On Digital Filtering

G-AE CONCEPTS SUBCOMMITTEE
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Abstract

Digital filtering is the process of spectrum shaping of signal waveforms, using digital components as the basic elements for implementation. This process is extensively used in the computer simulation of analog filters. The unmistakable trends toward increased speed and decreased cost and size of digital components make digital filtering especially attractive at this time. These trends promise to end the virtual monopoly of analog components for realizing real-time filters.

This paper attempts to set the stage for the companion papers on digital filtering to follow in this topical issue. After introducing the z-transform of a discrete-time series, the use of this transform in linear system analysis is considered. The relationship between discrete and continuous signals and systems is then discussed. Since all the papers of this issue are concerned with digital filter implementations in one form or another, only an overview of these implementations is given here. These include filter configurations, design methods, quantization effects, and the fast convolution method for implementing nonrecursive filters.

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The members of the subcommittee are: W. T. Cochran, Bell Telephone Laboratories, Inc., Holmdel, N. J.; J. W. Cooley, IBM Corporation, Yorktown Heights, N. Y.; H. D. Helms, Bell Telephone Laboratories, Inc., Whippany, N. J.; R. A. Kaenel, Bell Telephone Laboratories, Inc., Murray Hill, N. J.; J. F. Kaiser, Bell Telephone Laboratories, Inc., Murray Hill, N. J.; W. W. Lang, IBM Corporation, Poughkeepsie, N. Y.; Ch. C. Meling, IBM Corporation, Poughkeepsie, N. Y.; C. M. Rader, M.I.T. Lincoln Laboratory, Lexington, Mass. [operated with support from the U. S. Air Force]; K. Steiglitz, Princeton University, Princeton, N. J.

I. Introduction

Linear network theory is based on the electrical properties of inductances, capacitances, and resistances. These lead, via Kirchoff's laws, to a description of the performance of a network by a set of linear differential equations. By contrast, a set of linear difference equations is used to describe a discrete linear system; these equations are realized (by manipulating numbers) in a special or general purpose digital computer. To realize a linear difference equation, the input signal must be composed of discrete samples, i.e., a sequence of numbers. All considerations here are based on uniformly spaced samples. Nonuniform spacing of samples lies outside the scope of this paper.

The discussion is based on a model whose input consists of discrete samples quantized in amplitude. The samples are then processed by digital logic, which performs the numerical operations required to realize the linear difference equation(s). Initially, it is assumed that the idealized digital logic manipulates the unquantized data with perfect accuracy. The effects of quantization will be considered later. In many practical cases, the effects of numerical error due to quantization may be treated as a noise superimposed on the ideal unquantized data.

An increasingly large number of examples can be identified in which digital filtering appears to be more practical than analog processing for performing such operations as interpolation, extrapolation, smoothing, and spectral decomposition. This is especially true when the data to be operated upon are generated in digital form, e.g., by a digital transducer. The unique advantages offered by digital techniques include the following: potentially small-size integrated circuit implementation; very predictable stable performance of arbitrarily high precision; absence of impedance-matching problems; no restrictions on the location of critical filter frequencies; greater flexibility, because of the ease with which the filter response can be changed by varying the proper coefficients; and the intrinsic possibility of time-sharing major implementation segments. These advantages together with larger scale circuit integration (LSI) promise to make the digital filtering technique eminently suitable for the exacting requirements of modern communications-oriented computing facilities. In fact, the rapid development of LSI has greatly increased the possibility of digital-filtering techniques, thus threatening to end the virtual monopoly of analog processing [3], [4].

The study of discrete-time systems can be approached from two directions: first, they can be viewed as approximations to continuous-time systems and second, they can be considered as existing without reference to any continuous-time systems. Both viewpoints offer advantages; we shall begin with the second and come back to the first.

Digital Filtering An Introduction

Julius O. Smith

Digital Filtering An Introduction:

Introduction to Digital Filters Julius Orion Smith,2008 A digital filter can be pictured as a black box that accepts a sequence of numbers and emits a new sequence of numbers In digital audio signal processing applications such number sequences usually represent sounds For example digital filters are used to implement graphic equalizers and other digital audio effects This book is a gentle introduction to digital filters including mathematical theory illustrative examples some audio applications and useful software starting points The theory treatment begins at the high school level and covers fundamental concepts in linear systems theory and digital filter analysis Various small digital filters are analyzed as examples particularly those commonly used in audio applications Matlab programming examples are emphasized for illustrating the use and development of digital filters in practice **Digital Filtering** Edward P. Cunningham,1992-01-01 The order in which the subject matter is presented enables students to make an easy transition from continuous signals and systems to their discrete time counterparts A general introduction to terminology and a description of digital filters is followed by a review of continuous filter design Subsequent chapters deal with sampling theorem and the z transform design of recursive digital filters finite impulse response and nonrecursive filters basic concepts in probability theory and random processes and the methods of design and analysis of the Kalman filter Contains worked analytical examples diagrams and problem sets

Introduction to Digital Filters Trevor J. Terrell,1988-07-28 In this revised and updated edition particular attention has been paid to the practical implementations of digital filters covering such topics as microprocessors based filters single chip DSP devices computer processing of 2 dimensional signals and VLSI signal processing **Introduction to Digital Filtering** R. E. Bogner,A. G. Constantinides,1975 A Wiley Interscience publication **INTRODUCTION TO DIGITAL FILTERING** ,1980 Introduction to Digital Filtering in Geophysics O. Kulhánek,2012-12-02 Introduction to Digital Filtering in Geophysics *Digital and Kalman Filtering* S. M. Bozic,2018-11-14 The first half of this concise introductory treatment focuses on digital filtering and the second on filtering noisy data to extract a signal The text includes worked examples and problems with solutions 1994 edition Introduction to Digital Filters Julius O. Smith,2008-08-27

