Error Concealment Algorithm Using Interested Direction for JPEG 2000 Image Transmission

Pei-Jun Lee and Liang-Gee Chen, Fellow, IEEE

Abstract —*Digital image transmission is widely used in consumer products, e.g., digital camera and cellular phone, etc. The newly defined JPEG 2000 delivers image with lower bit rate in the internet and wireless communications. However, JPEG 2000 decoding is processed bitplane by bitplane. Any data loss in bitstream will affect the consequent bitplanes and even possibly destroy the whole picture. We propose a new algorithm to recover the damaged bitplanes data according to the interested directional sets (IDS) of in-subband. The proposed algorithm is quite simple, but is very efficient in concealing the loss data of any subband in streaming real-time video data in the internet and wireless communications. The simulation results show that the proposed algorithm has 1.5~3dB improvement than previously presented error resilient mechanism. In a subjective view, the proposed concealment algorithm can achieve much smoother edges on the reconstructed images.*[1]

Index Terms — Error concealment, Interested directional set, Bitplane, Image transmission.

I. Introduction

In recent years, the digital consumer products are widely used in human life, e.g., Digital camera, cellular phone, mp3... Moreover, the internet and wireless communications have grown astronomically. The images captured by the digital camera and transmitted through the internet and wireless communication is one of the trends of consumer electronics. However, the bandwidth of the wireless channel is narrow and expensive, when errors occur, it is not economical and adequate to re-transmit the corrected data through this narrow bandwidth. Moreover, unreliable wireless channels may inject errors into the transmitted bitstream. Since wireless multimedia will have much wider application in the future, a system of high compression rate image codec with error resilience property has become necessary for image/video transmission. The new standard JPEG 2000 is a growing image coding standard under development by ISO/IEC Joint Photographic Experts Group (JPEG) [1]. JPEG 2000 is suitable to be applied to wireless image transmutation, since, JPEG 2000 delivers image with lower bit rate and takes account of error resilience. For the mobile applications, a report of ISO/IEC JTC 1/SC 29/WG 1 [4] recommends the above-mentioned encoding options.

P.J. Lee is a Ph.D. candidate at Graduate Institute of Electronics Eng. and Department of Electrical Eng., National Taiwan University, Taiwan, R.O.C. (email: pjlee@video.ee.ntu.edu.tw)

L.G. Chen is with the Graduate Institute of Electronics Eng. and Department of Electrical Eng., National Taiwan University, Taiwan, R.O.C. (email: lgchen@video.ee.ntu.edu.tw)

Discrete wavelet transform (DWT), quantization, and EBCOT (Embedded Block Coding with Optimization Truncation of the embedded bitstream) algorithms [2] are important technologies used in JPEG 2000. DWT has higher performance and a finer scalability than DCT-based coding. EBCOT algorithm includes context model arithmetic coding and post-compression rate allocation. Those algorithms make JPEG 2000 have better error robustness than that of JPEG. However, there is still a drawback in JPEG 2000, that is, even one bit error will as a result of the fact that in loss of synchronization at the entropy decoder mainly because the DWT coefficient can be fully damaged. Then the reconstructed image will be severely influenced.

In order to solve this problem, the error resilience tools are developed for JPEG 2000 applications. The error resilient tools adopted by JPEG 2000 can be classified into two major types [3], the *entropy coding level*, and the *packet level*. The entropy coding level contains code-blocks, termination of the arithmetic coder for each pass, reset of contexts, selective arithmetic coding bypass, and segmentation symbol. Packet with resynchronization marker is included in the packet level.

The error resilient tools have been presented in JPEG 2000 Verification Model (VM) [5]. Resynchronization tools cause resynchronization in the decoder when errors are detected in the bitstream. The error detection tools, such as segmentation symbols termination marker, enable the decoder to detect residual bit errors. After detecting errors, the decoder must be able to conceal the error with some concealment methods. However, the existing traditionally block-based methods [6,7,8] for JPEG/MPEG are not suitable for JPEG 2000. [1,5] replace the missing wavelet coefficients by zero. However, the replacement may affect lots of significant non-zero coefficients; for example, some high frequency components will be lost. [10] conceals the lost bitplane by using the concept of cross-subband correlation. The method does not apply to low frequency subband (LL band and the lowest level). Therefore, when upper low frequency subband is lost, there is still significant image deterioration.

In this paper, we propose an efficient algorithm to recover damaged wavelet coefficients is presented, the interested direction sets (IDS) of in-subband are proposed to estimate the significant nodes position of damaged bitplane.

