

ADAPTIVE PARAMETER ESTIMATION USING INTERIOR POINT OPTIMIZATION TECHNIQUES: CONVERGENCE ANALYSIS

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ABSTRACT

Interior Point Optimization techniques have recently emerged as a new tool for developing parameter estimation algorithms [1, 2]. These algorithms aim to take advantage of the fast convergence properties of interior point methods, to yield, in particular, fast transient performance. In this paper we develop a simple *analytic center* based algorithm, which updates estimates with a constant number of computation (independent of number of samples). The convergence analysis shows that the asymptotic performance of this algorithm matches that of the well-known least squares filter (provided some mild conditions are satisfied). Some numerical simulations are provided to demonstrate the fast transient performance of the interior point algorithm.

1. INTRODUCTION

Consider the following system:

$$y_i = \mathbf{x}_i^T \mathbf{w}_* + v_i \quad i = 1, 2, \dots$$

where $y_i \in \mathbb{R}$ is the output, $\mathbf{x}_i \in \mathbb{R}^M$ is the input vector, $\mathbf{w}_* \in \mathbb{R}^M$ is the unknown parameter vector and $v_i \in \mathbb{R}$ is additive measurement noise. The parameter estimation problem is to identify the parameter vector \mathbf{w}_* from input/output pairs $\{\mathbf{x}_i, y_i\}$. The same task is also referred to as adaptive system identification and has applications in adaptive filtering [3].

The error measure used most commonly to evaluate the performance of a particular parameter estimate \mathbf{w} is the mean-squared error:

$$\mathcal{F}_n(\mathbf{w}) = \sum_{i=1}^n \lambda^{n-i} [y_i - \mathbf{x}_i^T \mathbf{w}]^2$$

where λ is the forgetting factor typically included to allow the estimation algorithm to adapt to slow changes in the parameter vector \mathbf{w} . It will be helpful to rewrite $\mathcal{F}_n(\mathbf{w})$ in

vector notation,

$$\mathcal{F}_n(\mathbf{w}) = \mathbf{y}_n^T \Lambda \mathbf{y}_n - 2\mathbf{w}_n^T \mathbf{p}_{xy}(n) + \mathbf{w}_n^T \mathbf{R}_{xx}(n) \mathbf{w}_n$$

where

$$\begin{aligned} \mathbf{y}_n &= [y_1, y_2, \dots, y_n]^T, \\ \Lambda &= \text{diag}(\sqrt{\lambda^{n-1}}, \dots, \sqrt{\lambda}, 1), \\ \mathbf{p}_{xy}(n) &= \sum_{i=1}^n \lambda^{n-i} \mathbf{x}_i y_i, \\ \mathbf{R}_{xx}(n) &= \sum_{i=1}^n \lambda^{n-i} \mathbf{x}_i \mathbf{x}_i^T. \end{aligned}$$

$\mathbf{R}_{xx}(n)$ and $\mathbf{p}_{xy}(n)$ are the input signal auto-correlation matrix and the cross-correlation vector of desired and input signal, respectively (both are exponentially weighted). The least-squares solution is obtained by solving $\nabla \mathcal{F}_n(\mathbf{w}) = 0$, which yields

$$\hat{\mathbf{w}}_{LS}(n) = \mathbf{R}_{xx}^{-1}(n) \mathbf{p}_{xy}(n). \quad (1.1)$$

$\hat{\mathbf{w}}_{LS}(n)$ sometimes suffers from poor transient performance due to ill-conditioning of $\mathbf{R}_{xx}(n)$ (caused, for example, from a lack of observation data).

In Section 2 we develop an adaptive estimation algorithm using concepts from interior point optimization. In contrast to other algorithms based on similar ideas [2] our algorithm has a computational complexity that does not increase with the number of samples. In Section 3 we show that the asymptotic performance of our algorithm matches that of the least-squares estimator. Finally, we include some numerical simulations to demonstrate the potential of our algorithm, especially with regard to its transient performance.

2. ALGORITHM IPM

In the optimization theory literature interior point algorithms are often applied to the convex feasibility problem: to find

