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A weighted L_2-based method for the design of arbitrary one-dimensional FIR digital filters

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Abstract

In FIR filter design problems, filter specifications do not constrain in any way the ideal frequency response inside the transition regions. Most existing L_2-based filter design techniques utilize this flexibility in order to improve their performance. In this paper we propose a new general method for the weighted L_2-based design of arbitrary FIR filters. In particular, we propose a well-defined optimization criterion that depends on the selection of the desired response inside the transition regions. By optimizing our criterion we obtain desired responses that produce weighted mean square error optimum filters with extremely good characteristics. The proposed method is computationally simple since it requires the solution of a linear system of equations.

Keywords: 1-D Digital filters; Filter design methods; FIR filters

1. Introduction

The design of one-dimensional (1-D) digital filters, although it is an old problem with significant existing literature, has been of growing interest over the last decade. This is because digital filters are widely used in a variety of signal processing applications such as speech and image processing, communications, seismology, radar, sonar and medical signal processing.

The best known class of 1-D FIR filters is the class of linear phase filters. Their popularity stems mainly from the fact that corresponding design methods involve only real functions which also allows for the successful employment of the L_∞ criterion, the most suitable one, for the filter design problem. Linear phase filters are known however to introduce significant delays when their lengths are large. In applications where long delays are unacceptable, it is clear that there is a need of alternative filters. Furthermore, there are problems which are by nature nonlinear-phase such as, piecewise constant group delay FIR filters, FIR equalizers, beamformers, seismic migration filters,

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etc. These problems require a filter design methodology that is significantly different from the conventional used in linear phase. Moreover, one can no longer be limited to real coefficient filters and needs to take into account general complex coefficient filters.

What constitutes the complex function design problem challenging, from a methodology point of view, is the lack of efficient L_∞ techniques as compared to linear phase where the Remez Exchange Algorithm [1] is dominant. This is largely due to the non-existence of a suitable counterpart, in the complex case, to the Alternation Theorem [2] that can serve as a base for developing computationally efficient algorithms. Consequently, all L_∞ techniques rely on sophisticated and computationally intense optimization machinery.

Existing L_∞ techniques can be broadly classified into four categories. The first includes methods that replace the complex L_∞ approximation problem with two real ones and therefore their solution is suboptimal [3,4]. The second includes methods that solve the L_∞ problem using linear programming [3,5–7]. The third category involves methods based on Lawson's algorithm (also known as iterated reweighted least squares), [8–10]. Finally, the last category includes methods that enforce an equiripple structure on the solution [11,12] which, however, does not guarantee L_∞ optimality [13].

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