The paper is organized as follows: Section II starts with the problem description of the error in transmission channel and JPEG 2000 error resilience. Section III presents the algorithm for JPEG 2000 error recovery. Extensive experimental results are included in section IV. Finally, a conclusion is drawn in section V.

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II. THE PROBLEM DESCRIPTION

In JPEG 2000, the quality of the decoded erroneous image depends on which subbands are damaged. If the error occurs on higher subbands (high frequency) that contain the "edge" information, the decoded image will look blurred and contain ringing artifact. In fact, each subband block is coded by bitplane in JPEG 2000. However, the bit-error during transmission will result in the loss of some wavelet coefficients relevant to a code-block in the subband. Thus, all wavelet coefficients of the code block will be incorrect. Let us illustrate the problem in Fig.1. Fig.1 (b) and Fig.1 (d) are the compressed DWT coefficients of the picture of "Lena" with bit rate=1.0. Since there is a bit error in the 2nd bitplane in HL_{i-1} subband in Fig.1 (b) and another in the HL_i subband is shown in Fig.1 (d), the reconstructed image is shown in Fig.1 (a) and Fig.1 (c) respectively. Therefore, it is seen that a single bit error may affect the quality of the image. When the bit error occurs in the lower level subband, the image quality can be affected much more seriously. The received wavelet coefficients in the upper bitplanes are much more seriously affected than those in the lower bitplanes when errors exist.

When the errors are detected by the error detection mechanisms (ERTERM, RESTART and SEGMAK) [5] in JPEG 2000, the relevant coding pass is discarded. The error concealment should be triggered. Unfortunately, in JPEG 2000, no concealment is used. The simplest in VM [5] method is using zero to replace the missing bitplane data. In the case in Fig.1 (a) and (b), it is seen that Fig.2 (a) is the reconstructed image by zero replacement in the missing bitplane data of DWT coefficients (shift 127) in Fig.2 (b). Fig.2 (c) and (d) are the original image and its DWT coefficients (shift 127). If zero replaces the missing bitplane data, some significant data will be lost to IDWT. Therefore, it is necessary to recover the significant data on bitplane domain.

To solve this problem, we adopt the interested direction sets (IDS) of in-subband to estimate the significant nodes' positions to replace the missing bitplane data. We will present the algorithm in details below.

III. THE PROPOSED CONCEALMENT ALGORITHM

In the relative literature [9,11], there are many efficient wavelet coding techniques to detect significant nodes. [11] utilizes the interested direction patterns of in-subband to express the relationship among subbands. The relation among wavelet coefficients has two properties. First, the new significant nodes are situated in certain directions of the significant nodes already detected in the previous bitplanes and they are clustered. Next, the pattern formed by significant nodes at the neighborhood of father node is usually very similar to that formed in the current subband. Typically there

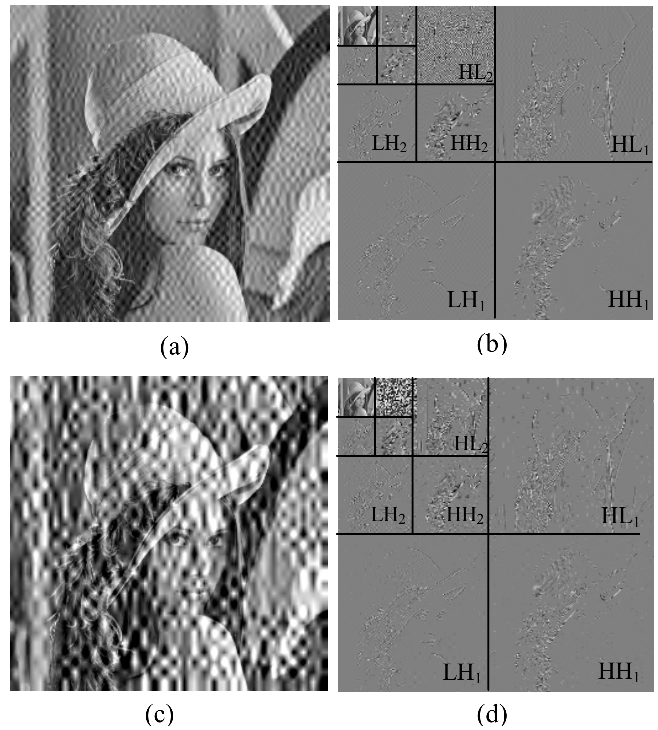


Fig.1 Single bit-error on different subbands with bit rate=1.0.

