

Design of a DCT-based Image Compression with Efficient Enhancement Filter

Yen-Yu Chen, Pao-Ching Chu and Ya-Ling Tsai

Abstract—The algorithm represents the DCT coefficients to concentrate signal energy and proposes combination and dictator to eliminate the correlation in the same level subband for encoding the DCT-based images. This work adopts DCT and modifies the SPIHT algorithm to encode DCT coefficients. The proposed algorithm also provides the enhancement function in low bit rate in order to improve the perceptual quality. Experimental results indicate that the proposed technique improves the quality of the reconstructed image in terms of both PSNR and the perceptual results close to JPEG2000 at the same bit rate.

Keywords—JPEG 2000, enhancement filter

I. INTRODUCTION

THE performance of Discrete Cosine Transform (DCT) [1] is very much near to the statistically optimal Karhunen-Loeve transform (KLT) [2] because of its nice decorrelation and energy compaction properties. Moreover, as compared to KLT, DCT is data independent and many fast algorithms exist for its fast calculation so it is extensively used in multimedia compression standards. In image compression, Discrete Wavelet Transform (DWT) [3] based schemes have outperformed other coding schemes like the ones based on DCT. Since there is no need to divide the input image into non-overlapping 2-D blocks and its basis functions have variable length, wavelet-coding schemes at higher compression ratios avoid blocking artifacts. Because of their inherent multi-resolution nature, wavelet-coding schemes are especially suitable for applications where scalability and tolerable degradation are important. New image coding standard, JPEG-2000[4], which has been based upon DWT. And the DWT is the popular one and many excellent algorithms, such as SPIHT [5], embedded image compression based on wavelet pixel classification and sorting etc, are proposed to encode the transform coefficients. But the disadvantages of DWT include the cost computing of DWT as compared to DCT are higher, the use of larger DWT basis filters produces blurring and ringing effect near edge regions in images, and compression time with DWT based schedule decomposed time longer than DCT based one.

II. PROPOSED ALGORITHM

An algorithm for DWT coefficients, such as SPIHT, is excellent in image compression, but the computing com

plexity of DWT is a common defect in these algorithms. Therefore, this algorithm adopts DCT and modified SPIHT algorithm[6] that designed for encoding the DWT coefficients. The algorithm that was called DCT-based-MSPIHT was modified to suit it to encode DCT coefficients. Finally, the proposed algorithm provides the enhancement function in low bit rate. [7]

A. DCT-based-MSPIHT

The compression performance of MSPIHT is more exceptional than of the original SPIHT, but it was proposed to encode the DWT-based image. Therefore, we modified the MSPIHT algorithm that use the combined function and dictator function to reduce the relationship between the same level subbands, the MSPIHT algorithm flowchart are shown in Figure 1. First, we decompose the image into ten subbands. Second, the significant DWT coefficients are sorted and this pass is suited for progressive transmission. Third, the combined function and dictator function reduce the redundancy between the same level subbands. The refinement pass evaluates the reconstructive value. The classification of the significant quadtree is good to get exceptional entropy coding. Finally, we transmit the bitstream.

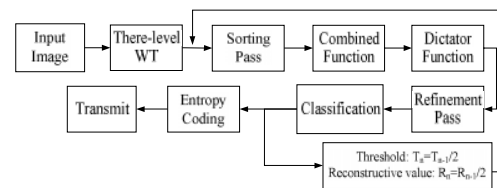


Fig. 1 MSPIHT algorithm.

The MSPIHT compression performance is exceptional than the original SPIHT's, but that encodes DWT coefficients not DCT coefficients. Therefore, we represent the DCT coefficients into subbands and use the MSPIHT to encode the represented DCT coefficients.

For block-based DCT coding, an input image is first partitioned into $n \times n$ blocks, where $n = 2L$, $L > 2$. Each block is then transformed into the DCT domain and can be taken as an L -scale tree of coefficients with $3 \times L + 1$ subbands decomposition. After that, the same subbands for all DCT blocks are grouped and put onto their corresponding positions. We represent this reorganization of DCT coefficients into a single DCT clustering entity. Figure 2 demonstrates an 8×8 DCT block taken as three-scale tree structure with ten-subband decomposition. The reorganization of 8×8 DCT with ten-subband decomposition is illustrated in Figure 3. In Figure 3, Go0 denotes Group of subband 0 and GoN denotes Group of subband N.

