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Vikram Kapila is an associate professor of mechanical engineering at Polytechnic University. He directs an NSF-funded RET Site in Mechatronics and an NSF-funded GK-12 Fellows project. His research interests are in linear and nonlinear control, aerospace control applications, and mechatronics. He has edited one book and published four chapters in edited books and more than 100 journal and conference papers.

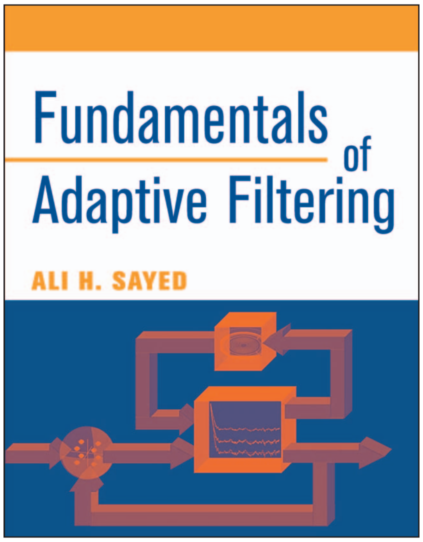
Review of Fundamentals of Adaptive Filtering by Ali H. Sayed, Wiley, 2003, ISBN:0-471-46126-1, US$132. *Reviewed by Phillip A. Regalia.*

Adaptive Filters

Adaptive filters, which aim to transform information-bearing signals into “cleaned up” or “improved” versions, adjust their characteristics according to the signals encountered. They form the simplest examples of algorithms within the field of machine learning. Adaptive filters are often preferred over their fixed-characteristic counterparts, which are fundamentally unable to adjust to changing signal conditions. The convenient autonomous adaptability of adaptive filters explains their widespread application in signal restoration, interference cancellation, system identification, and medical diagnostics, to name just a few areas.

Ubiquitous among the different adaptive filtering algorithms are the least-mean-square (LMS) and recursive least-squares (RLS) approaches. A considerable body of research on these approaches has been developed over the past four decades, enumerated in countless journal papers and textbooks. Indeed, given the nearly exhaustive character of such research into these algorithms, and the plethora of texts on adaptive filters that populate library shelves, academic offices, and research labs, one may legitimately ask: How much more could possibly be written on this subject? The answer is no less than 1,000 pages, according to Prof. Ali H. Sayed, in this remarkable book.

The competition in this arena is tough, leading one to ask what this text offers beyond the standard fare. The short answer is that this work is remarkably up to date, encyclopedic in its historic notes, respectful towards the earlier contributors to the field, and replete with detailed examples and guided homework problems, including an abundance of thoroughly designed computer assignments. The text is well written, detailed, and quite accessible to students and researchers alike.



Contents

The first few chapters present estimation theory as it relates to LS approximation, beginning with optimal estimation in Chapter 1, linear estimation in Chapter 2, and constrained linear estimation in Chapter 3. The opening chapters are quite pedagogical and display keen analytic skill, preparing the reader with the tools and insights necessary to analyze adaptive filtering algorithms and their corresponding signal environments in subsequent chapters.

Steepest descent procedures and the LMS algorithm are developed in Chapters 4 and 5, respectively. Although the material in these chapters may be considered standard, Sayed’s clarity and thoroughness avoid the “dull, overworked” qualifiers that could otherwise be attached to this material. Indeed, the sections on iteration-dependent optimal step sizes, and the illustration of performance in the context of channel estimation and equalization, lend a refreshing perspective since they reinforce the core material in ways not developed in other texts.

Detailed performance analyses account for Chapters 6–9, which address steady-state performance, tracking behavior, finite precision effects, and transient phases, respectively. Although this material has traditionally been handled with complicated analysis requiring dexterity and sophistication, Sayed’s treatment is surprisingly balanced and accessible. Key to this approach is the energy balance relation established for the basic parameter update equation underlying a broad class of algorithms; this relation has fueled much of the research emanating from Prof. Sayed’s laboratory in recent years. The use of energy balance and energy conservation approaches has a rich history in applied mathematics, especially in circuit theory, classical network synthesis, and more recently in $\mathcal{H}_\infty$ control and model reduction. It is fitting, therefore, to apply this approach to adaptive filter analysis. In particular, the energy balance perspective leads to a reasonably unified treatment for the many relations on step-size bounds, excess mean-square error, tracking lag and offsets, finite precision degradation, and initial weight-vector evolution.