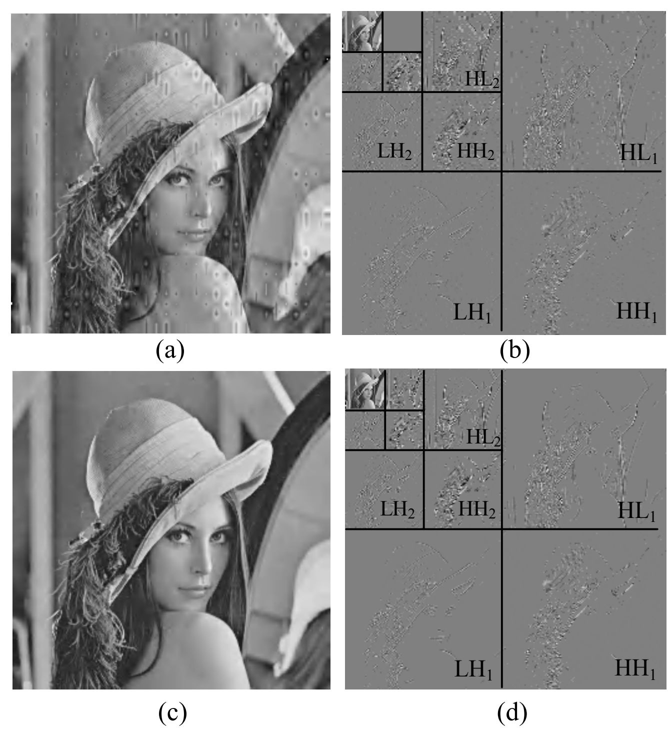


Fig.2 (a)(b) Reconstructed image by zero replacement. (c)(d) The original image.

are eight directions in directional of significance. But actually the directions of edges can be more than eight. In bitplane based wavelet image compression, the significant nodes are always clustered. According to the concept, we use the interested direction sets (IDS) of in-subband to determine the lost bitplane data. The direction sets (IDS) are shown in Fig.3. For different subbands, the interested directions are different.

(I) In HL subbands, we only consider the directions v-1 to v-4, their 180-degree rotations, and reflections with respect to x and y axes, respectively.

(II) We consider h-1 to h-4 in LH subbands, their 180-degree rotations, and reflections with respect to x and y axes, respectively.

(III) In HH subbands, the interested direction set is d-1, we should consider both v-1 and h-1 directions and their 180-degree rotations.

The decoder system overview is shown in Fig.4 (a). When the compressed image bitstream comes into the decoder, every pass will be decoded. Then errors can be detected by the error resilience mechanism in JPEG2000.

