

Springer Series in Information Sciences

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P.A. Ruymgaart T.T. Soong

# Mathematics of **Kalman-Bucy Filtering**



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# Mathematics Of Kalman Bucy Filtering Springer Series In Information Sciences

**Christian Drosten**



## **Mathematics Of Kalman Bucy Filtering Springer Series In Information Sciences:**

**Mathematics of Kalman-Bucy Filtering** Peter A. Ruymgaart, Tsu T. Soong, 2013-03-08 The second edition has not deviated significantly from the first The printing of this edition however has allowed us to make a number of corrections which escaped our scrutiny at the time of the first printing and to generally improve and tighten our presentation of the material Many of these changes were suggested to us by colleagues and readers and their kindness in doing so is greatly appreciated Delft The Netherlands and P A Ruymgaart Buffalo New York December 1987 T T Soong Preface to the First Edition Since their introduction in the mid 1950s the filtering techniques developed by Kalman and by Kalman and Bucy have been widely known and widely used in all areas of applied sciences Starting with applications in aerospace engineering their impact has been felt not only in all areas of engineering but as all also in the social sciences biological sciences medical sciences as well other physical sciences Despite all the good that has come out of this development however there have been misuses because the theory has been used mainly as a tool or a procedure by many applied workers without fully understanding its underlying mathematical workings This book addresses a mathematical approach to Kalman Bucy filtering and is an outgrowth of lectures given at our institutions since 1971 in a sequence of courses devoted to Kalman Bucy filters

Mathematics of Kalman-Bucy Filtering P A Ruymgaart, Tsu T Soong, 1985-02-01 **Kalman Filtering** Charles K. Chui, Guanrong Chen, 2013-03-09 Kalman Filtering with Real Time Applications presents a thorough discussion of the mathematical theory and computational schemes of Kalman filtering The filtering algorithms are derived via different approaches including a direct method consisting of a series of elementary steps and an indirect method based on innovation projection Other topics include Kalman filtering for systems with correlated noise or colored noise limiting Kalman filtering for time invariant systems extended Kalman filtering for nonlinear systems interval Kalman filtering for uncertain systems and wavelet Kalman filtering for multiresolution analysis of random signals The last two topics are new additions to this third edition Most filtering algorithms are illustrated by using simplified radar tracking examples The style of the book is informal and the mathematics is elementary but rigorous The text is self contained suitable for self study and accessible to all readers with a minimum knowled Kalman Filtering with Real-Time Applications Charles K. Chui, Guanrong Chen, 2013-03-09 Kalman filtering is an optimal state estimation process applied to a dynamic system that involves random perturbations More precisely the Kalman filter gives a linear unbiased and minimum error variance recursive algorithm to optimally estimate the unknown state of a dynamic system from noisy data taken at discrete real time intervals It has been widely used in many areas of industrial and government applications such as video and laser tracking systems satellite navigation ballistic missile trajectory estimation radar and fuel control With the recent development of high speed computers the Kalman filter has become more useful even for very complicated real time applications In spite of its importance the mathematical theory of Kalman filtering and its implications are not well understood even among many applied mathematicians and engineers In fact

most practitioners are just told what the filtering algorithms are without knowing why they work so well One of the main objectives of this text is to disclose this mystery by presenting a fairly thorough discussion of its mathematical theory and applications to various elementary real time problems A very elementary derivation of the filtering equations is first presented By assuming that certain matrices are nonsingular the advantage of this approach is that the optimality of the Kalman filter can be easily understood Of course these assumptions can be dropped by using the more well known method of orthogonal projection usually known as the innovations approach

Number Theory in Science and Communication M.R. Schroeder, 2005-11-03 Number Theory in Science and Communication introduces non mathematicians to the fascinating and diverse applications of number theory This best selling book stresses intuitive understanding rather than abstract theory This revised fourth edition is augmented by recent advances in primes in progressions twin primes prime triplets prime quadruplets and quintuplets factoring with elliptic curves quantum factoring Golomb rulers and baroque integers