Still, one could argue that the analysis as presented assumes an idealized signal model: the minimized modeling error is white and independent of the input regressors, which themselves are assumed to be mutually independent. This long-standing criticism has been levied against many analysis attempts, and considerable debate has ensued over the years concerning the relative merits and drawbacks of alternative approaches, such as averaging theory or stochastic differential equations. Sayed takes a pragmatic road, noting that, for "sufficiently slow" adaptation, the different analysis methods agree more than differ and that experimental results are in good agreement with behavior predicted from the so-called independence assumption. In the spirit of the encyclopedic coverage that characterizes this work, due recognition is given to alternative approaches, including averaging theory, the ordinary differential equation approach, and even the notion of almost sure convergence.

Chapter 10 covers block adaptive filters, which are of interest when seeking efficient implementation of filters with long impulse responses. The text then delves into a comprehensive treatment of LS algorithms. Chapters 11 and 12 develop in detail the LS and RLS formulations, respectively, setting the stage for Chapter 13, which covers array-based implementations. The array forms have been known for many years, usually associated with square-root algorithms that have recognized numerical advantages, but often seem to be relegated to an appendix in other texts. Sayed breaks from tradition by finally putting such array forms in the forefront. This approach is refreshing, not only due to its implementation advantages, but also since many important algebraic relations can be more expediently derived in this framework, as subsequent chapters amply demonstrate.

Fast LS algorithms form the basis of the next three chapters, starting with transversal filters in Chapter 14, and moving to lattice and Laguerre filters in Chapters 15 and 16. "Fast" in this context refers to the computational complexity of this algorithm class, which is linear in the number of adjustable filter parameters, as opposed to conventional LS algorithms whose complexity is quadratic in the number of parameters. The subject has a rich history dating back nearly 30 years, beginning with so-called transversal-based filters, which directly adjust the impulse response terms of a tapped delay line filter structure. Sayed's treatment of fast transversal-based filters is fairly clear and coherent, which is no small feat given the notational nightmares that this subject often conjures even for experienced DSP engineers.

Throughout their history, fast algorithms have been tainted by numerical instability problems that were observed early on; these problems initially put such algorithms into ill repute. Sayed's treatment certainly notes these difficulties, but rather than offering heuristic or "hand-waving" partial remedies that have permeated the technical folklore over the decades, he instead brings forward works that demystify the true origins of this problem. This, in turn, lends a much-improved understanding to some partial successes in stabilizing this algorithm class. In short, instability is not inherent to fast LS algorithms but regrettably afflicts fast transversal-based algorithms due to unstable "parasitic" dynamics that are excited only in finite precision arithmetic.

Alternative classes of fast algorithms are not afflicted by these unstable dynamics; most notable are lattice algorithms, which are covered in Chapter 15. Here Sayed displays his pedagogical skill by reducing a set of complicated relations to a sequence of well-reasoned manipulations using the array algorithm framework developed earlier in the text. An added bonus is that, unlike most treatments of the subject, this development is not limited to regressor vectors displaying the so-called shift structure. This generalization sets the stage for Laguerre-based adaptive filtering algorithms, which extend some of the power of orthonormal basis functions to linear adaptive filtering. These three chapters on fast LS algorithms constitute one of the more complete catalogues of available algorithms, which clearly situates this work as a valuable reference text.

The closing chapter of the book reexamines robustness issues in adaptive filtering algorithms. This consideration is important when confronted with unknown signals and disturbances. The favored development measures the extent to which estimation errors are influenced by the presence of disturbances in the signal and seeks to minimize this measure. Readers familiar with robust control will recognize the $\mathcal{H}_\infty$ flavor of this setting. Interestingly, many of the algorithms in the previous chapters can be shown to be $\mathcal{H}_\infty$-optimal solutions once the appropriate weighting matrix is identified. This final chapter distinguishes this book from others in adaptive signal processing and adaptive control.

Conclusions

Inevitably, one can find specific faults within this work. Although Sayed's attention to detail is commendable, this attention results in perhaps too many footnotes for specific points that, on occasion, could have been merged into the main text for improved continuity. On a lesser level, the size of this book (1,125 pages) may prove daunting to prospective instructors considering it as a course text, not to mention students who may fear having to lug this volume around. The book does include, however, detailed guidelines on how the various chapters can be structured into a one-semester or two-semester course, with provisions for adapting the material according to the audience's level. In this sense, the size of the volume may be considered a testament to the versatility and adaptability of its contents.