Following features can be seen. Signal energy is compacted mostly into dc coefficients and small numbers of ac coefficients are related to the edges in spatial domain. Similarity between cross subbands and magnitude decay across

Yen-Yu Chen is with the Chung Chou Institute of Technology, Changhua, Taiwan (e-mail: miscyy@tcts1.seed.net.tw).

Pao-Ching Chu is with the Chung Chou Institute of Technology, Changhua, Taiwan (e-mail: chumike@dragon.ccut.edu.tw).

Ya-Ling Tsai is with the Chung Chou Institute of Technology, Changhua, Taiwan (e-mail: cateye0425@yahoo.com.tw).

subbands can be observed. The significant coefficients within subbands tend to be more clustered.

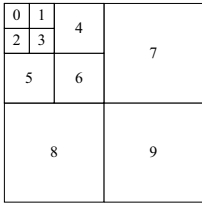


Fig. 2 8 x 8 DCT block taken as ten-subband decomposition.

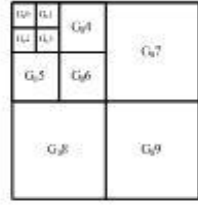


Fig. 3 Reorganization of 8 x 8 DCT blocks into a single DCT clustering entity.

B. Enhancement filter

A low computational enhancement filter with four modes is proposed, including three frequency-related modes (smooth modes, intermediate mode, and complex mode for low-frequency, mid-frequency, and high-frequency regions, respectively) and one special mode (steep mode for a large offset between two blocks). A mode decision procedure is also needed to decide which mode is given by observing pixel behavior around the block boundary. To take the masking effect of HVS into consideration, the filter for smooth mode is designed much stronger than that for complex mode, because the human eyes are more sensitive to smooth regions.

Because most of the blocking artifacts occur on 8 x 8 block boundaries, the filtering should make its efforts on pixels around the block boundaries. Figure 4 shows how the pixel vectors are extracted from the block boundaries horizontally and vertically. The pixel vector is filtered one by one. The updated pixels are retained for next filtering.

The flowchart of the proposed algorithm is shown in Figure 5. The blocking artifact is caused by the discontinuity between V3 and V4. For simplicity, we use word offset to represent the difference of V3 and V4. If offset is larger than a threshold 'edge_Thre', this pixel vector is skipped because it may contain a real edge. Otherwise, the pixel vector is passed to the mode decision stage to decide which mode it belongs to. After that, a suitable filter for each mode is used to remove the blockiness. The proposed algorithm is composed of mode decision stage part and filtering stage.

The purpose of the mode decision is to determine the mode of filtering required to alleviate the blocking effect without excessively blurring the local feature. It is achieved by calculating the variation in the pixel vector and the calculating formulation is listed as follow:

$$'activity' = \sum_{i=1}^5 \Phi(v_i - v_{i+1}) \quad (1)$$

$$\text{where, } \Phi(\Delta) = \begin{cases} 0, & \text{if } |\Delta| \leq S \\ 1, & \text{otherwise} \end{cases} \quad (2)$$

The activity value represents the variation of the pixel vector. That is, a small 'activity' indicates a smooth region, whereas a high 'activity' indicates a region with edge detail.

The 'activity' value is compared with two thresholds,

Tlow and Thigh, to determine the appropriate filtering mode. Tlow is set to suitable small value to ensure that the region is sufficiently smooth to apply smooth mode filtering when 'activity' < Tlow. Similarly, the use of complex mode filtering is specified if 'activity' > Thigh in areas of high spatial complexity. If 'activity' is between Tlow and Thigh, intermediate filtering is adopted to improve visual quality. For the above three cases, if the absolute value of offset is too large, for example, when the pixel vector belongs to smooth mode and the offset is larger than 2T, steep mode is designed for this situation.

There are total four filter modes in the filtering stage: smooth mode, intermediate mode, complex mode and steep mode. Excepting steep mode, the other modes are corresponding to three different frequency bands that are low-frequency, mid-frequency and high-frequency. Implementation of these filters is discussed below.