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Lectures on Adaptive Parameter Estimation C. Richard Johnson, 1988 Adaptive Control Design and Analysis Gang Tao, 2003-07-09 A systematic and unified presentation of the fundamentals of adaptive control theory in both continuous time and discrete time Today adaptive control theory has grown to be a rigorous and mature discipline As the advantages of adaptive systems for developing advanced applications grow apparent adaptive control is becoming more popular in many fields of engineering and science Using a simple balanced and harmonious style this book provides a convenient introduction to the subject and improves one's understanding of adaptive control theory Adaptive Control Design and Analysis features Introduction to systems and control Stability operator norms and signal convergence Adaptive parameter estimation State feedback adaptive control designs Parametrization of state observers for adaptive control Unified continuous and discrete time adaptive control L1 a robustness theory for adaptive systems Direct and indirect adaptive control designs Benchmark comparison study of adaptive control designs Multivariate adaptive control Nonlinear adaptive control Adaptive compensation of actuator nonlinearities End of chapter discussion problems and advanced topics As either a textbook or reference this self contained tutorial of adaptive control design and analysis is ideal for practicing engineers researchers and graduate students alike *Lessons from AlphaZero for Optimal, Model Predictive, and Adaptive Control* Dimitri Bertsekas, 2022-03-19 The purpose of this book is to propose and develop a new conceptual framework for approximate Dynamic Programming DP and Reinforcement Learning RL This framework centers around two algorithms which are designed largely independently of each other and operate in synergy through the powerful mechanism of Newton's method We call these the off line training and the on line play algorithms the names are borrowed from some of the major successes of RL involving games Primary examples are the recent 2017 AlphaZero program which plays chess and the similarly structured and earlier 1990s TD Gammon program which plays backgammon In these game contexts the off line training algorithm is the method used to teach the program how to evaluate positions and to generate good moves at any given position while the on line play algorithm is the method used to play in real time against human or computer opponents Both AlphaZero and TD Gammon were trained off line extensively using neural networks and an approximate version of the fundamental DP algorithm of policy iteration Yet the AlphaZero player that was obtained off line is not used directly during on line play it is too inaccurate due to approximation errors that are inherent in off line neural network training Instead a separate on line player is used to select moves based on multistep lookahead minimization and a terminal position evaluator that was trained using experience with the off line player The on line player performs a form of policy improvement which is not degraded by neural network approximations As a result it greatly improves the performance of the off line player Similarly TD Gammon performs on line a policy improvement step using one step or two step lookahead minimization which is not degraded by neural network approximations To this end it uses an off line neural network trained terminal position

evaluator and importantly it also extends its on line lookahead by rollout simulation with the one step lookahead player that is based on the position evaluator Significantly the synergy between off line training and on line play also underlies Model Predictive Control MPC a major control system design methodology that has been extensively developed since the 1980s This synergy can be understood in terms of abstract models of infinite horizon DP and simple geometrical constructions and helps to explain the all important stability issues within the MPC context An additional benefit of policy improvement by approximation in value space not observed in the context of games which have stable rules and environment is that it works well with changing problem parameters and on line replanning similar to indirect adaptive control Here the Bellman equation is perturbed due to the parameter changes but approximation in value space still operates as a Newton step An essential requirement here is that a system model is estimated on line through some identification method and is used during the one step or multistep lookahead minimization process In this monograph we aim to provide insights often based on visualization which explain the beneficial effects of on line decision making on top of off line training In the process we will bring out the strong connections between the artificial intelligence view of RL and the control theory views of MPC and adaptive control Moreover we will show that in addition to MPC and adaptive control our conceptual framework can be effectively integrated with other important methodologies such as multiagent systems and decentralized control discrete and Bayesian optimization and heuristic algorithms for discrete optimization One of our principal aims is to show through the algorithmic ideas of Newton s method and the unifying principles of abstract DP that the AlphaZero TD Gammon methodology of approximation in value space and rollout applies very broadly to deterministic and stochastic optimal control problems Newton s method here is used for the solution of Bellman s equation an operator equation that applies universally within DP with both discrete and continuous state and control spaces as well as finite and infinite horizon

Design Methods of Control Systems D.

Franke,F. Kraus,2014-05-23 These Proceedings contain a selection of papers presented at the first IFAC Symposium on Design Methods of Control Systems The volume contains three plenary papers and 97 technical papers the latter classified under 15 section headings as listed in the contents

Optimal and Adaptive Signal Processing Peter M.

Clarkson,2017-11-01 Optimal and Adaptive Signal Processing covers the theory of optimal and adaptive signal processing using examples and computer simulations drawn from a wide range of applications including speech and audio communications reflection seismology and sonar systems The material is presented without a heavy reliance on mathematics and focuses on one dimensional and array processing results as well as a wide range of adaptive filter algorithms and implementations Topics discussed include random signals and optimal processing adaptive signal processing with the LMS algorithm applications of adaptive filtering algorithms and structures for adaptive filtering spectral analysis and array signal processing Optimal and Adaptive Signal Processing is a valuable guide for scientists and engineers as well as an excellent text for senior undergraduate graduate level students in electrical engineering