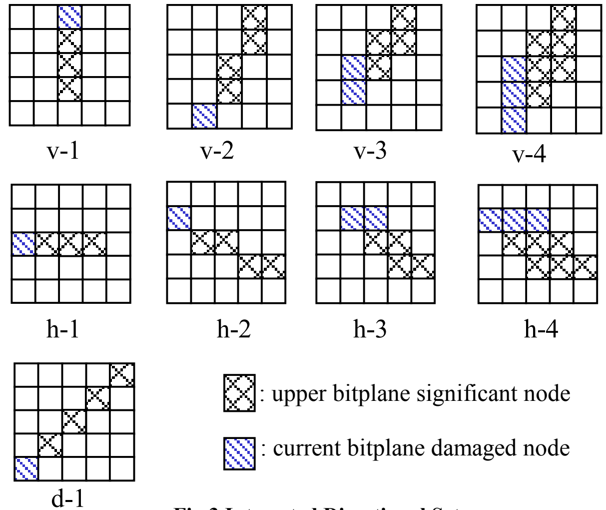
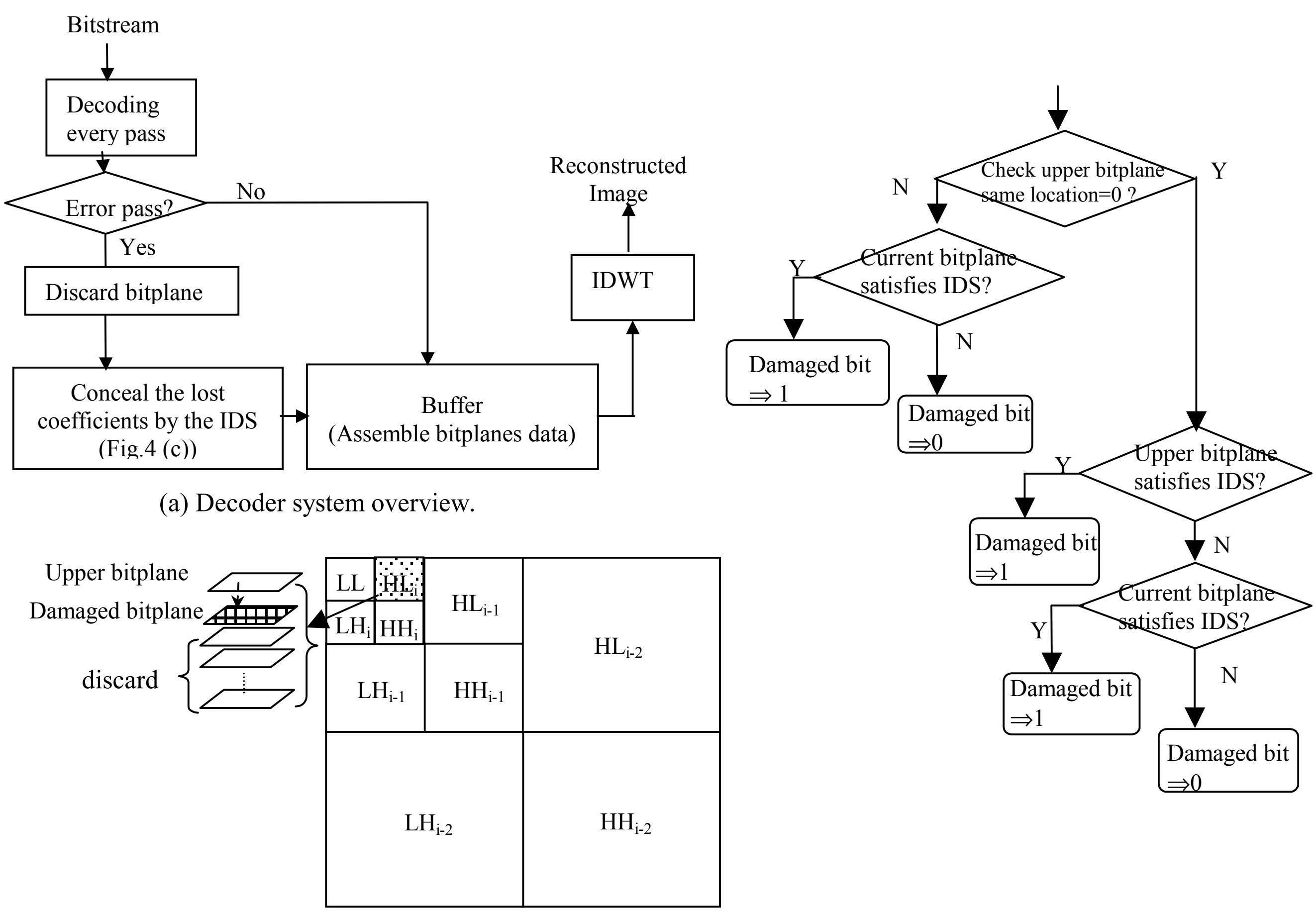


Fig.3 Interested Directional Sets.



(a) Decoder system overview.

(b) The structure of DWT coefficients.

(c) Proposed error concealment.

Fig.4 Flowchart of the recovering damaged bitplane.

If errors are detected, the relevant bitplane data will be discarded. The structure of DWT coefficients in the decoded bitstream is shown in Fig.4 (b). For each lost bit in any bitplane, the error concealment algorithm is triggered. The proposed error concealment algorithm shows the recovering procedure of the lost bit as follows.

Step 1: **Select the interested direction patterns:** Check which subband of (I)~(III) the lost bit belongs to, and then consider the corresponding interested directions in Fig.3.

Step 2: **Determine the replacement of the lost bit:** There are two cases to be considered.

Case 1: In the upper bitplane, the same location of the lost bit is “0”. If its interested direction sets (IDS) are satisfied, the lost bit is set to “1”. Otherwise, check the interested direction pattern with concealed bits in the current bitplane. If it is satisfied, then the lost bit is set to “1”; if not, it is set to “0”.

Case 2: In the upper bitplane, the same location of the lost bit is “1”. We only need to check the interested direction pattern with concealed bits in the current bitplane. If it is satisfied, then the lost bit is set to “1”, if not, it is set to “0”

The above is summarized as the flowchart of Fig.4 (c). After the two steps above, the lost bitplane data are recovered. Then the recovered data are collected for the coefficients of IDWT and for reconstructing the image.