C. Filter for Smooth Mode

The filter for smooth mode is shown as following step:

1. Calculate the difference between two blocks:
 $offset = V4 - V3;$
2. Update V1, V2, V3, V4, V5, V6:
 $V1' = V1 + offset / 8;$ $V2' = V2 + offset / 4;$
 $V3' = V3 + offset / 2;$ $V4' = V4 - offset / 2;$
 $V5' = V5 - offset / 4;$ $V6' = V6 - offset / 8;$
3. Adjust these all updated pixels value within 0 to 255

It can be seen that the updated pixels not only contain two pixels across block boundary (V3 and V4) but also adjacent pixels (V1, V2, V5 and V6). The filtered pixel vector no longer has sharp discontinuity around block boundary.

D. Filter for Complex Mode

In complex mode, gray values of pixel vector are oscillated and human eyes are not sensitive to this region. If the blocking effects occur in a high activity region, strong filtering is not appropriate because it over-blurs the true edge also imposes an unnecessary computational burden. Following the concept, the total length of the line of filtered pixels is limited to two. The filter for complex mode is discussed below:

1. Calculate the difference between two blocks:
 $offset = V4 - V3;$
2. Update V3 to V3':
 $\text{if } |V2 - V3| < T \text{ then } V3' = (V2 + 2 \times V3 + V4) / 4;$
 $\text{else } V3' = V3 + offset / 4;$
 end
3. Update V4 to V4':
 $\text{if } |V4 - V5| < T \text{ then } V4' = (V3 + 2 \times V4 + V5) / 4;$
 $\text{else } V4' = V4 - offset / 4;$
 end
4. Adjust these all updated pixels value within 0 to 255

Although the updated pixels include only two pixels across block boundary (V3 and V4), the adjacent pixels (V2 and V5) can be used as reference for more accurate reconstruction of image. If adjacent pixels are referable (difference of grayscale value not exceeding a threshold, T), a 3-tap low-pass filter can be used to smooth this region. Otherwise, the filter will alleviate the blockiness by

shortening the distance between V3 and V4.

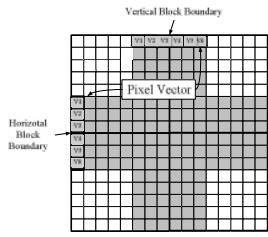


Fig. 4 Pixel vectors across block boundaries

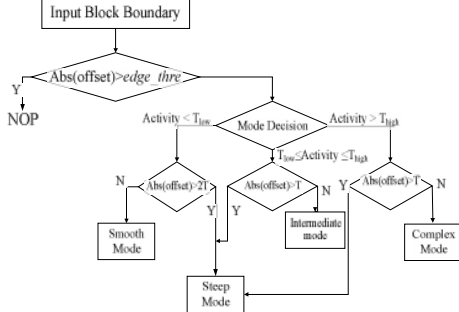


Fig. 5 Flowchart of the proposed enhancement algorithm

E. Filter for Intermediate Mode

Filtering for intermediate mode is shown as follow:

1. Calculate the difference between two blocks:
 $offset = V4 - V3;$
2. Update V3 to V3'
if $|V2 - V3| < T$ then $V3' = (V2 + 2 \times V3 + V4) / 4;$
else $V3' = V3 + offset / 2;$
end
3. Update V4 to V4'
if $|V4 - V5| < T$ then $V4' = (V3 + 2 \times V4 + V5) / 4;$
else $V4' = V4 - offset / 2;$
end
4. Adjust these all updated pixels value within 0 to 255

Both complex mode and intermediate mode use the same 3-tap low-pass filter when adjacent pixels are referable. If adjacent pixels are not referable, intermediate mode update pixels by offset/2 while complex mode update pixels by offset/4. This is because that in complex mode, it is reasonable to preserve high-frequency characteristic to prevent over-smoothing.

F. Filter for Steep Mode

The steep mode is a special filter that is used to not only improve visual quality but also remove blocking artifact. In many cases, an edge happened on block boundaries may be enhanced because of blocking artifact. The enhanced edges sometimes make human eyes uncomfortable. Filtering for steep mode is shown as follow:

1. Calculate the difference between two blocks:
 $offset = V4 - V3;$
2. Update V3 and V4 by means of the offset:
 $V3' = V3 + offset / 4;$
 $V4' = V4 - offset / 4;$
3. Adjust these all updated pixels value within 0 to 255

