Improved JPEG 2000 System Using LS Prediction and Grouping Context Coding Scheme

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***Abstract*— In this paper, two coding strategies are proposed to improve the coding efficiency of the JPEG2000 system. First, instead of using the embedded block coding with optimized truncation (EBCOT) scheme in all subbands, we apply the algorithm based on least square prediction in the LL part of the discrete wavelet transform domain. Moreover, in the LH, HL, and HH parts, instead of using the MQ coder and the fixed probability table, we group the 19 contexts into 7 classes. Since the characteristics of the contexts in EBCOT are different from one another, it is proper to use different probability tables for different classes. Simulation results demonstrate that the proposed methods significantly improve the coding efficiency of the JPEG2000 system.**

I. INTRODUCTION

JPEG2000 [1][2] is a popular discrete wavelet transform (DWT) based still image compression standard. It provides better performance in terms of visual quality and peak signal-to-noise ratio (PSNR). Compared with Joint Picture Experts Group (JPEG)], it has very low bit rate. The high coding efficiency of JPEG2000 is due to the use of the DWT and its effective entropy coding scheme. The DWT offers an efficient multiresolution representation [3] and LL subband contains most information of the original image. The coding process of JPEG 2000 can be divided into two steps: Tier 1 coding and Tier 2 coding, as in Fig. 1. In Tier 1, bit plane conversion, the EBCOT scheme, the MQ coder, and arithmetic coding are applied to encode each subband.

Although JPEG2000 has very high coding efficiency, we believe that it still have room to further improve the performance. In this paper, we propose two methods to further improve the coding efficiency of JPEG 2000: (1) Instead of using EBCOT for all the four subbands (LL, LH, HL, and HH) in the DWT domain, we use least square prediction (LSP) in the LL subband. The LSP approach can effectively predict the image due to its powerful capability of predicting arbitrarily oriented edges [4][5]. Note that the magnitude of the DWT coefficients in the LL subband is usually very large and a lot of bit planes are required. Therefore, using EBCOT may not be efficient for coding the DWT coefficients in the LL subband. (2) For the LH, HL, and HH subbands, the 19 contexts in EBCOT are grouping into 7 classes and each class has its own probability table. The classification is based on the characteristics of contexts.

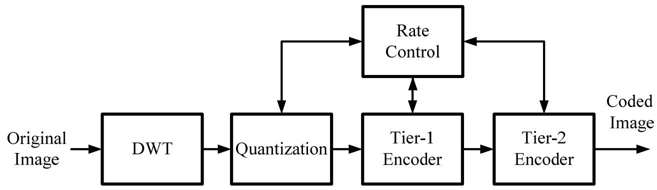

Fig. 1 Block diagram of the JPEG2000 encoder.

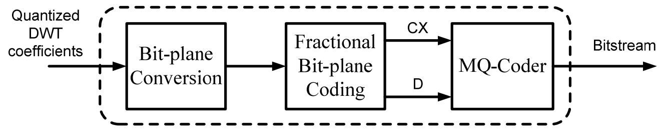

Fig. 2 Block diagram of the Tier-1 encoder.

The paper is organized as follows. In Section II, the JPEG2000 standard is reviewed. In Section III, the proposed methods are introduced. Section IV describes the experimental results. Section V presents a conclusion.

II. REVIEW OF JPEG2000

In this section, we present the overview the JPEG2000 image compression standard. Fig. 1 shows the block diagram of the JPEG2000 encoder which can be divided into four basic steps: (1) the DWT, (2) quantization, (3) the Tier-1 encoder, and (4) the Tier-2 encoder. The DWT is used to compact most energy of the input image into a few coefficients which are then quantized and entropy encoded [1][2]. In JPEG2000, the input image is partitioned into nonoverlaping blocks called tiles. Then each tile is transformed into subbands by the DWT. Then, various quantization steps for different frequency bands are applied. After performing the DWT and quantization, the wavelet coefficients are partitioned into 4×4 blocks, which are the basic units of entropy coding. The central part of entropy coding is the embedded block coding with optimized truncation (EBCOT) algorithm [6][7]. EBCOT is a two-tiered coding algorithm, which refers to Tier-1 coding and Tier-2 coding. The former one includes bit-plane conversion, fractional bit-plane coding (BPC), the MQ-coder, and binary arithmetic coding (BAC), as in Fig. 2. The latter one is aimed at rate-distortion optimization. In EBCOT, Tier-1 coding first encodes each bit-plane by fractional BPC in three coding passes sequentially and generates intermediate data: a context (CX) and a binary decision D. The three coding passes called

