On Digital Filtering

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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.

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.

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