Nonlinear Digital Filtering with Python Ronald K. Pearson,Moncef Gabbouj,2018-09-03 Nonlinear Digital Filtering with Python An Introduction discusses important structural filter classes including the median filter and a number of its extensions e g weighted and recursive median filters and Volterra filters based on polynomial nonlinearities Adopting both structural and behavioral approaches in characterizing and designing nonlinear digital filters this book Begins with an expedient introduction to programming in the free open source computing environment of Python Uses results from algebra and the theory of functional equations to construct and characterize behaviorally defined nonlinear filter classes Analyzes the impact of a range of useful interconnection strategies on filter behavior providing Python implementations of the presented filters and interconnection strategies Proposes practical bottom up strategies for designing more complex and capable filters

from simpler components in a way that preserves the key properties of these components Illustrates the behavioral consequences of allowing recursive i e feedback interconnections in nonlinear digital filters while highlighting a challenging but promising research frontier Nonlinear Digital Filtering with Python An Introduction supplies essential knowledge useful for developing and implementing data cleaning filters for dynamic data analysis and time series modeling Solutions Manual to Accompany Digital Filtering an Introduction Edward P. Cunningham,1994-12-01 **Introduction to Digital Signal Processing and Filter Design** B. A. Shenoi,2005-10-24 A practical and accessible guide to understanding digital signal processing Introduction to Digital Signal Processing and Filter Design was developed and fine tuned from the author s twenty five years of experience teaching classes in digital signal processing Following a step by step approach students and professionals quickly master the fundamental concepts and applications of discrete time signals and systems as well as the synthesis of these systems to meet specifications in the time and frequency domains Striking the right balance between mathematical derivations and theory the book features Discrete time signals and systems Linear difference equations Solutions by recursive algorithms Convolution Time and frequency domain analysis Discrete Fourier series Design of FIR and IIR filters Practical methods for hardware implementation A unique feature of this book is a complete chapter on the use of a MATLAB r tool known as the FDA Filter Design and Analysis tool to investigate the effect of finite word length and different formats of quantization different realization structures and different methods for filter design This chapter contains material of practical importance that is not found in many books used in academic courses It introduces students in digital signal processing to what they need to know to design digital systems using DSP chips currently available from industry With its unique classroom tested approach Introduction to Digital Signal Processing and Filter Design is the ideal text for students in electrical and electronic engineering computer science and applied mathematics and an accessible introduction or refresher for engineers and scientists in the field **Introduction to Digital Filters** Julius O. Smith,2006 **An Introduction to Parametric Digital Filters and Oscillators** Mikhail Cherniakov,2003-09-12 Since the 1960s Digital Signal Processing DSP has been one of the most intensive fields of study in electronics However little has been produced specifically on linear non adaptive time variant digital filters The first book to be dedicated to Time Variant Filtering Provides a complete introduction to the theory and practice of one of the subclasses of time varying digital systems parametric digital filters and oscillators Presents many examples demonstrating the application of the techniques An indispensable resource for professional engineers researchers and PhD students involved in digital signal and image processing as well as postgraduate students on courses in computer electrical electronic and similar departments **An Introduction to Digital Filters** Trevor J. Terrell,1982-04-01 **Digital and Kalman Filtering** Svetozar Mile Bozic,1979 This text provides a concise introduction to digital filtering filter design and applications in the form of the Kalman and Wiener filters Throughout the book concepts are developed gradually and the material is presented systematically with appropriate illustrations Introductory Signal

Processing Roland Priemer,1990-11-29 A valuable introduction to the fundamentals of continuous and discrete time signal processing this book is intended for the reader with little or no background in this subject The emphasis is on development from basic principles With this book the reader can become knowledgeable about both the theoretical and practical aspects of digital signal processing Some special features of this book are 1 gradual and step by step development of the mathematics for signal processing 2 numerous examples and homework problems 3 evolutionary development of Fourier series Discrete Fourier Transform Fourier Transform Laplace Transform and Z Transform 4 emphasis on the relationship between continuous and discrete time signal processing 5 many examples of using the computer for applying the theory 6 computer based assignments to gain practical insight 7 a set of computer programs to aid the reader in applying the theory

Signal Processing and Data Analysis Tianshuang Qiu,Ying Guo,2018-07-09 This book presents digital signal processing theories and methods and their applications in data analysis error analysis and statistical signal processing Algorithms and Matlab programming are included to guide readers step by step in dealing with practical difficulties Designed in a self contained way the book is suitable for graduate students in electrical engineering information science and engineering in general *CRC Handbook of Electrical Filters* John Taylor,Qiuting Huang,2020-11-25 Interest in filter theory and design has been growing with the telecommunications industry since the late nineteenth century Now that telecommunications has become so critical to industry filter research has assumed even greater importance at companies and academic institutions around the world The CRC Handbook of Electrical Filters fills in the gaps for engineers and scientists who need a basic introduction to the subject Unlike the currently available textbooks which are filled with detailed highly technical analysis geared to the specialist this practical guide provides useful information for the non specialist about the various types of filters their design and applications The handbook covers approximation theory and methods and introduces CAD packages that perform approximation and synthesis for both analog and digital filters Also included are design methods for LCR active RC digital mechanical and switched capacitor SC filters A thorough survey of current design trends rounds out this complete assessment of a key field of study **Digital and Kalman Filtering** S. M. Bozic,1980-04-29 Provides a basic introduction to digital filtering filter design and application in the form of Kalman and Wiener filters The approach used throughout the book is a transition from continuous to discrete time systems since electrical engineering is usually taught from continuous time concepts Various central topics are developed gradually with a number of examples and problems with solutions The book is suitable both as an undergraduate and as a postgraduate text

Digital Filtering ,1972

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