**Kalman Filtering** Charles K. Chui, Guanrong Chen, 2013-06-29 In addition to making a number of minor corrections and updating the references we have expanded the section on real time system identification in Chapter 10 of the first edition into two sections and combined it with Chapter 8 In its place a very brief introduction to wavelet analysis is included in Chapter 10 Although the pyramid algorithms for wavelet decompositions and reconstructions are quite different from the Kalman filtering algorithms they can also be applied to time domain filtering and it is hoped that splines and wavelets can be incorporated with Kalman filtering in the near future College Station and Houston Charles K Chui September 1990 Guanrong Chen Preface to the First Edition Kalman filtering is an optimal state estimation process applied to a dynamic system that involves random perturbations More precisely the Kalman filter gives a linear unbiased and minimum error variance recursive algorithm to optimally estimate the unknown state of a dynamic system from noisy data taken at discrete real time It has been widely used in many areas of industrial and government applications such as video and laser tracking systems satellite navigation ballistic missile trajectory estimation radar and fire control With the recent development of high speed computers the Kalman filter has become more useful even for very complicated real time applications

*Self-Organizing Maps* Teuvo Kohonen, 2012-12-06 The second revised edition of this book was suggested by the impressive sales of the first edition Fortunately this enabled us to incorporate new important results that had just been obtained The ASSOM Adaptive Subspace SOM is a new architecture in which invariant feature detectors emerge in an unsupervised learning process Its basic principle was already introduced in the first edition but the motivation and theoretical discussion in the second edition is more thorough and consequent New material has been added to Sect 5.9 and this section has been rewritten totally Correspondingly Sect 1.4 which deals with adaptive subspace classifiers in general and constitutes the prerequisite for the ASSOM principle has also been extended and rewritten totally Another new SOM development is the WEBSOM a two layer architecture intended for the organization of very large collections of full text documents such as those found in the Internet

and World Wide Web This architecture was published after the first edition came out The idea and results seemed to be so important that the new Sect 7 8 has now been added to the second edition Another addition that contains new results is Sect 3 15 which describes the acceleration in the computing of very large SOMs It was also felt that Chap 7 which deals with 80M applications had to be extended

**The Mathematical Intelligencer**, 1986

**Number Theory in Science and Communication** Manfred Schroeder, 2013-06-29 Number Theory in Science and Communication is an introduction for non mathematicians The book stresses intuitive understanding rather than abstract theory and highlights important concepts such as continued fractions the golden ratio quadratic residues and Chinese remainders trapdoor functions pseudoprimes and primitive elements Their applications to problems in the real world is one of the main themes of the book This third edition is augmented by recent advances in primes in progressions twin primes prime triplets prime quadruplets and quintuplets factoring with elliptic curves quantum factoring Golomb rulers and baroque integers

*Calibration and Orientation of Cameras in Computer Vision* Armin Gruen, Thomas S. Huang, 2013-03-09 This book was conceived during the Workshop Calibration and Orientation of Cameras in Computer Vision at the XVIIth Congress of the ISPRS International Society of Photogrammetry and Remote Sensing in July 1992 in Washington D C The goal of this workshop was to bring photogrammetry and computer vision experts together in order to exchange ideas concepts and approaches in camera calibration and orientation These topics have been addressed in photogrammetry research for a long time starting in the second half of the 19th century Over the years standard procedures have been developed and implemented in particular for metric cameras such that in the photogrammetric community such issues were considered as solved problems With the increased use of non metric cameras in photogrammetry they are revealingly called amateur cameras especially CCD cameras and the exciting possibilities of acquiring long image sequences quite effortlessly and processing image data automatically online and even in real time the need to take a new and fresh look at various calibration and orientation issues became obvious Here most activities emerged through the computer vision community which was somewhat unaware as to what had already been achieved in photogrammetry On the other hand photogrammetrists seemed to ignore the new and interesting studies in particular on the problems of orientation that were being performed by computer vision experts

