Image Error Concealment Based on Watermarking

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Abstract. Imperfect transmission of block-coded images often causes lost blocks. These blocks may contain very important information of image. In this paper a new error concealment scheme is proposed for restoring lost blocks of images. It is based on the robust watermark technique to restore lost blocks in the region-of-interest (ROI) and the best-neighborhood-matching (BNM) technique to restore lost blocks in the region-of-background (ROB) of images. The ROI of image contains the human-interested information and is the most important part of image. It can be defined by user or decided by some algorithms. In addition, a novel fragile watermark technique is designed and applied to detect the error blocks of images. With this technique, the proposed scheme can find out all the errors of damaged images. Experiments show that very good restoration results are obtained by the proposed scheme, especially for the human-interested regions of images.

1 Introduction

Many image and video compression standards such as the Joint Photographers Expert Group (JPEG), Motion Picture Expert Group (MPEG) and H.263 have been designed for efficient data transmission and representation on the Internet. Image manipulation based on image block is the most practical strategy for image processing and is essential for these compression standards. Specifically in the JPEG compression standard, an image is segmented into non-overlapping blocks. Then each block is transformed via discrete cosine transform (DCT) to remove the spatial redundancy and compact the energy into a small number of coefficients. These DCT coefficients are subsequently quantized and entropy coded using variable length codes. Compression is achieved by assigning more bits to code the high-energy coefficients and fewer bits to the low-energy ones. The compressed image can be stored or transmitted over communication channels. However, the real-world communication channels are not perfect and the block-based coding systems are very sensitive to transmission error. As the image is highly compressed, the effect of bit error becomes more serious. One bit error often causes loss of a whole block and may cause consecutive block losses.

The problem of recovering lost blocks in images due to imperfect transmission has attracted much attention. This problem becomes more important if retransmission is impossible. As an alternative, error concealment takes advantages of the spatial correlation of images without incurring much overhead and delay [1]. Various methods have been proposed to conceal the missing data by exploring the spatial redundancy [2]-[4]. To restore lost blocks without retransmission, many error concealment methods have been proposed in recent years [1],[5]-[6]. These techniques are related to block-based image coding techniques. The goal of error concealment is to improve the visual quality of damaged image by masking the effect of missing blocks at the receiver. Among the error concealment techniques, the BNM [6] scheme is an information loss restoration technique for block-based image coding systems. It obtains good restoration results when the lost blocks are loosely scattered over image. However, for images with serious block losses in the ROI of image or with contiguous lost blocks, the restoration results are unsatisfactory.

Digital image watermarking technology has been widely studied and presented over last decade. A digital watermark is a visually imperceptible and information-carrying signal embedded in a digital image. It allows one to establish ownership, identify the buyer, or provide some additional information about the digital image. The watermarking techniques can be broadly classified into two categories: fragile watermarking and robust watermarking. Fragile watermarks [7] are useful for purposes of content authentication and integrity verification since they are completely fragile to any modifications. In comparison, robust watermarks [8] are generally used for copyright protection and ownership proof since they are robust to nearly all kinds of image manipulations.

In this paper, we propose a new error concealment scheme that takes advantages of fragile watermarking and robust watermarking. In order to detect error blocks, we design a novel fragile watermarking technique suitable for block-based images. To restore the human-interested portion of image, the information of ROI is embedded into the region-of-background (ROB) of image by robust watermarking. The ROI of image can be defined by user or decided by some algorithms [9]. The goal of our scheme is to restore each missing pixel with a value that approximate to the original one, especially for the pixels in the human-interested portion of image.

The rest of this paper is organized as follows. The overall error concealment scheme for block-based images is introduced in Section 2. Some experimental results and discussions are given in Section 3. Finally, Section 4 draws conclusions.

2 The Proposed Error Concealment Scheme

The overall error concealment scheme consists of two stages: the data embedding stage at the transmitter and the error concealment stage at the receiver. Assume that the input image is $\mathbf{X}$ with $m \times n$ pixels, where m and n are multiples of w. Let the ROI of $\mathbf{X}$ be $\mathbf{X}_{ROI}$ and the ROB of $\mathbf{X}$ be $\mathbf{X}_{ROB}$. Our objective is to embed most important information of $\mathbf{X}_{ROI}$, together with some error detection codes, into $\mathbf{X}_{ROB}$, and have a slightly modified image $\mathbf{X}'$ at the output after the embedding process is accomplished. In case that some blocks of $\mathbf{X}'$ were lost during transmission, the errors of image can be found and concealed at the receiver. Before describing the proposed scheme, we have to define the set of ROI blocks, S_{ROI}, and the set of ROB blocks, S_{ROB}. Let $\mathbf{X}$ be divided into a set of blocks, S, with block size $w \times w$ pixels. Therefore, $S_{ROI} = \{b \mid b$ locates inside $\mathbf{X}_{ROI}$ or on the contour of it$\}$ and $S_{ROB} = \{b \mid b \in S - S_{ROI}\}$, where b is a block of $\mathbf{X}$.