I. Simulation Results

In this section, we illustrate the effectiveness of the proposed algorithm. The algorithm is tested with several pictures characterized by different bit rates. The simulation includes the following pictures: ”Lena,” ”Baboon,” ”Jet,” ”Barbara,” ”Pepper” and ”Goldhill” with 256×256 pixels. During the experiments, three decomposition levels and 5/3 filter are used. The simulation tests are based on JPEG 2000 Verification Model VM7.2, including with a single layer and a single tile-part compression. In the coded bitstream, the main header, the tile-part header and the packet data (headers and compressed data) can be found. We get full protection of the main header and the tile-part header. Each coded bitstream has error resilient properties, such as a resynchronization marker for each subband, a segmentation marker for each bitplane, and termination at each coding pass. Then the channel with burst error of BER 10e-3 transmits the bitstream. When the error occurs, DWT coefficients below the error bitplane will be affected. In decoding with error detection mechanism, the errors can be detected. In the experiment, the errors occur on the 2nd bitplane of the second decomposition level HL_2 and HL_3 subbands, respectively. The relevant bitplane data will be discarded until the resynchronization marker appears in the next subband. Then the error concealment mechanism is triggered. In the simulation, we compare three different methods:

(A) Zero replacements of the missing wavelet coefficients.

(B) The error concealment algorithm in [10].

(C) The proposed error concealment algorithm.

The PSNR values in the following figures and table are defined for the entire reconstructed image, since; the entire reconstructed image PSNR values are the important indicator of image quality. In Table.1 the comparison of PSNR for all test images among three different methods is shown. It is noted that HL_3 is the lowest subband. Method (B) must have correct and the lowest subbands information since it utilizes cross-subband correlation. If there is an error in the lowest subband, method (B) cannot be adopted. Therefore we use symbol “---“ to denote that there is no results. It is obvious that the proposed method can not only be used in the case of errors occurring in the lowest subband, but also has an improvement over method (A) by 1.5~3 dB.

Fig.5 (a) shows the results of the test images with low bit rate (bit rate=0.5bpp) in HL_3 subband. The proposed algorithm has a 0.5~3 dB improvement over the method (A). It is seen that our proposed algorithm is very suitable to the transmission of low bit rate images. Fig.5 (b) shows the objective comparison for “Lena” image with various bit rates in HL_3 subband. Our method is superior to the zero replacement method (A) in various bit rates.

It should be emphasized that the proposed algorithm can be applied to any subband. Fig.6 (a) and (b) are the results in HL_2 subband. Since method (B) uses the information of cross-subband and in-subband correlation, our method uses only in-subband interested direction sets (IDS). The information in our method is less than that in method (B), but the PSNR results of our method are close to those of [10]. We can summarize that the proposed method can be used in any subband, especially in the lowest subband.

The experimental results demonstrate that the proposed algorithm improves performance significantly in terms of subjective measurements compared with other methods as shown in Fig.7. Fig.7 (d) is the reconstructed image by our proposed algorithm, which has at least 2 dB improvement over the other two methods in Fig.7 (b) and Fig.7 (c). It also illustrates that Fig.7 (d) has much smoother edges than the other two figures in “mirror” and Lena’s “shoulder” and “face”, etc. The overall performance show that the proposed algorithm is much more efficient and robust for recovering the lost data in JPEG 2000 bitstream information.

II. Conclusion

In this paper, we have proposed a new technique to improve the error resilience ability for future digital consumer products using JPEG 2000 as image transmission. The proposed approach utilizes interested direction sets of in-subband and undamaged bitplane information instead of replacing the missing wavelet coefficients by zeros to recover damaged wavelet coefficients so that the recovered wavelet coefficients will be much similar with the noise free data. Furthermore, the proposed algorithm can be used in any subband, especially in the lowest subband. The experiments show that we have the objective results with at least 1.5~3 dB improvement over the methods without error resilient mechanism. And the subjective result can achieve much smoother edges on the reconstructed image. By using the proposed algorithm, more error robust image transmission using JPEG 2000 can be achieved.

REFERENCES

[1] D. Taubman, and M.W. Marcellin, "JPEG 2000 Image Compression Fundamentals, Standards and Practice," Kluwer Academic Publishers, Boston/Dordrecht/London, 2002.

[2] D. Taubman, "High performance scalable image compression with EBCOT," *IEEE Trans. Image Processing*, Vol.9, No.7, pp. 1158-1170, July 2000.

[3] C. Christopoulos, and E. Majani, (co-editors) " JPEG 2000 Part I Final Committee Draft Version 1.0," ISO/IEC JTC 1/SC 29/WG 1 N 1646R, March 16, 2001.

[4] C. Poulliat, and D. Nicholson, " Impact and efficiency of error resilience tools for mobile applications," ISO/IEC JTC 1/SC 29/WG1 N 2176, June 25, 2001.