**Number Theory in Science and Communication** Manfred R. Schroeder, 2013-11-11 Beauty is the first test there is no permanent place in the world for ugly mathematics G H Hardy Number theory has been considered since time immemorial to be the very paradigm of pure some would say useless mathematics In fact the Chinese characters for mathematics are Number Science Mathematics is the queen of sciences and number theory is the queen of mathematics according to Carl Friedrich Gauss the lifelong Wunderkind who himself enjoyed the epithet Princeps Mathematicorum What could be more beautiful than a deep satisfying relation between whole numbers One is almost tempted to call them wholesome numbers In fact it is hard to come up with a more appropriate designation than their learned name the integers meaning the untouched

ones How high they rank in the realms of pure thought and aesthetics above their lesser brethren the real and complex number whose first names virtually exude unsavory involvement with the complex realities of everyday life Yet as we shall see in this book the theory of integers can provide totally unexpected answers to real world problems In fact discrete mathematics is taking on an ever more important role If nothing else the advent of the digital computer and digital communication has seen to that But even earlier in physics the emergence of quantum mechanics and discrete elementary particles put a premium on the methods and indeed the spirit of discrete mathematics

**Psychoacoustics** Eberhard Zwicker, Hugo Fastl, 2013-03-14 Psychoacoustics Facts and Models represents a comprehensive collection of data describing the processing of sound by the human hearing system It includes quantitative relations between sound stimuli and auditory perception in terms of hearing sensations In addition quantitative psychoacoustic models of hearing sensations are given The monograph contains a unique collection of data on the human hearing system as a receiver of acoustic information as well as many examples of the practical application of the results of basic research in fields such as audiology noise evaluation and sound engineering Many helpful hints for the solution of practical problems will be of particular benefit to engineers and the book as a whole should serve as an important benchmark in the field of psychoacoustics The treatment given in this second edition has been thoroughly updated with recent results

**Books in Series, 1876-1949** R.R. Bowker Company, 1982

**Fundamentals of Electronic Imaging Systems** William F. Schreiber, 2012-12-06 Image processing is an applications area In this area there are many opportunities to apply art and experience as well as knowledge from various sciences and engineering disciplines to the creation of products and processes for which society has urgent need Without this need few would be interested in the subject This point of view motivates this work and has influenced the selection and treatment of topics It will be noticed that the word digital is not in the title While much of present day image processing is implemented digitally this work is not intended for those who think that image processing is a branch of digital signal processing except perhaps to try to change their minds This book grew out of courses taught at the Massachusetts Institute of Technology by the author and two of his former students T S Huang and O J Tretiak Like the courses it is primarily intended for electrical engineers and computer scientists who plan to work in the field It has not proven necessary to spend much time on strictly digital issues since the students either know that material already or can learn it very easily by themselves It also has been unnecessary to be encyclopedic since Pratt has already performed this important service

**Self-Organization and**

**Associative Memory** Teuvo Kohonen, 2012-12-06 Two significant things have happened since the writing of the first edition in 1983 One of them is recent arousal of strong interest in general aspects of neural computing or neural networks as the previous neural models are nowadays called The incentive of course has been to develop new computers Especially it may have been felt that the so called fifth generation computers based on conventional logic programming do not yet contain information processing principles of the same type as those encountered in the brain All new ideas for the neural computers

are of course welcome On the other hand it is not very easy to see what kind of restrictions there exist to their implementation In order to approach this problem systematically certain lines of thought disciplines and criteria should be followed It is the purpose of the added Chapter 9 to reflect upon such problems from a general point of view Another important thing is a boom of new hardware technologies for distributed associative memories especially high density semiconductor circuits and optical materials and components The era is very close when the parallel processors can be made all optical Several working associative memory architectures based solely on optical technologies have been constructed in recent years For this reason it was felt necessary to include a separate chapter Chap 10 which deals with the optical associative memories Part of its contents is taken over from the first edition

Linear Systems and Optimal Control Charles K. Chui, Guanrong Chen, 2012-12-06 A knowledge of linear systems provides a firm foundation for the study of optimal control theory and many areas of system theory and signal processing State space techniques developed since the early sixties have been proved to be very effective The main objective of this book is to present a brief and somewhat complete investigation on the theory of linear systems with emphasis on these techniques in both continuous time and discrete time settings and to demonstrate an application to the study of elementary linear and nonlinear optimal control theory An essential feature of the state space approach is that both time varying and time invariant systems are treated systematically When time varying systems are considered another important subject that depends very much on the state space formulation is perhaps real time filtering prediction and smoothing via the Kalman filter This subject is treated in our monograph entitled Kalman Filtering with Real Time Applications published in this Springer Series in Information Sciences Volume 17 For time invariant systems the recent frequency domain approaches using the techniques of Adamjan Arov and Krein also known as AAK balanced realization and  $H_\infty$  theory via Nevanlinna Pick interpolation seem very promising and this will be studied in our forthcoming monograph entitled Mathematical Approach to Signal Processing and System Theory The present elementary treatise on linear system theory should provide enough engineering and mathematics of these two subjects

