

Algorithms and Systolic Architectures for Real-Time Multidimensional Adaptive Filtering of Frequency Domain Multiplexed Video Signals

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Abstract

Algorithms are developed simultaneously with systolic architectures for multidimensional adaptive filtering. Because of the extremely high data rate required for real-time video processing, even with the use of highly concurrent algorithms and architectures, there is a strong motivation to limit the size of any adaptation problem. The combination of the McClellan transformation as an efficient *parameterization* for a multidimensional least-squares (LS) adaptive filter, coupled with systolic arrays to adapt and implement the filter, yields a novel solution to the problem of adapting a large zero-phase FIR multidimensional filter, having arbitrary directional biases, with only a few parameters.

The application of the McClellan transformation as a parameterization for the LS adaptive filter is a fairly general technique that is quite different from any of its previous applications. It is shown how the McClellan transformation is a decomposition that roughly corresponds to separating the specification of a multidimensional filter into a normal component, via the 1-D prototype filter, and a tangential component, via the 2-D transformation function, thereby giving an adaptive system the potential to exploit local directional biases in any direction. Furthermore, it is shown that these filters can be adapted abruptly on a block-by-block basis without causing blocking effects.

After developing a basic processing element for a systolic array realization of the Chebychev structure for the McClellan transformation, it is shown that for a given 2-D transformation function, the adaptation of the 1-D prototype filter becomes a small multichannel adaptation problem, similar to adaptive array problems. For real-time video applications, such an adaptation algorithm can be performed efficiently using a systolic array of CORDIC processing elements. A similar approach is also taken in developing algorithms to adapt the transformation function.

This adaptive filtering technique is then applied to the adaptive combination and separation of frequency-domain multiplexed (FDM) video signals of the type used to combine luminance and chrominance in NTSC composite video signals. Although FDM is an extremely bandwidth-efficient format for transmitting composite video signals, the performance of such a format is severely limited by either crosstalk at the band edges or a loss of resolution resulting from the global tradeoff made by systems which apply fixed separation filters. Adaptive filters parameterized by the McClellan transformation have been effective in *locally* optimizing the crosstalk vs. resolution tradeoff by adapting the separation filters for adjacent bands to minimize an error norm defined on local signal statistics.

Based on computer simulation, a two-dimensional NTSC “semi-compatible” adaptive separation system has been developed and studied. In this scheme, the computation of the adapted filter coefficients for both the transmitter and receiver occurs at the transmitter. The resulting coefficients are transmitted to the receiver along a side-channel of approximately 500 kilobits per second. Since most of the complexity involved in adaptation occurs at the transmitter, the adaptive receiver can be implemented with only a modest number of simple processing elements and memory elements. Visually, the resulting images exhibit much less crosstalk than current NTSC, and much greater vertical and diagonal resolution than those obtained by using fixed 2-D comb-filters. For the same test image, global peak-to-peak (PP) signal-to-mean-square-error ratios (SNR) of 30.6, 33.4, and 36.6 dB and worst block PP SNRs of 24.4, 25.6, and 28.9 dB were obtained for the 1-D NTSC system, 2-D comb-filter system, and 2-D adaptive system, respectively. Furthermore, the images that result when the adaptively combined signal is received on current NTSC receivers exhibit only slightly more crosstalk artifacts than would be seen on current NTSC systems.

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