[5] C. Christopoulos, (editor) " JPEG 2000 Verification Model 7.2 (Technical description)," ISO/IEC JTC 1/SC 29/WG1 N 1684.

[6] C. Christopoulos, A. Skodras, and T. Ebrahimi, "The JPEG 2000 still image coding system: An overview," *IEEE Trans. on Consumer Eletronics*, Vol.46, No.4, pp. 1103-1127, Nov. 2000.

[7] I. Moccagatta, S. Soudagar, J. Liang, and H. Chen, "Error-Resilient coding in JPEG 2000 and MPEG-4," *IEEE Journal on Selected Areas in Communications,* Vol.18, No.6, pp. 899-914, June 2000.

[8] L.Atzori, S. Corona, and D.D Giusto, "Error recovery in JPEG 2000 image transmission," *IEEE International Conference on Acoustics, Speech, and Signal Processing*, Vol.3, pp.1733-1736, 2001.

[9] C. Hanqiang, Z. Guangxi, and Z. Yaoting, "3D Visual Surface Reconstruction Based on Wavelet Decomposition and Fractal Interpolation," *Visual Communications and Image Processing, Proceeding of SPIE,* Vol. 4671, pp.1205-1209, 2002.

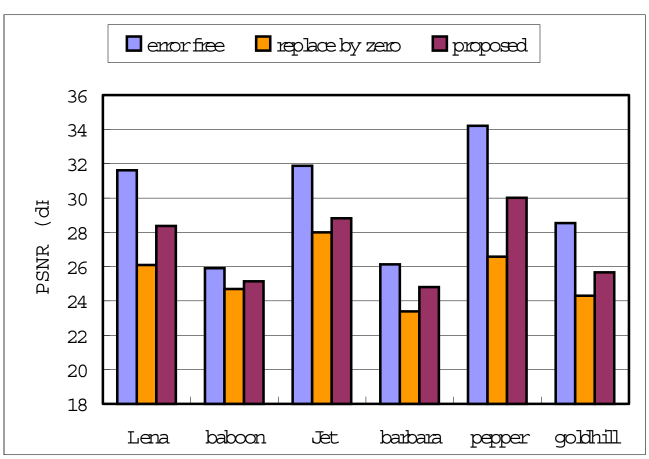
[10] P.J. Lee and L.G. Chen, "Bit-plane error recovery via cross subband for image transmission in JPEG 2000", *IEEE International Conference on Multimedia and Expo*, Switzerland, August 2002.

[11] Jia Wang, Songyu Yu and Jun Sun, "Wavelet image coding based on directional dilation," *SPIE Visual Communications and Image Processing,* Vol. 4671, pp.1175-1184, 2002.

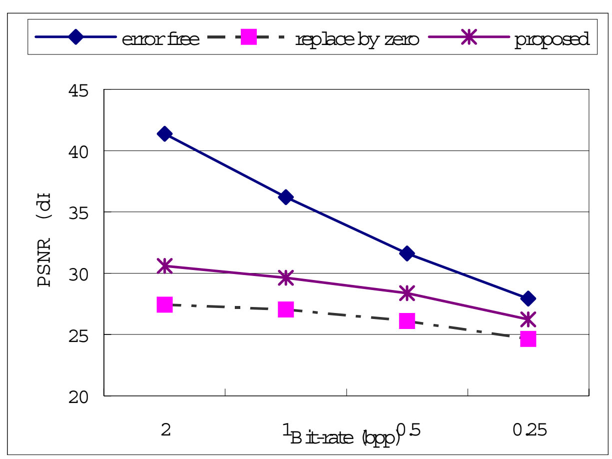
Table.1 PSNR(dB) comparison of all test images in HL_3 subband with various bit rate and BER 10e-3

Test image	Lena				Baboon				Jet			
Bit rate(bpp)	2.0	1.0	0.5	0.25	2.0	1.0	0.5	0.25	2.0	1.0	0.5	0.25
Error free	41.38	36.21	31.61	27.94	34.66	28.96	25.91	24.13	44.64	37.25	31.87	28.00
Replace by zero	27.43	27.05	26.1	24.65	29.33	26.8	24.69	23.32	28.89	28.45	27.99	27.19
Reference [10]	---	---	---	---	---	---	---	---	---	---	---	---
Proposed	30.59	29.64	28.38	26.24	30.09	27.26	25.15	23.75	30.95	30.3	28.81	27.51