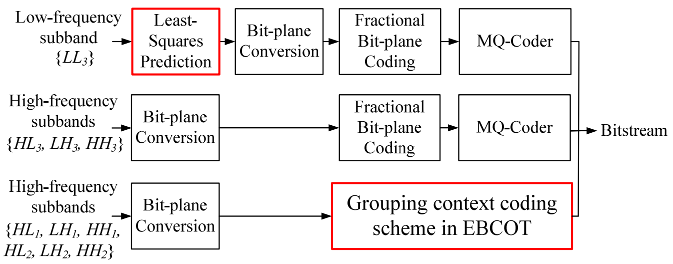

Fig. 3 Block diagram of the proposed scheme. The parts marked by red borders are the proposed schemes.

the significance propagation pass (SPP), the magnitude refinement pass (MRP), and the cleanup pass (CUP). They are performed in order. Then, four primitive coding operations, which are zero coding (ZC), run-length coding (RLC), sign coding (SC), and magnitude refinement (MR), are used to generate the intermediate data pairs (CX, D) in the coding passes.

The MQ-coder, which is the context adaptive BAC, uses the context information selected by the MQ probability table to encode the binary decision values. The MQ-coder is originally used in the JBIG2 standard to compress bi-level images [8]. In JPEG2000, it uses 19 different contexts (CX= 0~18) generated by four coding operations to keep track of the 47 indexes of the MQ table [1][2].

III. Proposed Schemes for JPEG2000

In this section, the use of LSP in the low-frequency subband and the proposed grouping context coding scheme for the context-adaptive BAC algorithm is introduced. Fig. 3 shows the block diagram of the proposed scheme. We denote LL_0 by the original image at scale 0. After the n-level DWT, a set of subbands $\{HL_k, LH_k, HH_k;\ k = 1, 2, \ldots, n\}$ can be obtained. In this paper, we use the 3-level DWT for image compression to compare the performance. All the subbands are divided into three parts: $\{LL_3\}$, $\{HL_3, LH_3, HH_3\}$, and $\{HL_1, LH_1, HH_1, HL_2, LH_2, HH_2\}$, which are encoded by different algorithms, as shown in Fig. 3.

A. Least-Squares Prediction Approach

The LSP approach determines the current pixel value by adaptively filtering its causal neighbors. According to the N^{th} order Markovian model, the filtering coefficients are derived based on the training window using the reconstructed data. This linear prediction well suits for matching the arbitrarily oriented edge. Consider the N nearest neighbors, which are the supports of the predictor, the value of the current pixel $X(n)$ can be predicted by the LPS approach as follows:

$$\hat{X}(n) = \sum_{k=1}^{N} a_k X(n-k) \qquad (1)$$

where a_k is the prediction coefficient of the neighbor $X(n\text{-}k)$. These coefficients are locally optimized using a causal training window whose size is chosen as $M = 2T(T+1)$ elements (see Fig. 4(a)).

The training sequence can be obtained by an $M \times 1$ column vector $\mathbf{y} = [X(n\text{-}1), X(n\text{-}2), \ldots, X(n\text{-}N)]^{\mathrm{T}}$ and the order of causal neighbors is shown as in Fig. 4(b).

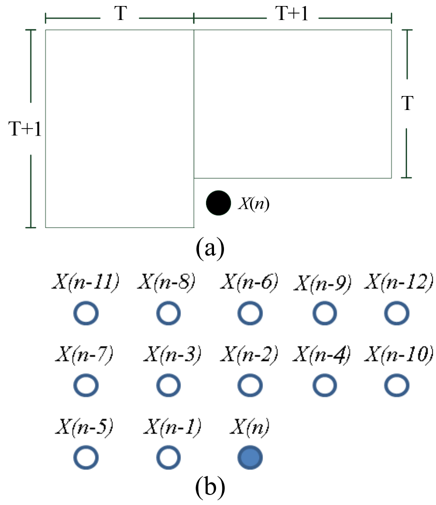

Fig. 4 (a) Training window for LSP. (b) Ordering of causal pixels for $X(n)$.

