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A fast and low memory image coding algorithm based on lifting wavelet transform and modified SPIHT

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Abstract

Due to its excellent rate–distortion performance, set partitioning in hierarchical trees (SPIHT) has become the state-of-the-art algorithm for image compression. However, the algorithm does not fully provide the desired features of progressive transmission, spatial scalability and optimal visual quality, at very low bit rate coding. Furthermore, the use of three linked lists for recording the coordinates of wavelet coefficients and tree sets during the coding process becomes the bottleneck of a fast implementation of the SPIHT. In this paper, we propose a listless modified SPIHT (LMSPIHT) approach, which is a fast and low memory image coding algorithm based on the lifting wavelet transform. The LMSPIHT jointly considers the advantages of progressive transmission, spatial scalability, and incorporates human visual system (HVS) characteristics in the coding scheme; thus it outperforms the traditional SPIHT algorithm at low bit rate coding. Compared with the SPIHT algorithm, LMSPIHT provides a better compression performance and a superior perceptual performance with low coding complexity. The compression efficiency of LMSPIHT comes from three aspects. The lifting scheme lowers the number of arithmetic operations of the wavelet transform. Moreover, a significance reordering of the modified SPIHT ensures that it codes more significant information belonging to the lower frequency bands earlier in the bit stream than that of the SPIHT to better exploit the energy compaction of the wavelet coefficients. HVS characteristics are employed to improve the perceptual quality of the compressed image by placing more coding artifacts in the less visually significant regions of the image. Finally, a listless implementation structure further reduces the amount of memory and improves the speed of compression by more than 51% for a 512×512 image, as compared with that of the SPIHT algorithm.

Keywords: Low bit rate image compression; Lifting wavelet transform; Listless SPIHT

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1. Introduction

Recently image compression, especially at low bit rate, has assumed a major role in applications such as storage on low memory devices, narrow-band channel transmitting, wireless transmitting and streaming data on the internet. Wavelet-based coding [2,5–8,13,16,17,24] provides substantial improvements in picture

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quality at higher compression ratios. Over the past few years, a variety of powerful and sophisticated wavelet-based image compression schemes, such as the embedded zerotree wavelet (EZW) coding scheme [17], set partitioning in hierarchical trees (SPIHT) algorithm [16], set partitioned embedded block (SPECK) coder [5,13] and embedded block coding with optimized truncation (EBCOT) [24], have been developed.

Among the wavelet zerotree-based image coding algorithms, SPIHT [16] is the most well recognized coding method because of its excellent rate–distortion performance. However, it does not entirely provide the desired features of progressive transmission, spatial scalability and optimal visual quality in that the algorithm uses an inefficient coefficient partitioning method and does not consider human visual system (HVS) properties. Moreover, a larger amount of memory is required to maintain three lists that are used for storing the coordinates of wavelet coefficients and tree sets in the coding and decoding process. A great number of operations to manipulate the memory are also required in the codec scheme, which greatly reduces the speed of coding procedure. These become drawbacks for the realization of the algorithm. So a high-speed image compression algorithm using a simple wavelet transform is desired for the algorithm implementation.

In this paper, we propose a fast and low memory image coding algorithm based on the lifting wavelet transform and listless modified SPIHT (LMSPIHT). This algorithm uses the lifting scheme as the transform method and does a breadth first search without using lists. State information is kept in a fixed size array that corresponds to the matrix of coefficient values. By introducing a significance reordering scheme that codes more significant information belonging to the lower frequency bands earlier in the bit stream than that of the SPIHT, our approach can better exploit the energy compaction of the wavelet coefficients. Further visual gains are achieved by incorporating HVS characteristics to weight wavelet coefficients according to their visual importance, during a perceptual reordering of the wavelet coefficients. Therefore, our LMSPHIT provides a better visual quality and higher PSNR values than that of the SPIHT at very low bit rates. The remarkable point of our work is that the coding time is reduced by 51%, on average for a 512 × 512 image, as compared with that of the SPIHT. In addition, the memory requirement and coding complexity of the LMSPIHT are also reduced significantly.

This paper is organized as follows. Section 2 describes the lifting wavelet transform used in our algorithm. Section 3 gives an overview of the philosophy of SPIHT coder and explains the inefficient transmission of information of SPIHT. The LMSPIHT algorithm is elaborated in Section 4. Section 5 gives some experimental results comparing our algorithm with the SPIHT in terms of compression performance, coding efficiency and perceptual quality. Rate–distortion curves and codec time of both algorithms as well as the JPEG-2000 coder are illustrated. Finally, we draw a conclusion in Section 6.

2. Fast wavelet transform using lifting scheme

The lifting wavelet transform introduced by Sweldens [4,21–23] is a new method for the construction of second generation wavelets that allow a fast realization and fully in-place operations.

As shown in [4], by applying the polyphase representation to analysis filter banks $\{\tilde{h}(z^{-1}), \tilde{g}(z^{-1})\}$ and synthesis filter banks $\{h(z), g(z)\}$, the forward and inverse discrete wavelet transform can be written as Eqs. (1) and (2), respectively:

$$\begin{bmatrix} \lambda \\ \gamma \end{bmatrix} = \tilde{P}(z^{-1})^{\mathrm{T}} \begin{bmatrix} x_e(z) \\ z^{-1}x_o(z) \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} y_e(z) \\ zy_o(z) \end{bmatrix} = P(z) \begin{bmatrix} \lambda \\ \gamma \end{bmatrix} \tag{2}$$

where x and y are the input signal and the reconstructed signal; λ and γ are the outputs of lowpass filter $\tilde{h}(z^{-1})$ and bandpass filter $\tilde{g}(z^{-1})$;

$$\tilde{P}(z) = \begin{bmatrix} \tilde{h}_e(z) & \tilde{g}_e(z) \\ \tilde{h}_o(z) & \tilde{g}_o(z) \end{bmatrix}$$

is the dual polyphase matrix and

$$P(z) = \begin{bmatrix} h_e(z) & g_e(z) \\ h_o(z) & g_o(z) \end{bmatrix}$$

is the polyphase matrix.

Daubechies and Sweldens [4] proved that given a complementary filter pair (h, g), there always exist Laurent polynomials $s_i(z)$ and $t_i(z)$ and a non-zero normalization constant K so that the polyphase