

Spatial Error Concealment Technique for Losslessly Compressed Images Using Data Hiding in Error-Prone Channels

Kyung-Su Kim, Hae-Yeoun Lee, and Heung-Kyu Lee

Abstract: Error concealment techniques are significant due to the growing interest in imagery transmission over error-prone channels. This paper presents a spatial error concealment technique for losslessly compressed images using least significant bit (LSB)-based data hiding to reconstruct a close approximation after the loss of image blocks during image transmission. Before transmission, block description information (BDI) is generated by applying quantization following discrete wavelet transform. This is then embedded into the LSB plane of the original image itself at the encoder. At the decoder, this BDI is used to conceal blocks that may have been dropped during the transmission. Although the original image is modified slightly by the message embedding process, no perceptible artifacts are introduced and the visual quality is sufficient for analysis and diagnosis. In comparisons with previous methods at various loss rates, the proposed technique is shown to be promising due to its good performance in the case of a loss of isolated and continuous blocks.

Index Terms: Data hiding, error concealment (EC), error-prone channel, image restoration.

I. INTRODUCTION

In error-prone channels such as satellite links and wireless links, the loss of image blocks inevitably occurs for many reasons. Error concealment (EC) techniques have been suggested to obtain a close approximation of the original image and to make the received image least objectionable to human eyes. EC techniques can be classified into three major categories, as follows [1].

- 1) Forward error concealment (FEC): The sender adds a certain amount of redundancy to the signal to be transmitted at the encoder. When errors occur during transmission, EC techniques use this redundancy to restore a corrupted image in the decoder.

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- 2) Post-processing at the decoder: Most image contents have spatial redundancy and locality. Without communication with the sender, EC techniques recover the lost information by making use of such a priori knowledge about the image.
- 3) Interaction between the encoder and the decoder: If a backward channel from the decoder to the encoder is available, errors are restored by retransmitting the copy of the damaged data from the encoder to the decoder by interaction.

Here, 1) and 3) require sufficient available bandwidth for (re)transmission. These techniques are associated with problems such as the high possibility of loss again, high propagation delay, and the low efficiency of the transmission operation. Alternatively, post-processing at the decoder does not experience the burden of retransmission. Moreover, it increases the transmission bandwidth [2]. For example, satellite images are transmitted through error-prone satellite links and hence have a high error possibility. In satellite links, retransmission has various difficulties stemming from the channel bandwidth, the satellite visiting time, the complex protocols among satellites, mission control systems, and the image receiving and processing system. Therefore, post-processing at the decoder is preferable.

Spatial interpolation is a simple post-processing technique which estimates each pixel of missing blocks by utilizing the information of the neighboring blocks corresponding to the pixel. It is simple, but causes over-blurring [3]–[5]. As a method of post-processing at the decoder, an approach is proposed that uses an EC algorithm based on data hiding for corrupted images. Data hiding techniques hide information directly into the original media itself without any perceptual distortion. When such a technique is used for error concealment, it provides the same bit rate as the media to be transmitted (i.e., no extra channels are needed).

In the past few years, various approaches have dealt with EC using data hiding. Yin et al. [6] extracted key features (e.g., edge features) from the image and then hide these features in the discrete cosine transform (DCT) domain of the original image. Although their method has relatively low computational complexity, a lost block including a strong edge or a complex texture can be improperly restored due to the limited embedding capacity. Wang and Ji [7] classified an image into two regions, a region of interest (ROI) and a region of background (ROB). The coded bitstream of the ROI is embedded into the wavelet coefficients of the ROB by data hiding. When data loss occurs in the ROI, the embedded data is extracted from the ROB for reconstruction. This technique can give better results when perception-based encoding is employed. However, if the loss rate in the ROB is increasing at a faster rate than that in the ROI, the abil-