*Parallel Algorithms in Computational Science* Dieter W. Heermann, Anthony N. Burkitt, 2012-12-06 Our aim in this book is to present and enlarge upon those aspects of parallel computing that are needed by practitioners of computational science Today almost all classical sciences such as mathematics physics chemistry and biology employ numerical methods to help gain insight into nature In addition to the traditional numerical methods such as matrix inversions and the like a whole new field of computational techniques has come to assume central importance namely the numerical simulation methods These methods are much less fully developed than those which are usually taught in a standard numerical mathematics course However they form a whole new set of tools for research in the physical sciences and are applicable to a very wide range of problems At the same time there have been not only enormous strides forward in the speed and capability of computers but also dramatic new developments in computer architecture and particularly in parallel computers These improvements offer

exciting prospects for computer studies of physical systems and it is the new techniques and methods connected with such computer simulations that we seek to present in this book particularly in the light of the possibilities opened up by parallel computers It is clearly not possible at this early stage to write a definitive book on simulation methods and parallel computing

**VLSI for Pattern Recognition and Image Processing** K.S. Fu, 2013-03-08 During the past two decades there has been a considerable growth in interest in problems of pattern recognition and image processing PRIP This interest has created an increasing need for methods and techniques for the design of PRIP systems PRIP involves analysis classification and interpretation of data Practical applications of PRIP include character recognition remote sensing analysis of medical signals and images fingerprint and face identification target recognition and speech understanding One difficulty in making PRIP systems practically feasible and hence more popularly used is the requirement of computer time and storage This situation is particularly serious when the patterns to be analyzed are quite complex Thus it is of the utmost importance to investigate special computer architectures and their implementations for PRIP Since the advent of VLSI technology it is possible to put thousands of components on one chip This reduces the cost of processors and increases the processing speed VLSI algorithms and their implementations have been recently developed for PRIP This book is intended to document the recent major progress in VLSI system design for PRIP applications

**The Maximum Entropy Method** Nailong Wu, 2012-12-06 Forty years ago in 1957 the Principle of Maximum Entropy was first introduced by Jaynes into the field of statistical mechanics Since that seminal publication this principle has been adopted in many areas of science and technology beyond its initial application It is now found in spectral analysis image restoration and a number of branches of mathematics and physics and has become better known as the Maximum Entropy Method MEM Today MEM is a powerful means to deal with ill posed problems and much research work is devoted to it My own research in the area of MEM started in 1980 when I was a graduate student in the Department of Electrical Engineering at the University of Sydney Australia This research work was the basis of my Ph D thesis The Maximum Entropy Method and Its Application in Radio Astronomy completed in 1985 As well as continuing my research in MEM after graduation I taught a course of the same name at the Graduate School Chinese Academy of Sciences Beijing from 1987 to 1990 Delivering the course was the impetus for developing a structured approach to the understanding of MEM and writing hundreds of pages of lecture notes

**Linear Prediction Theory** Peter Strobach, 2012-12-06 Linear prediction theory and the related algorithms have matured to the point where they now form an integral part of many real world adaptive systems When it is necessary to extract information from a random process we are frequently faced with the problem of analyzing and solving special systems of linear equations In the general case these systems are overdetermined and may be characterized by additional properties such as update and shift invariance properties Usually one employs exact or approximate least squares methods to solve the resulting class of linear equations Mainly during the last decade researchers in various fields have contributed techniques and nomenclature for this type of



least squares problem This body of methods now constitutes what we call the theory of linear prediction The immense interest that it has aroused clearly emerges from recent advances in processor technology which provide the means to implement linear prediction algorithms and to operate them in real time The practical effect is the occurrence of a new class of high performance adaptive systems for control communications and system identification applications This monograph presumes a background in discrete time digital signal processing including Z transforms and a basic knowledge of discrete time random processes One of the difficulties I have encountered while writing this book is that many engineers and computer scientists lack knowledge of fundamental mathematics and geometry

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