Test image	Pepper				Goldhill			
Bit rate(bpp)	2.0	1.0	0.5	0.25	2.0	1.0	0.5	0.25
Error free	43.65	38.97	34.21	29.74	39.35	32.45	28.53	25.34
Replace by zero	26.59	25.32	23.39	21.79	28.85	24.15	24.31	24.23
Reference [10]	---	---	---	---	---	---	---	---
Proposed	29.75	27.67	24.8	22.96	30.14	26.72	25.67	25.28



(a)



(b)

Fig.5 (a) The result by test images with BER=10e-3, bit rate=0.5bpp in HL_3 subband (b) Objective comparison of the "Lena" image with various bit rates HL_3 subband

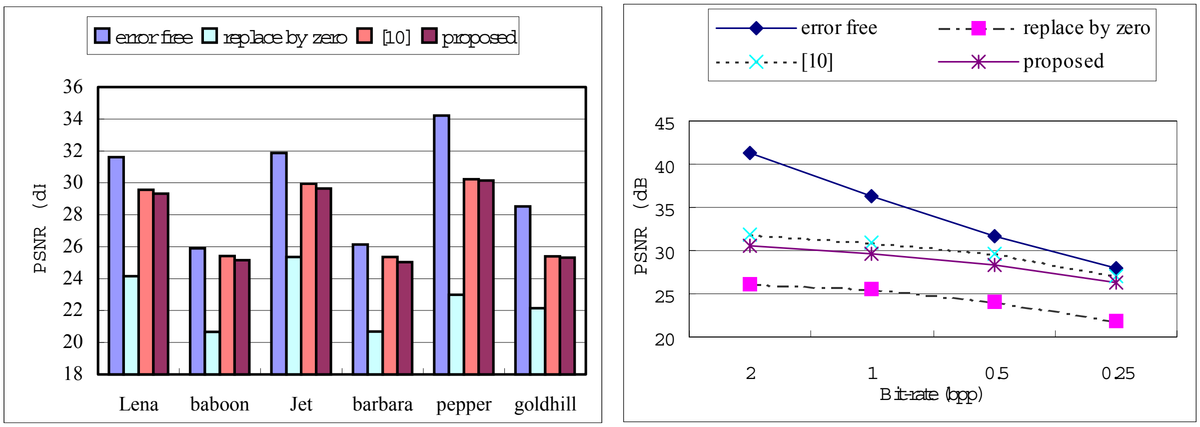


Fig.6 (a) The result of the test images with BER=10e-3 and bit rate=0.5bpp in HL_2 subband, and (b) objective comparison of "Lena" image with various bit rates HL_2 subband