In data embedding stage, all ROI blocks are transformed into frequency domain by discrete cosine transformation (DCT). After DCT transformation, each coefficient in the DCTed block is quantized based on the luminance normalization matrix defined in the JPEG sequential baseline system. To extract information from an ROI block, we select some important coefficients and allocate various numbers of bits to encode them based on the zonal mask and the zonal bit allocation map [10], respectively. In fact, we scan and collect the first k coefficients of one ROI block in zigzag order and transform these coefficients into one bit string. Each bit string stands for information of the corresponding ROI block and is totally embedded into an ROB block selected by the mapping function f. For robustness, several copies of a bit string are embedded into different ROB blocks, respectively. The bit in the bit string is sequentially embedded into a pixel of the selected ROB block by the least significant bit (LSB) substitution. In addition, we reserve the last w pixels of a block for error detection code. Therefore, the number of bit in each bit string is limited to w^2-w.

After all the ROI information is embedded into ROB blocks, we have to embed codes for error detection. A w-bits error detection code D, $D = (d_1,d_2,\ldots,d_w)$, is embedded into each block of S. These error detection codes are different among blocks. Fig. 1 shows the processes of code generation and code embedding with w = 8. For each block b in S (b may contain the information of ROI block), we generate a pseudo-random w-bits string P, $P = (p_1,p_2,\ldots,p_w)$, based on a seed, key_1, and extract the first w^2-w LSBs L, $L = (l_1,l_2,\ldots,l_{(w-1)w})$, of b in zigzag order. The error detection code D for block b is generated by the following rule and is embedded into the LSBs of the remaining w pixels of b. The embedding sequence is shown as Fig. 1(b).

$$d_1 = p_1 \oplus (l_1,l_2,l_3,\ldots,l_{(w-1)})$$

$$d_2 = p_2 \oplus (l_{(w-1)+1},l_{(w-1)+2},l_{(w-1)+3},\ldots,l_{(w-1)+(w-1)})$$

$$d_3 = p_3 \oplus (l_{2(w-1)+1},l_{2(w-1)+2},l_{2(w-1)+3},\ldots,l_{2(w-1)+(w-1)})$$

$$\ldots$$

$$d_w = p_w \oplus (l_{(w-1)(w-1)+1},l_{(w-1)(w-1)+2},l_{(w-1)(w-1)+3},\ldots,l_{(w-1)(w-1)+(w-1)})$$

where

$$d_i = \begin{cases} 1, \text{if the number of bit '1' in } p_i \text{ and } (l_{(i-1)(w-1)+1}, l_{(i-1)(w-1)+2}, \ldots, l_{i(w-1)}) \text{ is even} \\ 0, \text{otherwise} \end{cases}$$

The error concealment stage at receiver is quite simple. The first step is to find out all the error blocks of damaged image **X′′**. Based on the seed key_1, the error detection code for each block of **X′′** can be extracted for checking. The process of error detection code extraction (computation) is totally the same as that of code embedding at transmitter. Each damaged block can be found by comparing the extracted (computed) code with the error detection code directly obtained from the last w pixels of the block itself. After all the damaged blocks are found, the proposed scheme first restores the lost blocks in ROI by extracting the information from the undamaged blocks of ROB. The ROB blocks that mapped by one ROI block can be obtained by the inverse function of f. And finally, we reconstruct the lost blocks in ROB by the BNM algorithm.

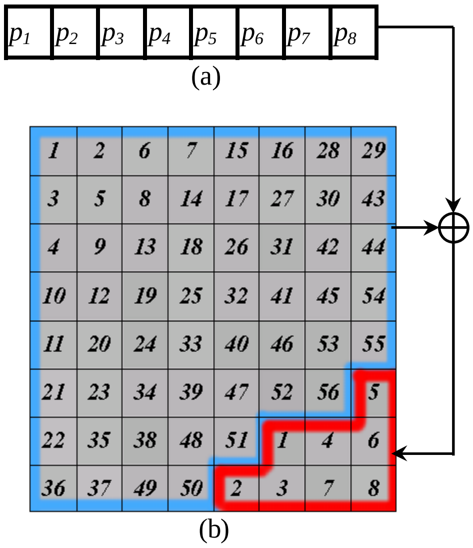

Fig. 1. Generation of error detection codes with w = 8. (a) Pseudo-random w-bits string P. (b) Scan order of the first w^2-w LSBs and the embedding positions of error detection codes in a w×w block.