In summary, Ali Sayed's book is a remarkably clear, accessible, and up-to-date text. It is highly recommended for students at the graduate level, and it is an invaluable and comprehensive reference text in the field of adaptive filtering for researchers at all levels.

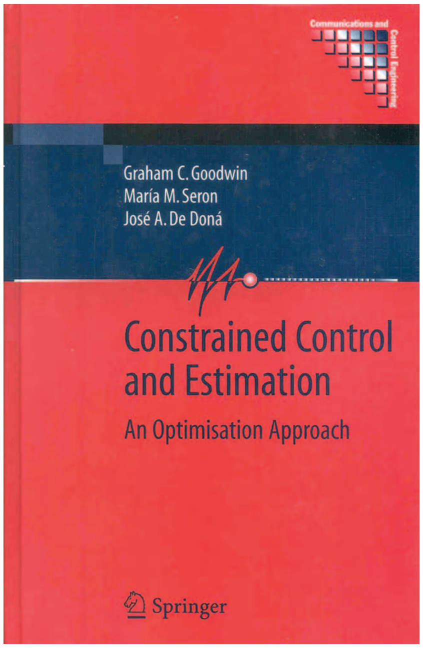
Phillip A. Regalia received the Ph.D. degree in electrical and computer engineering from the University of California at Santa Barbara in 1988 and the Habilitation à Diriger des Recherches from the University of Paris-Orsay in 1994. His research interests include adaptive filtering, wireless communications, and algorithm design and analysis. He was associate editor for *IEEE Transations on Circuits and Systems II* and *IEEE Transactions on Signal Processing*. He is on the editorial boards of *Signal Processing* and the *EURASIP Journal of Applied Signal Processing,* is a subject editor with the *International Journal of Adaptive Control and Signal Processing*, and editor-in-chief of the *EURASIP Journal of Wireless Communications and Networking*. He is currently with the Electrical Engineering and Computer Science Department of the Catholic University of America in Washington, DC, on leave from the Institut National des Télécommunications in Evry, France. He is a Fellow of the IEEE.

Constrained Control and Estimation: An Optimization Approach by Graham C. Goodwin, María M. Seron, and José A. DeDoná, Springer, 2005, ISBN: 1-8523-3548-3, US$109. *Reviewed by Vincent J. Winstead and Ilya V. Kolmanovsky.*

Background

Once considered only an implementation issue, the subject of control with input and state constraints has recently emerged as an active research area with numerous approaches and directions. Powerful techniques based on receding horizon optimization and model predictive control have been developed for controlling constrained systems. In its basic form, receding horizon optimization applied to a discrete-time system involves computing a control sequence that minimizes a cost function over a finite horizon, where the current state of the system serves as the initial state. The first element of the optimal control sequence is then applied to the system, and the same procedure is repeated at each subsequent time instant.

While the basic ideas have existed for more than 30 years (according to [1]), an understanding of stability and robustness properties as well as computational aspects has evolved significantly in recent years (see [1]–[4] and references therein). Related developments have taken place in the area of receding horizon estimation and fault monitoring (see, for example, [5]). The opportunities for systematic treatment of constrained hybrid systems have greatly contributed to the appeal of receding horizon control methodology [6].



Communications and Control Engineering

Graham C. Goodwin
María M. Seron
José A. De Doná

Constrained Control and Estimation
An Optimisation Approach

Springer

On the application side, receding horizon control techniques have been quite successful in the chemical process industry [7]. In fact, the basic tools have not only been applied but, in part, developed and optimized by the practitioners. In more recent years, the range of feasible applications has expanded to include automotive systems characterized by fast dynamics and limited computational resources. Toward this end, [8], which addresses idle speed control of internal combustion engines with constraints, appears to be one of the first reported automotive applications; several others have been reported in more recent years. Procedures that precompute the receding horizon control law as a function of the system state and store the control for online implementation have been developed to accommodate computational demands (see [3] and references therein). The stored control law is referred to as the explicit form of the receding horizon control law. These procedures are advantageous compared to online optimization for systems with low state dimension.

Contents of the Book

This text covers established previous work as well as recent extensions to the field of constrained optimal control for discrete-time systems. The text is organized in a natural progression from introductory remarks and intuitive observations on control of systems with constraints, to the development of concrete tools for treating constrained optimal control problems for discrete-time systems. It covers fixed horizon and receding horizon problems and develops a framework for solving these and related problems in estimation and output

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