Figure 6(a) presents the complete block diagram of the encoder for compressing still images. First, the test image is transformed by 8 x 8 DCT and represented into subband distribution image. Then the proposed algorithm deals with

subband LL3 in a sorting pass that is the same as that of the MSPIHT algorithm. The results of sorting pass include the bitmap and the sign information of significant coefficients. LH3, HL3, and HH3 subbands are handled by a combined function that reduces the interband redundancy, and the results include information indicates which subband has significant coefficients. The proposed algorithm deals with the other subbands using a dictator function and the results decide which should be sent. The proposed algorithm also uses the refinement pass and the results include the bits to correct the reconstructed value. Finally, entropy coding is used to improve performance and transmit the bit stream. The receiver decodes the bit stream and reverses the entropy coding. And then the receiver reconstructs the bit plane and adjusts the reconstructive DCT values by exact pass. When all of the bit streams are decoded, the reconstructive DCT values are represented and the decoder reverses the reconstructive DCT values to reconstructive spatial pixel values. Figure 6(b) presents the complete block diagram of the decoder with enhancement algorithm.

The enhancement function based on four filtering modes is proposed. These four filtering modes include three frequency-related filters (low-frequency, mid-frequency, and high-frequency) and one special filter. By observing the characteristic across block boundaries, suitable filter is used to remove the blocking artifact. After applying filters on the block boundaries, the block artifact is removed without over-smoothing the image details. The deblocking function is better to contain no multiplication and division instruction. All the instructions can be used are addition, subtraction, comparison and shift operations. Finally, the computation must be low enough for real time applications.

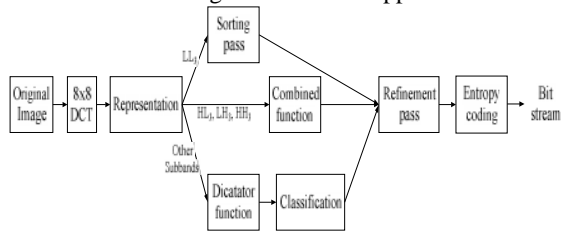


Fig. 6(a) Flowchart of the DCT-based-MSPIHT encoder



Fig. 6(b) Flowchart of the DCT-based-MSPIHT decoder with the enhancement function

III. SIMULATION RESULTS

The performance is evaluated by PSNR (peak signal to noise ratio) value. PSNR value is a mathematics evaluation expression. The DCT-based-MSPIHT is compared with JPEG2000 and JPEG. Table 1 compares the PSNR values at various bit rates obtained using JPEG, JPEG 2000 and the DCT-based-MSPIHT algorithm with/ without enhancement function. The values in () are the PSNR of the reconstructive image decoded by DCT-based-MSPIHT algorithm without enhancement function. And the visual quality of the DCT-based-MSPIHT algorithm with enhancement is obviously better than JPEG and JPEG 2000.

TABLE I
PSNR VALUES FOR JPEG, JPEG 2000 AND DCT-BASED-MSPIHT
ALGORITHM AT VARIOUS BIT RATES IN WOMAN TEST IMAGE

Bit-rate (bpp)	JPEG (dB)	JPEG2000 (dB)	DCT-based-MSPIHT (dB)
0.03		24.17	23.71 (23.48)
0.12	24.91	27.01	27.05 (26.97)
0.28	28.69	30.53	30.34 (30.96)
0.53	31.40	33.99	35.30
0.94	34.60	37.97	39.58
1.60	38.75	42.03	44.55

IV. CONCLUSIONS

This work proposed a novel algorithm for encoding of the still image and reducing of blocking artifact in transform coded images. The challenges posed by imaging involve the development of a compression algorithm that has a computational complexity near that of the DCT, yet supports the DWT-based high-compression ratios to reduce storage, transmission, and processing.

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Yen-Yu Chen received his Ph.D. degree in Electrical Engineer from the National Cheng Kung University, Tainan, Taiwan. He is currently a Professor of Department of Information Management at the Chung Chou Institute of Technology, Taiwan. His research interests include biomedical signal processing, image processing, and data compression.

Pao-Ching Chu received his Ph.D. degree in Sociology, Ecole des Hautes Etudes en Sciences Sociales, France. He is currently an Assistant Professor of Department of Creative Fashion Design and Management, Chung Chou Institute of Technology, Taiwan. His research includes paternalistic management, organizational behavior, and service failure and recovery.

Ya-Ling Tsai received his BS and MS in Chung Chou Institute of Technology, Taiwan. His research interests include image processing, and multimedia communication.