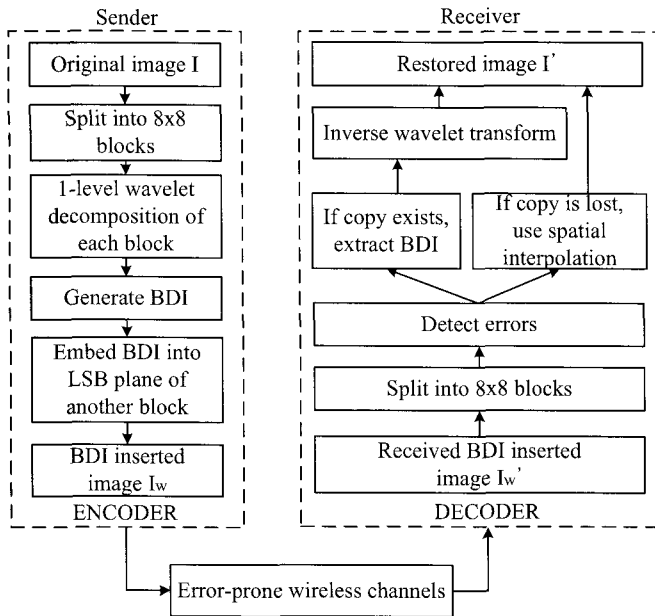


Fig. 1. Block diagram of the proposed EC technique.

ity to conceal the lost ROI is weakened. Another EC method using data hiding was proposed by Yilmaz and Alatan [8]. They embedded the edge direction, block bit-length, and parity bits for intra-coded frame concealment. For inter-coded frame concealment, the motion vector of the current block was hidden to other blocks. Essentially, the data is always embedded into the frames through the even-odd signaling of DCT coefficients.

These EC methods that were designed for lossy channels must modify low-frequency coefficients to survive against lossy compression techniques such as joint photographic experts group (JPEG) or JPEG2000; hence, they are limited in capacity when used in conjunction with message embedding when it is used for recovery. Therefore, they cannot be applied efficiently to applications where the contents are stored or transmitted in a lossless fashion. For example, medical imaging, military images, precious artworks, and remote-sensing images, where the images are subject to further processing and where they are often obtained at great cost, are all candidates for lossless processing [9]. When loss occurs over the entire image in lossless compression applications, it is not easy to reconstruct the original images because the EC methods mentioned above do not have enough capacity to embed all of the required data for to conceal errors.

Lee et al. [10] proposed an EC technique for satellite imagery transmission using least significant bit (LSB)-based data hiding. However, it caused visible artifacts between the blocks as it employed DCT coefficients that had only frequency characteristics. The presents study proposes an improved EC algorithm for corrupted images using LSB-based data hiding. After splitting an image into blocks, the block description information (BDI) of each block is calculated from quantization following wavelet decomposition and is then inserted into the LSB planes of the image itself. Each BDI represents a low-quality copy, specifically the approximation coefficients, of the block itself. Using this BDI, the loss of blocks caused by transmission errors is concealed. In an experiment, the improvements in the visual quality

as well as in the peak signal-to-noise ratio (PSNR) are measured by comparing spatial interpolation and DCT-based EC methods [10].

The proposed algorithm uses LSB planes for the quality issue of original contents. Although there are some limits when applying this method in lossy compression applications, there often lossless compression applications such as satellite and surveillance images are valuable and expensive.

The paper is organized as follows. Section II describes the proposed EC algorithm using data hiding, while the experimental results are shown in Section III. Finally, the paper is concluded in Section IV.

II. THE PROPOSED EC ALGORITHM

This section proposes an EC algorithm in which BDI is generated and inserted into the LSB bit-plane of the image itself at encoder. At the decoder, the BDI is extracted and used to conceal any missing blocks that are noted during the transmission. Fig. 1 illustrates the proposed EC algorithm.