To determine the coefficients, LS optimization is used to solve for $\|\mathbf{y}\text{-}\mathbf{C}\mathbf{a}\|^2$, $\mathbf{a}= [\,a_1, a_2, \ldots, a_N\,]^{\mathrm{T}}$ with the prediction neighbors of $\mathbf{y}$. The matrix $\mathbf{C}$ is

$$C = \begin{bmatrix} X(n-1-1) & \ldots & X(n-1-N) \\ \vdots & & \vdots \\ X(n-M-1) & \ldots & X(n-M-N) \end{bmatrix}$$

and the optimal coefficients $\mathbf{a}$ is

$$\mathbf{a}= (\mathbf{C}^{\mathrm{T}}\mathbf{C})^{-1}(\mathbf{C}^{\mathrm{T}}\mathbf{y}). \qquad (2)$$

Since the edge-directed property, which means that edge pixels play a dominant role in the LS optimization, LSP is capable of tuning the prediction coefficients to arbitrarily oriented edges.

B. Using LSP for the Low-Frequency Subband of JPEG2000

After the 3-level DWT, the low-frequency LL_3 subband of the image represents the downscaled approximation of the original image. In traditional JPEG2000, it is directly fed into the Tier-1 encoder. Since interpixel redundancy still exists, the pixel values of the LL_3 subband after quantization are usually not zero and have a large magnitude. It will degrade the coding performance. In our approach, the LSP approach discussed above is used to achieve decorrelation before the entropy coding. Because the optimal coefficients are obtained by the already neighboring coded samples, the same optimal ones are also available at the decoder. Hence, no side information needs to be transmitted.

C. Proposed Grouping Context Coding Scheme High-Frequency Subbands

In this subsection, the grouping context coding scheme is performed on high-frequency subbands, $\{HL_1, LH_1, HH_1, HL_2, LH_2, HH_2$, where the subscripts 1 and 2 means the subbands in the 1st and the 2nd layers of the DWT$\}$ are introduced to improve the performance of the MQ-coder.

TABLE I CLASSIFYING THE 19 CONTEXTS IN EBCOT INTO 7 CLASSES

CX	Edge	Non-edge
0, 1, 3	Class1	Class2
2, 4~8, 14~16	Class3	Class4
9~13	Class5	
17	Class6	
18	Class7	

The characteristics of the 19 contexts (CX = 0~18) used in EBCOT are different from one another. Therefore, it is improper to use the same probability table for all the contexts, as the case of the JPEG2000 standard. However, since there are 47 indexes in a probability table, it is also inconvenient to generate the probability table for each context. Therefore, we group the context into 7 classes, as in Table I. Each class has its own probability table, as the example in Table II.

Note that, in EBCOT [6][7], CX0~CX8 correspond to zero coding. Among them, CX0, CX1, and CX3 are related to the small variation case and others are related to the large variation case. Therefore, we group CX0, CX1, and CX3 into a category and group CX2, CX4~CX8 into the other category. Furthermore, we observe that the probabilities of CX0~CX8 are quite different in the edge case and the non-edge case. Therefore, according to whether a block belongs the edge region of the original image, we further separate CX0, CX1, and CX3 into two classes (i.e., Classes 1 and 2) and separate CX2, CX4~CX8 into Classes 3 and 4. Whether a block belongs the edge region can be predicted by calculating the gradients of the LL_3 subband.

Moreover, since CX9~CX13 correspond to sign coding, we group them into Class 5. CX14~CX16 correspond to magnitude refinement coding. However, we find that their probabilities are close to those of CX2, CX4~CX8. Therefore, we merge them into Classes 3 and 4. CX17 and CX18 are related to run length coding and we set them as Class 6 and Class 7. In Table II, we give an example of Lena image which is encoded by JPEG2000 with the above grouping context scheme and calculate the probabilities of each index corresponding to its class when the MQ-coder is performed. It is observed that probabilities of the indexes of the 7 classes are different from one another.

