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Review Paper on Infinite Impulse Response

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1 Introduction

Infinite impulse response (IIR) is a property applying to many linear time-invariant systems. Common examples of linear time-invariant systems are most electronic and digital filters. Systems with this property are known as *IIR systems* or *IIR filters*, and are distinguished by having an impulse response which does not become exactly zero past a certain point, but continues indefinitely. This is in contrast to a finite impulse response in which the impulse response $h(t)$ *does* become exactly zero at times $t > T$ for some finite T, thus being of finite duration.

In practice, the impulse response even of IIR systems usually approaches zero and can be neglected past a certain point. However the physical systems which give rise to IIR or FIR (*finite impulse response*) responses are dissimilar, and therein lies the importance of the distinction. For instance, analog electronic filters composed of resistors, capacitors, and/or inductors (and perhaps linear amplifiers) are generally IIR filters. On the other hand, discrete-time filters (usually digital filters) based on a tapped delay line *employing no feedback* are necessarily FIR filters. The capacitors (or inductors) in the analog filter have a "memory" and their internal state never completely relaxes following an impulse. But in the latter case, after an impulse has reached the end of the tapped delay line, the system has no further memory of that impulse and has returned to its initial state; its impulse response beyond that point is exactly zero.

2 IIR Filter

IIR filters are digital filters with infinite impulse response. Unlike FIR filters, they have the feedback and are known as recursive digital filters. The IIR filters have much better frequency response than FIR filters of the same order. Unlike FIR filters, their phase characteristic is not linear which can cause a problem to the systems which need phase linearity. For this reason, it is not preferable to use IIR filters in digital signal processing when the phase is of the essence. FIR filters can have linear phase characteristic, which is not typical of IIR filters. When it is necessary to have linear phase characteristic, FIR filters are the only available solution. In other cases when linear phase characteristic is not necessary, such as speech signal processing, FIR filters are not good solution. IIR filters should be used instead. The resulting filter order is considerably lower for the same frequency response. The IIR filter transfer function is a ratio of two polynomials of complex variable z-1. The numerator defines location of zeros, whereas the denominator defines location of poles of the resulting IIR filter transfer function.

3 TYPES OF IIR FILTER

- Butterworth filters.
- Chebyshev filters.
- Inverse chebyshev filters.
- Elliptic filters.

The IIR filter designs differ in the sharpness of the transition between the pass band and stop band, where they exhibit various characteristics. The main advantage digital IIR filters have over FIR filters is their efficiency in implementation, in order to meet a specification in terms of pass band, stop band, ripple, and/or roll-off. Such a set of specifications can be accomplished with a lower order IIR filter than would be required for an FIR filter meeting the same requirements. If implemented in a signal processor, this implies a correspondingly fewer number of calculations per time step. FIR filters can be easier to design, for instance, to match a particular frequency response requirement. This is particularly true when the requirement is not one of the usual cases high-pass, low pass, notch, etc. which have been studied and optimized for analog filters. IIR filters are the potential for limit cycle behaviour when idle, due to the feedback system in conjunction with quantization.

4 Stability

The transfer function allows one to judge whether or not a system is bounded-input, bounded-output (BIBO) stable. To be specific, the BIBO stability criterion requires that the ROC of the system includes the unit circle. For example, for a causal system, all poles of the transfer function have to have an absolute value smaller than one. In other words, all poles must be located within a unit circle in the z-plane.

The poles are defined as the values of z which make the denominator of $H(z)$ equal to 0:

$$0 = \sum_{j=0}^{Q} a_j z^{-j}$$

Clearly, if $a_j \neq 0$ then the poles are not located at the origin of the z-plane. This is in contrast to the FIR filter where all poles are located at the origin, and is therefore always stable.

IIR filters are sometimes preferred over FIR filters because an IIR filter can achieve a much sharper transition region roll-off than an FIR filter of the same order.

5 Advantages and Disadvantages

The main advantage digital IIR filters have over FIR filters is their efficiency in implementation, in order to meet a specification in terms of passband, stopband, ripple, and/or roll-off. Such a set of specifications can be accomplished with a lower order (*Q* in the above formulae) IIR filter than would be required for an FIR filter meeting the same requirements. If implemented in a signal processor, this implies a correspondingly fewer number of calculations per time step; the computational savings is often of a rather large factor.

On the other hand, FIR filters can be easier to design, for instance, to match a particular frequency response requirement. This is particularly true when the requirement is not one of the usual cases (high-pass, low-pass, notch, etc.) which have been studied and optimized for analog filters. Also FIR filters can be easily made to be linear phase (constant group delay vs frequency)—a property that is not easily met using IIR filters and then only as an approximation (for instance with the Bessel filter). Another issue regarding digital IIR filters is the potential for limit cycle behavior when idle, due to the feedback system in conjunction with quantization.

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