了自适应滤波器原理。选材得当，论述严谨，逻辑性强，循序渐进。全书共分四个部分，共 20 章。每章末均有丰富的习题，有关章节还有许多计算机实验，用以进一步说明原理和方法。

可作为大学高年级本科生、研究生的教材或教学参考书，也可供工程技术人员参考。



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# 出 版 说 明

近年来，通信与信息科技发展之快和应用之广，大大超出了人们的预料和专家的预测。从国民经济到社会生活的日益信息化，标志着通信与信息科技的空前发展。

为了满足高等院校师生教改和教学的需求以及广大技术人员学习通信与信息新技术的需要，电子工业出版社约请北京地区的清华大学、北京大学、北京航空航天大学、北京邮电大学、北方交通大学，南京地区的东南大学、解放军通信工程学院、南京邮电学院，上海地区的上海交通大学、成都地区的西南交通大学、电子科技大学，西安地区的西安电子科技大学、西安交通大学，天津地区的南开大学，深圳地区的深圳大学，东北地区的哈尔滨工业大学等全国知名高等院校教学第一线上的教授和信息产业部有关科研院所的专家，请他们推荐和反复论证，从国外优秀的英文版教材中精选出版了这套《通信与信息科学教育丛书》（影印版）。

本套丛书可作为高等院校通信、计算机、电子信息等专业的高年级本科生、研究生的教材或教学参考书，也适合广大信息产业技术人员参考。

本套丛书所选取的均是国际上通信与信息科学领域具有代表性的经典名著，它们在全世界许多大学被用作教材或教学参考书。其主要特点是具有较强的先进性、实用性和权威性。丛书内容丰富，深入浅出，层次清楚，理论与应用并重，能够较好地引导读者将现代通信与信息科学的原理、技术与应用有机结合。我们希望本套丛书能够进一步推动国内高等院校教学与国际接轨，同时满足广大技术人员及时学习通信与信息科学领域中新知识的需求。

恳请广大读者提出宝贵意见和建议，以使我们奉献更多、更好的英文影印精品图书。

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1998 年 8 月

This book is dedicated to

- The many researchers whose significant contributions to adaptive filtering have made it possible to write the book.
- The many reviewers, readers, and students who have helped me to improve the book through insightful and critical comments.

# Preface

The subject of adaptive filters constitutes an important part of statistical signal processing. Whenever there is a requirement to process signals that result from operation in an environment of unknown statistics, the use of an adaptive filter offers an attractive solution to the problem as it usually provides a significant improvement in performance over the use of a fixed filter designed by conventional methods. Furthermore, the use of adaptive filters provides new signal-processing capabilities that would not be possible otherwise. We thus find that adaptive filters are successfully applied in such diverse fields as communications, control, radar, sonar, seismology, and biomedical engineering.

## Aims of the book

The primary aim of this book is to develop the mathematical theory of various realizations of *linear adaptive filters with finite-duration impulse response (FIR)* and do the development in a unified manner wherever possible. There is no unique solution to the linear adaptive filtering problem. Rather, we have a "kit of tools" represented by a variety of recursive algorithms, each of which offers desirable features of its own. This book provides such a kit.

Another aim of the book is to provide an introductory treatment of supervised *neural networks*, where the emphasis is on learning. Neural networks represent an emerging technology with a great deal of potential for solving difficult nonlinear adaptive filtering problems.

## Organization of the book

The book begins with an introductory chapter, where the operation of adaptive filters and their practical applications are discussed in general terms. The chapter ends with *histori-*

*cal notes*, which are included to provide a source of motivation for the interested reader to plough through the rich history of the subject. The concepts and algorithms introduced in this chapter are explained in detail in subsequent parts of the book.

The remaining 20 chapters of the book are organized in four parts, as described here:

- *Background material*, consisting of Chapters 1 through 4. This part reviews fundamentals of discrete-time signal processing, characterization of discrete-time stochastic processes in both time and frequency domains, and eigenanalysis. The background material so provided helps the reader to develop a deep understanding of what adaptive filters are all about.
- *Linear optimum filters*, consisting of Chapters 5 through 7. Specifically, the basic theory of Wiener filters, linear prediction, and Kalman filters is developed in detail. Wiener filters and Kalman filters, in their own individual ways, provide the framework for the formulation of linear adaptive filters.
- *Linear adaptive filters*, consisting of Chapters 8 through 17. This third part, by far the largest in the book, presents a detailed treatment of the two important families of linear adaptive FIR filters:
  1. *Least mean-square (LMS) algorithms*, the time-domain and frequence-domain versions of which are covered in Chapters 9 and 10, respectively. The method of steepest descent, related to the Wiener filter and from which the standard LMS algorithm is derived, is discussed in Chapter 8.
  2. *Recursive-least-squares (RLS) algorithms*, the formulation of which is presented in a "unified" manner under the umbrella of Kalman filtering. Specifically, the standard, square-root, and order-recursive forms of the RLS algorithm are discussed in Chapters 13, 14, and 15, respectively. Other related issues, namely, the method of linear least squares for block least-squares filtering and unitary rotations and reflections, are covered in Chapters 11 and 12, respectively. This part of the book finishes with Chapter 16 on finite-precision effects and Chapter 17 on the tracking of linear time-varying systems.
- *Nonlinear adaptive filters*, covered in Chapters 18 through 20. In particular, Chapter 18 discusses the *blind deconvolution* problems and how it can be solved by nonlinear modifications to conventional adaptive filtering algorithms; the use of cyclostationarity for solving the blind equalization problem is also covered here. The remaining two chapters are devoted to *multilayer feedforward neural networks*, with Chapter 19 discussing the multilayer perceptron (MLP) trained with the back-propagation algorithm, and Chapter 20 discussing radial-basis function (RBF) networks.

### Ancillary material

- A total of ten appendices are included on a variety of topics, to provide supporting material for the book.
- A Glossary is included, consisting of a list of definitions, notations and conventions, a list of abbreviations, and a list of principal symbols used in the book.

- All publications referred to in the text are compiled in the Bibliography. Each reference is identified in the text by the name(s) of the author(s) and the year of publication. The Bibliography also includes many other references that have been added for completeness.

### Computer Experiments

The book includes many computer experiments that have been developed to illustrate the underlying theory and applications of the LMS and RLS algorithms. These experiments help the reader to compare the performances of different members of these two families of linear adaptive filtering algorithms.

The reader is invited to verify the results of the computer experiments and use them as a basis for further exploration as he or she sees fit.

### Problems

Each chapter of the book, except for the introductory chapter, ends with problems that are designed to do two things:

- Help the reader to develop a deeper understanding of the material covered in the chapter
- Challenge the reader to extend some aspects of the theory discussed in the chapter

### Manual

The book has an accompanying *manual* composed of two parts:

- The software for all the computer experiments described in this book has been written, using MATLAB. Part I presents the MATLAB code used for this purpose.
- Part II presents detailed solutions to all the problems at the end of Chapters 1 through 20 of the book.

A copy of the Manual can be obtained by instructors who have adopted the book for classroom use by writing directly to the publisher.

The book is written at a level suitable for use in graduate courses on adaptive signal processing. In this context, it is noteworthy that the organization of the material covered in the book offers a great deal of flexibility in the selection of a suitable list of topics for such a graduate course. It is hoped that the book will also be useful to engineers in industry working on problems relating to the theory and applications of adaptive filters.

*Simon Haykin*

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*Simon Haykin*

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