IV. SIMULATION RESULTS

In this section, we present some simulation results that justify the use of the proposed LSP approach in the LL_3 subband in the DWT domain and the grouping context coding scheme in high frequency subbands can improve the coding efficiency. Results of the state-of-the-art image compression standard, JPEG2000, are also presented.

In Tables III, IV, and V, it can be observed that the results demonstrated the performance of the proposed use of LSP and the grouping context coding scheme. In all the cases, our proposed scheme needs less number of bits to encode both the low-frequency subband $\{LL_3\}$ and high-frequency subbands $\{HL_1, LH_1, HH_1, HL_2, LH_2, HH_2\}$.

In Figs. 5(a), 5(b), and 5(c), the PSNR versus bit-rate curves for the proposed method and JPEG 2000 are shown.

TABLE II
THE PROBABILITY TABLES (MULTIPLIED BY 128) FOR THE 7 CLASSES WHEN USING EBCOT TO ENCODING THE HIGH FREQUENCY SUBBANDS OF LENA IMAGE AT 40.41 DB

Index	Probability of 0 (Multiplied by 128)						
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
0	116	124	92	92	52	/	/
1	100	116	76	76	84	/	/
2	108	116	100	100	100	/	/
3	116	116	116	116	116	116	/
4	116	116	116	116	116	116	/
5	126	126	126	126	126	126	/
6	84	92	68	68	60	124	/
7	84	108	84	76	76	124	/
8	104	104	104	88	72	120	/
9	108	116	92	84	76	124	/
10	104	120	88	88	88	120	/
11	120	120	88	88	88	120	/
12	108	116	100	100	100	108	/
13	120	104	104	104	104	104	/
14	78	74	74	66	66	74	/
15	90	86	78	70	66	86	/
16	102	90	86	74	66	90	/
17	106	94	90	78	74	90	/
18	98	94	94	82	74	94	/
19	102	98	98	86	82	98	/
20	110	98	98	86	86	102	/
21	110	102	106	90	90	106	/
22	110	106	106	94	98	110	/
23	114	106	110	94	102	110	/
24	114	106	114	98	106	110	/
25	114	110	110	98	110	114	/
26	118	110	106	98	106	114	/
27	118	114	110	98	110	118	/
28	118	114	106	98	110	118	/
29	118	114	114	98	110	118	/
30	118	114	114	114	114	118	/
31	118	114	114	114	114	122	/
32	122	114	126	126	122	122	/
33	118	118	126	126	114	126	/
34	122	122	126	126	126	126	/
35	122	122	126	126	126	126	/
36	126	126	126	126	126	126	/
37	127	127	127	127	127	127	/
38	127	127	127	127	127	127	/
39	127	127	127	127	127	127	/
40	127	127	127	127	127	127	/
41	127	127	127	127	127	127	/
42	127	127	127	127	127	127	/
43	127	127	127	127	127	127	/
44	127	127	127	127	127	127	/
45	127	127	127	127	127	127	/
46	/	/	/	/	/	/	66

Since the proposed LSP approach can reduce the redundancy in the LL subband, and the proposed grouping context coding scheme can make ECBOT more efficient in the high frequency subbands, the proposed method outperforms JPEG2000 in all cases, as shown in Fig. 5.

TABLE III NUMBER OF BITS REQUIRED FOR LOW-FREQUENCY LL_3 SUBBAND AND SIX HIGH-FREQUENCY SUBBANDS FOR *LENA* IMAGE (INCLUDING THE BITS USED FOR ENCODING THE PROBABILITY TABLES).

PSNR (dB)	Number of bits required			
	LL_3 subbands		High-frequency subbands $\{HL_1, LH_1, HH_1, HL_2, LH_2, HH_2\}$	
	JPEG2000	**Proposed LSP**	JPEG2000	**Proposed Method**
34.71	30304	20312	25012	23729
37.31	33984	23320	74164	71644
40.41	38432	28384	199704	194913

TABLE IV NUMBER OF BITS REQUIRED FOR LOW-FREQUENCY LL_3 SUBBAND AND HIGH-FREQUENCY SUBBANDS FOR *BARBARA* IMAGE (INCLUDING THE BITS USED FOR ENCODING THE PROBABILITY TABLES).