Parameter Estimation for Nonlinear

Systems Leehter Yao,1992 **Blind Equalization and Identification** Zhi Ding,Ye Li,2018-10-08 This text seeks to clarify various contradictory claims regarding capabilities and limitations of blind equalization It highlights basic operating conditions and potential for malfunction The authors also address concepts and principles of blind algorithms for single input multiple output SIMO systems and multi user extensions of SIMO equalization and identification *Software Receiver Design* C. Richard Johnson, Jr,William A. Sethares,Andrew G. Klein,2011-08-18 Have you ever wanted to know how modern digital communications systems work Find out with this step by step guide to building a complete digital radio that includes every element of a typical real world communication system Chapter by chapter you will create a MATLAB realization of the various pieces of the system exploring the key ideas along the way as well as analyzing and assessing the performance of each component Then in the final chapters you will discover how all the parts fit together and interact as you build the complete receiver In addition to coverage of crucial issues such as timing carrier recovery and equalization the text contains over 400 practical exercises providing invaluable preparation for industry where wireless communications and software radio are becoming increasingly important A variety of extra resources are also provided online including lecture slides and a solutions manual for instructors **Open Problems in Mathematical Systems and Control Theory** Vincent D. Blondel,Eduardo D. Sontag,Mathukumalli Vidyasagar,Jan C. Willems,2012-12-06 System and Control theory is one of the most exciting areas of contemporary engineering mathematics From the analysis of Watt s steam engine governor which enabled the Industrial Revolution to the design of controllers for consumer items chemical plants and modern aircraft the area has always drawn from a broad range of tools It has provided many challenges and possibilities for interaction between engineering and established areas of pure and applied mathematics This impressive volume collects a discussion of more than fifty open problems which touch upon a variety of subfields including chaotic observers nonlinear local controllability discrete event and hybrid systems neural network learning matrix inequalities Lyapunov exponents and many other issues Proposed and explained by leading researchers they are offered with the intention of generating further work as well as inspiration for many other similar problems which may naturally arise from them With extensive references this book will be a useful reference source as well as an excellent addendum to the textbooks in the area Digital Signal Processing with Examples in MATLAB Samuel D. Stearns,Donald R. Hush,2016-04-19 Based on fundamental principles from mathematics linear systems and signal analysis digital signal processing DSP algorithms are useful for extracting information from signals collected all around us Combined with today s powerful computing capabilities they can be used in a wide range of application areas including engineering communicati **Making Innovations Happen (National Innovation Conclave, NIC 2015)** Prof. (Dr.) P.B. Sharma,Prof. (Dr.) Padmakali Banerjee,Prof. (Dr.) Jai Paul Dudeja,Prof. (Dr.) Priti Singh,Dr. Ranjeet K. Brajpuriya,2015-10-01 The proceedings of this conclave include invited talks from nearly a dozen persons of eminence from across the country including the Industry academia and the Government organisations This Conclave Brought

together all the stake holders viz Industry Academic Innovators Entrepreneurs R D organisations and Policy makers to synergistically discuss share display and learn about the cutting edge innovations and technologies that can help enhancing the productivity improve quality of production enhance self reliance and act as a catalyst to the economic growth of the country

Fuzzy Control and Identification John H. Lilly, 2011-03-10 This book gives an introduction to basic fuzzy logic and Mamdani and Takagi Sugeno fuzzy systems The text shows how these can be used to control complex nonlinear engineering systems while also suggesting several approaches to modeling of complex engineering systems with unknown models Finally fuzzy modeling and control methods are combined in the book to create adaptive fuzzy controllers ending with an example of an obstacle avoidance controller for an autonomous vehicle using modus ponendo tollens logic

Intelligent Control Christopher John Harris, Chris G. Moore, Martin Brown, 1993 With increasing demands for high precision autonomous control over wide operating envelopes conventional control engineering approaches are unable to adequately deal with system complexity nonlinearities spatial and temporal parameter variations and with uncertainty Intelligent Control or self organising learning control is a new emerging discipline that is designed to deal with problems Rather than being model based it is experiential based Intelligent Control is the amalgam of the disciplines of Artificial Intelligence Systems Theory and Operations Research It uses most recent experiences or evidence to improve its performance through a variety of learning schemas that for practical implementation must demonstrate rapid learning convergence be temporally stable be robust to parameter changes and internal and external disturbances It is shown in this book that a wide class of fuzzy logic and neural net based learning algorithms satisfy these conditions It is demonstrated that this class of intelligent controllers is based upon a fixed nonlinear mapping of the input sensor vector followed by an output layer linear mapping with coefficients that are updated by various first order learning laws Under these conditions self organising fuzzy logic controllers and neural net controllers have common learning attributes A theme example of the navigation and control of an autonomous guided vehicle is included throughout together with a series of bench examples to demonstrate this new theory and its applicability