3 Simulation Results

The proposed algorithm has been tested on several images with size 512×512 and 256 gray levels per pixel. In our experiments, block size is 8×8 (w = 8). And we select the first 9 (k = 9) coefficients of each ROI block and embed 3 copies of the corresponding bit string into ROB blocks. The peak signal-to-noise ratio (PSNR) is applied to evaluate the quality of reconstructed images. After the data embedding stage the PSNR of Lena is 56.55 dB.

Fig. 2 illustrates the experimental results of Lena. The ROI of Lena, with size 136×136 pixels, defined in our experiments is displayed as Fig. 2(a). Fig. 2(b) illustrates the damaged Lena with contiguous lost blocks in the ROI. The PSNR of it is 14.9 dB and that of ROI is 24.11 dB. Finally, we show the error-concealed image in Fig. 2(c). The PSNR of error-concealed Lena is improved to 36.34 dB and, moreover, that of ROI is up to 46.73 dB after accomplishing the error concealment process of our scheme. However, some restored blocks that do not match with the surrounding blocks in ROB can be found when we examine Fig. 2(c) with more care. This effect becomes more serious on the blocks whose adjacent blocks are also lost. By contrast, it is unobvious for the restored blocks in ROI. This is because there is much more accurate information for restoring lost blocks of ROI than ROB.

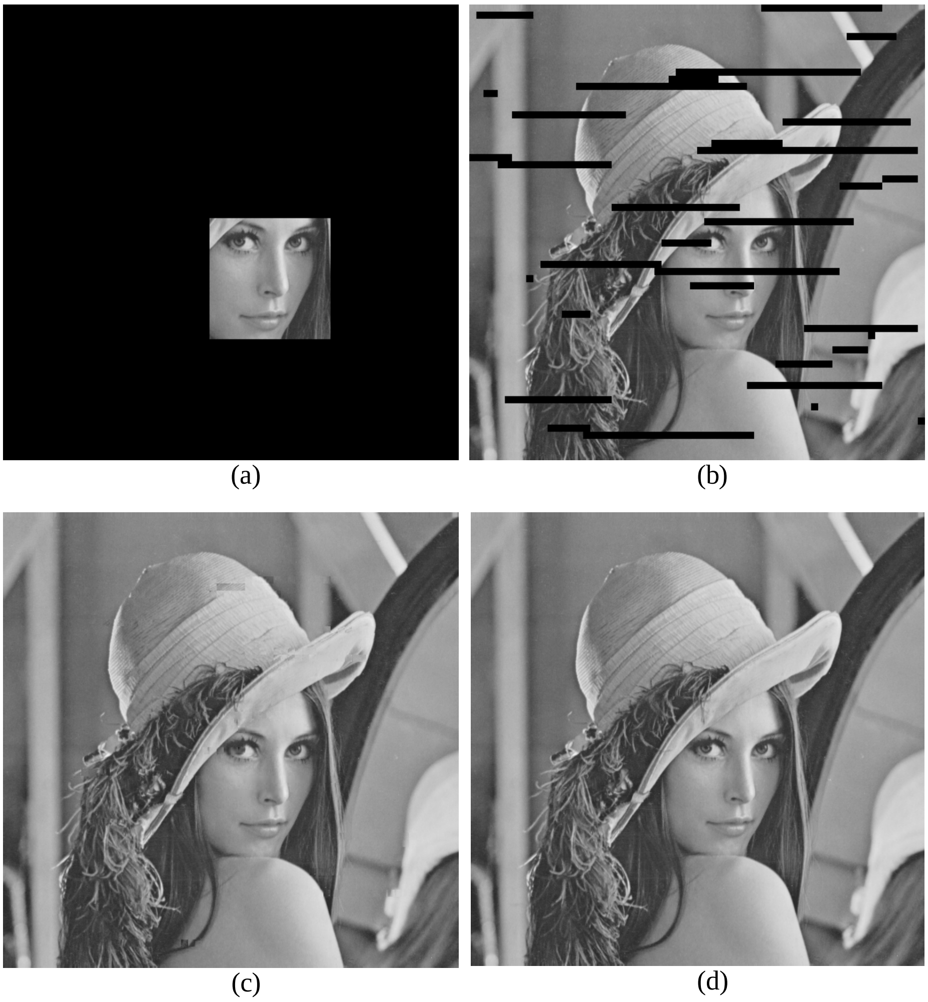

Fig. 2. Experimental results of Lena. (a) The defined ROI of Lena. (b) Damaged Lena (PSNR = 14.9 dB, PSNR of ROI = 24.11 dB). (c) Restored Lena (PSNR = 36.34 dB, PSNR of ROI = 46.73 dB). (d) The original Lena.