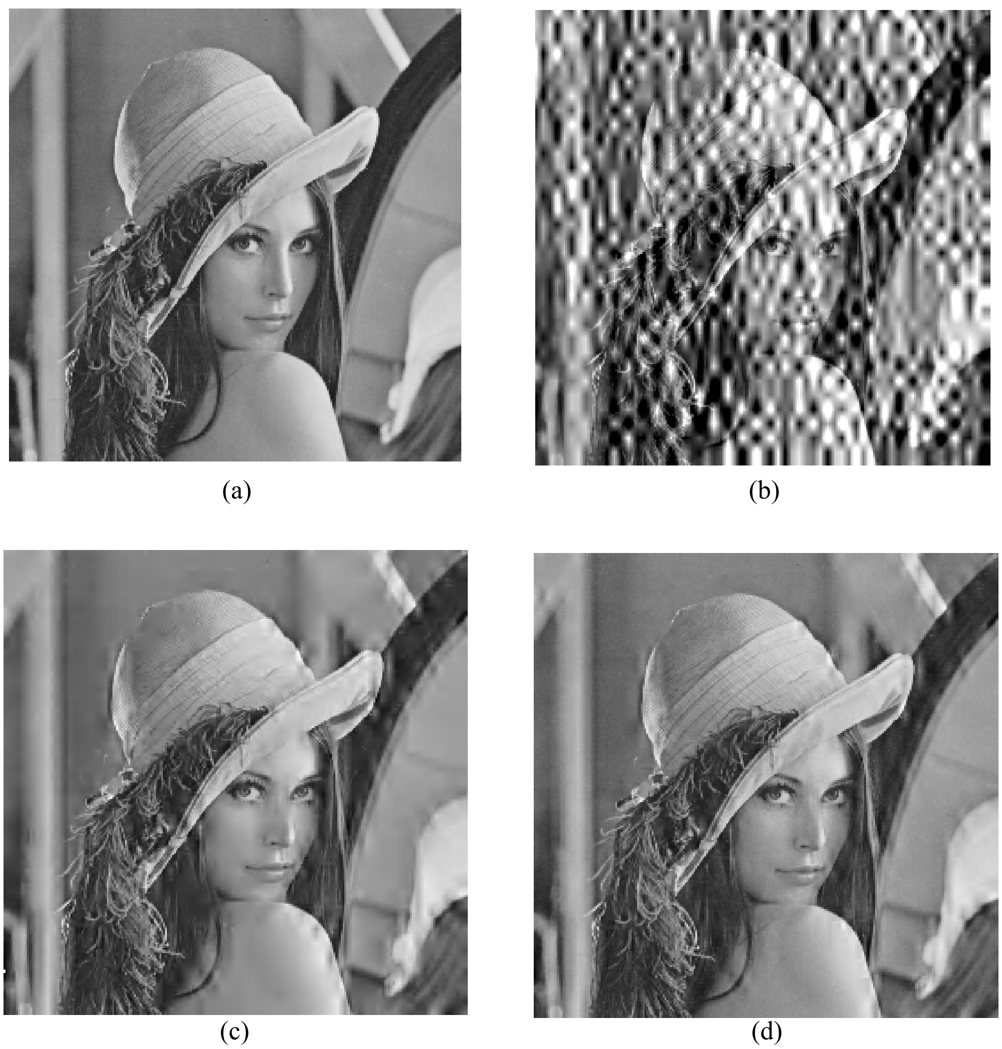


Fig.7 The subjective results of "Lena" image by BER=10e-3, bit rate=1bpp in the lowest HL_3 subband. (a) Reconstructed image by error free, PSNR=36.21dB; (b) Error resilience only by resynchronization marker, PSNR=14.49dB; (c) Missing wavelet coefficients replaced by zeros, PSNR=27.05dB; (d) Reconstructed image by our proposed algorithm, PSNR=29.64dB.

Pei-Jun Lee was born in I-lan, Taiwan, in 1969. She received the B.S. degrees in electrical engineering from National Ocean University, Keelung, Taiwan, in 1992 and M.S degree in the Institute of electrical engineering at National Dong-Hwa University, Hualien, Taiwan in 1999. In 1999, she joined the Department of Information Management, St. John's & St. Mary's Institute of Technology. She is currently working towards the Ph.D degree in Department of Electrical Eng. and Graduate institute of Electronics Eng. in National Taiwan University, Taipei, Taiwan. Her research interests include image processing, video compression and error concealment.

Liang-Gee Chen received the BS, MS, and Ph.D degrees in Electrical Engineering from National Cheng Kung University, in 1979, 1981, and 1986, respectively. From 1988, he joined the Department of Electrical Engineering, National Taiwan University. During 1993 to 1994 he was Visiting Consultant of DSP Research Department, AT&T Bell Lab, Murray Hill. At 1997, he was the visiting scholar of the Department of Electrical Engineering, University, of Washington, Seattle. Currently, he is Professor of National Taiwan University. His current research interests are DSP Architecture Design, Video processor design, and video coding system. Dr. Chen was the general chairman of the 7th VLSI Design/CAD Symposium, 1995. He was also the general chairman of the 1999 IEEE Workshop on Signal Processing Systems: Design and Implementation. He serves as Associate Editor of IEEE Trans. On Circuits and Systems for Video Technology from June 1996 till now, the Associate Editor of IEEE Trans. VLSI Systems from January 1999., and the Associate Editor of IEEE Trans. Circuits and Systems II from May 2000. He is the Associate Editor of the Journal of Circuits, Systems, and Signal Processing from 1999. He served as the Guest Editor of Journal of Video Signal Processing Systems. He is the Past-Chair of Taipei Chapter of IEEE CAS Society. He is the member of IEEE CAS Technical Committee of VLSI Systems and Applications and the Technical Committee of Visual Signal Processing and Communications and the member of IEEE SP Technical Committee of Design and Implementation of Signal Processing Systems. He is the Chair-elec of IEEE CAS Technical Committee of Multimedia Systems and Applications. From 2001-2002, he serves as the Distinguished Lecturer of IEEE Circuits and Systems Society. Dr. Chen is IEEE Fellow. He is also a member of the honor society Phi Tan Phi. He received the Best Paper Award from ROC Computer Society in 1990 and 1994. From 1991 to 1999, he received Long-Term (Acer) Paper Awards annually. In 1992, he received the Best Paper Award of the 1992 Asia-Pacific conference on circuits and systems in VLSI design track. In 1993, he received the Annual Paper Award of Chinese Engineer Society. In 1996, he received the Out-standing Research Award from NSC, and the Dragon Excellence Award for Acer. In 2000, he received the Out-standing Research Award from NSC, again.