Mechanical Engineers' Handbook, Volume 2 Myer Kutz, 2015-02-02

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Fifty Years of Fuzzy Logic and its Applications Dan E. Tamir, Naphtali D. Rishe, Abraham Kandel, 2015-05-23 This book presents a comprehensive report on the evolution of Fuzzy Logic since its formulation in Lotfi Zadeh's seminal paper on fuzzy sets published in 1965 In addition it features a stimulating sampling from the broad field of research and development inspired by Zadeh's paper The chapters written by pioneers and prominent scholars in the field show how fuzzy sets have been successfully applied to artificial intelligence control theory inference and reasoning The book also reports on theoretical issues features recent applications of Fuzzy Logic in the fields of neural networks clustering data mining and software testing and highlights an important paradigm shift caused by Fuzzy Logic in the area of uncertainty management Conceived by the editors as an academic celebration of the fifty years anniversary of the 1965 paper this work is a must have for students and researchers willing to get an inspiring picture of the potentialities limitations achievements and accomplishments of Fuzzy Logic based systems

European Control Conference 1995, 1995-09-05 Proceedings of the European Control Conference 1995 Rome Italy 5-8 September 1995

Evolving Intelligent Systems Plamen Angelov, Dimitar P. Filev, Nik Kasabov, 2010-03-25 From theory to techniques the first all in one resource for EIS There is a clear demand in advanced process industries defense and Internet and communication VoIP applications for intelligent yet adaptive evolving systems Evolving Intelligent Systems is the first self contained volume that covers this newly established concept in its entirety from a systematic methodology to case studies to industrial applications Featuring chapters written by leading world experts it addresses the progress trends and major achievements in this emerging research field with a strong emphasis on the balance between novel theoretical results and solutions and practical real life applications Explains the following fundamental approaches for developing evolving intelligent systems EIS the Hierarchical Prioritized Structure the Participatory Learning Paradigm the Evolving Takagi Sugeno fuzzy systems eTS the evolving clustering algorithm that stems from the well known Gustafson Kessel offline clustering algorithm Emphasizes the importance and increased interest in online processing of data streams Outlines the general strategy of using the fuzzy dynamic clustering as a foundation for evolvable information granulation Presents a methodology for developing robust and interpretable evolving fuzzy rule based systems Introduces an integrated approach to incremental real time feature extraction and classification Proposes a study on the stability of evolving neuro fuzzy recurrent networks Details methodologies for evolving clustering and classification Reveals different applications of EIS to address real problems in areas of evolving inferential sensors in chemical and petrochemical industry learning and recognition in robotics Features

downloadable software resources Evolving Intelligent Systems is the one stop reference guide for both theoretical and practical issues for computer scientists engineers researchers applied mathematicians machine learning and data mining experts graduate students and professionals Neuro-fuzzy Controllers Jelena Godjevac,1997-01-01 **Active Control of Vibration** Christopher C. Fuller, Sharon Elliott, P. A. Nelson, 1996-02-08 This book is a companion text to Active Control of Sound by P A Nelson and S J Elliott also published by Academic Press It summarizes the principles underlying active vibration control and its practical applications by combining material from vibrations mechanics signal processing acoustics and control theory The emphasis of the book is on the active control of waves in structures the active isolation of vibrations the use of distributed strain actuators and sensors and the active control of structurally radiated sound The feedforward control of deterministic disturbances the active control of structural waves and the active isolation of vibrations are covered in detail as well as the more conventional work on modal feedback The principles of the transducers used as actuators and sensors for such control strategies are also given an in depth description The reader will find particularly interesting the two chapters on the active control of sound radiation from structures active structural acoustic control The reason for controlling high frequency vibration is often to prevent sound radiation and the principles and practical application of such techniques are presented here for both plates and cylinders The volume is written in textbook style and is aimed at students practicing engineers and researchers Combines material from vibrations signal processing mechanics and controls Summarizes new research in the field **Signal Processing for Active Control** Stephen Elliott, 2000-09-26 Signal Processing for Active Control sets out the signal processing and automatic control techniques that are used in the analysis and implementation of active systems for the control of sound and vibration After reviewing the performance limitations introduced by physical aspects of active control Stephen Elliott presents the calculation of the optimal performance and the implementation of adaptive real time controllers for a wide variety of active control systems Active sound and vibration control are technologically important problems with many applications Active control means controlling disturbance by superimposing a second disturbance on the original source of disturbance Put simply initial noise other specially generated noise or vibration silence or controlled noise This book presents a unified approach to techniques that are used in the analysis and implementation of different control systems It includes practical examples at the end of each chapter to illustrate the use of various approaches This book is intended for researchers engineers and students in the field of acoustics active control signal processing and electrical engineering

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