To compare the proposed scheme with BNM [6], several damaged images of Lena are simulated with different block loss rates ranging from 2.5% to 12.5%. The PSNRs of these images before and after the error concealment processes of our scheme and BNM are given in Table 1, respectively. The corresponding results of ROIs are also listed in this table. It shows that the PSNR (visual quality) of damaged image decreases as the block loss rate increases. However, this regularity is disobeyed by the damaged ROIs of images in our experiment. As shown in the table, the PSNRs of damaged ROIs at 10% and 12.5% block loss rates are higher than that at 7.5%. This is because the numbers of lost blocks in ROI at 10% and 12.5% are less than that at 7.5%, respectively. Table 1 demonstrates that our scheme outperforms the BNM technique, especially for the ROI of image.

Block Loss Rate (%)	Damaged Image (dB)	Restored Image (dB)		Damaged ROI (dB)	Restored ROI (dB)	
		BNM [6]	proposed		BNM [6]	proposed
2.5	21.12	41.44	46.84	28.22	50.94	61.79
5.0	18.02	40.15	42.21	26.21	40.53	60.34
7.5	16.27	36.14	37.90	23.59	43.02	50.57
10.0	14.90	31.80	36.34	24.11	40.13	46.73
12.5	14.40	31.94	34.36	23.90	40.58	41.28

Table 1. PSNR performance for the proposed scheme and BNM [6] with block loss rates ranging from 2.5% to 12.5%.

4 Conclusions

A new error concealment scheme based on watermarking and the BNM technique is proposed for block-based images. This scheme provides better capability of error concealment than that of the pure BNM scheme, especially for the human-interested region of image. Simulation results demonstrate that the proposed scheme provides significant improvement in terms of both subjective and objective evaluations.

The advance of our scheme mainly comes from the watermarking techniques. As introduced in this paper, a novel and faithful fragile watermarking is designed and applied to detect the errors of image. More importantly, the information of ROI is well protected by the robust watermarking.

Acknowledgments

The authors are supported by NDHU-ROC and NSC-ROC with project no. NSC 91-2213-E-259-016.

References

1. Wenjun Zeng and Bede Liu, 'Geometric-structure-based error concealment with novel applications in block-based low-bit-rate coding', IEEE Trans. on Circuits and Systems for Video Technology, Vol. 9, No. 4, pp. 648-665, 1999.
2. K. Jung, J. Chang, and C. Lee, 'Error concealment technique using projection data for block-based image coding', in Proc. SPIE Conf. Visual Communications and Image Processing, vol. 2308, pp. 1466-1476, 1994.
3. H. Sun and W. Kwok, 'Concealment of damaged block transform coded images using projections on convex sets', IEEE Trans. Image Process., vol. 4, pp. 470-477, Apr. 1995.
4. X. Lee, Y. Zhang, and A. Leon-Garcia, 'Information loss recovery for block-based image coding techniques-a fuzzy logic approach', IEEE Trans. Image Process., vol. 4, pp. 259-273, Mar. 1995.

5. Wang, J., and Ji, L.: 'A region and data hiding based error concealment scheme for images', IEEE Trans. Consumer Electronics, 47, (2), pp. 257-262, 2001.
6. Wang, Z., Yu, Y., and Zhang, D.: 'Best neighborhood matching: an information loss restoration technique for block-based image coding systems', *IEEE Trans. Image Process.*, 7, (7), pp. 1056-1061, 1998.
7. M. Utku Celik, G. Sharma, E. Saber, and A. Murat Tekalp, 'Hierarchical watermarking for secure image authentication with localization', *IEEE Trans. Image Process.*, vol. 11, No. 6, pp. 585-595, 2002.
8. I. W. Agung and P. Sweeney, 'Oblivious robust watermarking method by image pre-processing', *IEE Electronics Letters*, vol. 38, No. 14, pp. 702-704, 2002.
9. Privitera, C.M., and Stark, L.W.: 'Algorithms for defining visual regions-of-interest: comparison with eye fixations', *IEEE Trans. Pattern Ana. Machine Intell.*, 22, (9), pp. 970-982, 2000.
10. Gonzalez, R.C., and Woods, R.E.: 'Digital Image Processing, 2/E', *(Prentice Hall, USR, New Jersey, 2002)*