PSNR (dB)	Number of bits required			
	LL_3 subbands		High-frequency subbands	
	JPEG2000	**Proposed LSP**	JPEG2000	**Proposed Method**
29.00	27720	19320	33236	31715
32.40	30392	21592	88164	85969
37.09	34952	26560	211888	207522

TABLE V NUMBER OF BITS REQUIRED FOR LOW-FREQUENCY LL_3 SUBBAND AND HIGH-FREQUENCY SUBBANDS FOR *PLANE* IMAGE (INCLUDING THE BITS USED FOR ENCODING THE PROBABILITY TABLES).

PSNR (dB)	Number of bits required			
	LL_3 subbands		High-frequency subbands	
	JPEG2000	**Proposed LSP**	JPEG2000	**Proposed Method**
23.81	27432	19368	25584	23864
25.87	28992	20464	80448	77346
29.37	30360	21968	213688	208248

V. CONCLUSIONS

In this paper, we propose the use of least-squares prediction in the LL subband and the grouping context coding scheme in the high-frequency subbands to improve the coding efficiency of JPEG2000. The simulation results demonstrated that the proposed methods lead to superior performance in comparison with JPEG2000 since the spatial correlation in the low-frequency subband is removed and the efficiency of EBCOT is improved when using the proposed schemes.

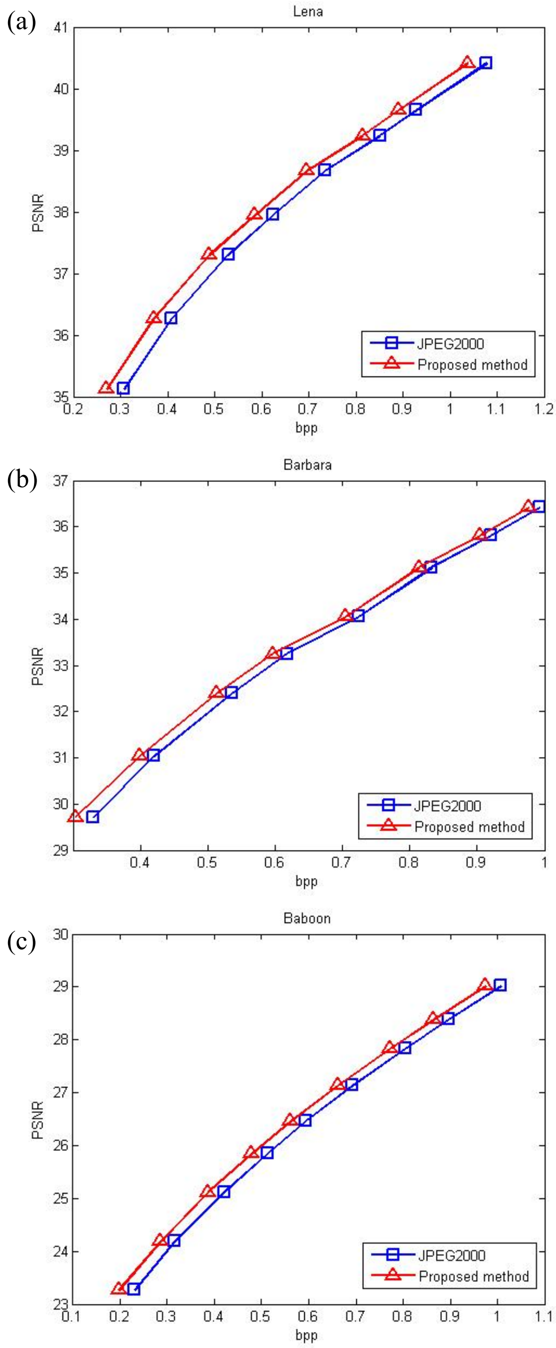

Fig. 5 Comparisons of PSNR versus bit-rate curves for the proposed method and JPEG2000. (a) *Lena*, (b) *Barbara*, and (c) *Baboon*.

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