A. BDI Generation

Discrete wavelet transform (DWT) provides powerful insight into the spatial and frequency characteristics of an image as opposed to other transforms such as discrete Fourier transform (DFT) and DCT, which reveal only the frequency attributes. As the human eye tolerates a certain degree of high-frequency distortion in an image [11], the BDI is generated using low-frequency coefficients in the wavelet domain. It is used to conceal the block artifacts caused by transmission errors. Additionally, to reduce the visual distortion after embedding the BDI, the length of the BDI is limited to 64 bits. To generate the BDI, the image first is split into 8×8 blocks and each block is then decomposed into four bands by applying level-1 DWT; this is denoted by LL, HL, LH, and HH. The approximation coefficients in the LL band are used as the BDI to embed into the LSB bit-plane of another block. As the size of the LL coefficients in level-1 of 2-D DWT will grow by a factor of 2, the coefficients are transformed into a four-bit representation using a quantization process.

B. BDI Insertion

The BDI insertion algorithm using the LSB-based data hiding technique is introduced here. Given that the resolution of the LL band is 4×4 in the level-1 DWT, the length of the BDI is $4 \times 4 \times 4$ bits = 64 bits. Here, an $N \times N$ image in which each pixel value is represented by k bits can be decomposed into a set of k , $N \times N$ bit planes. For instance, k -bit pixel A is represented by a base 2 polynomial, as follows:

$$A = a_{k-1}2^{k-1} + a_{k-2}2^{k-2} + \dots + a_12^1 + a_02^0. \quad (1)$$

A set of a_0 is denoted as A_0 and only a single bit plane is used to embed the BDI, as it is necessary to maintain quality of the original image. To increase the robustness against lossy compression applications, a plane with additional bits can be used, but this degrades the perceptual quality of the original image.

Here, I denotes the original image to be transmitted, and I_w

represents image after the BDI is inserted. First, we divide I into 8×8 blocks. For each block, quantization following DWT is applied, and all 16 quantized coefficients of the approximation band are selected. These 16 quantized coefficients are the BDI, as explained in Section II.A. This BDI information $B(i, j)$ is then encrypted using a symmetric key. That is, the binary random sequences $W(i, j)$ generated by the key are combined with $B(i, j)$ using a bit-wise XOR operation. The encrypted version $E(i, j)$ to be inserted is obtained as shown below. Thus, the restoration process is possible only with the same key.

$$E(i, j) = B(i, j) \oplus W(i, j), \quad 0 \leq i, j \leq 7. \quad (2)$$

Next, two blocks called block A and block B are repaired. The distance between these two blocks should be as great as possible because continuous blocks have the possibility to include errors simultaneously. This distance is also known at the receiver. Subsequently, the encrypted BDI of block A is inserted into the bit plane of block B (i.e., B_0 saves 16 coefficients of block A), and vice versa. The length of the BDI is 64 bits and the length of the size of LSB bit planes in the 8×8 block is also 64 bits. Therefore, I_w is obtained by replacing the bit plane with the BDI. The BDI inserted image is then transferred from the sender to the receiver through error-prone wireless channels.

C. BDI Extraction and Error Concealment

This section explains the method of extracting the inserted BDI and concealing errors during the transmission at the receiver. For the BDI extraction process, the received BDI inserted image I'_w is divided into 8×8 blocks. To detect block losses, blocks consisting of all zeros are determined. When block loss is detected, the location of the block B that contains the BDI of the lost block A is determined. As mentioned earlier, the receiver and the encoder share the information in which block B contains the BDI of the other block A . When the block B containing the BDI of the lost block A is also lost at the same time, a spatial interpolation technique is adopted. To attain the BDI information $B(i, j)$, a bit-wise XOR operation is conducted between the binary random sequence $W(i, j)$ generated by the same key at the encoder and the extracted binary sequences $E(i, j)$ from the LSB plane of the corresponding block.

$$B(i, j) = E(i, j) \oplus W(i, j), \quad 0 \leq i, j \leq 7. \quad (3)$$

Next, the decoder begins using the proposed EC algorithm to restore the lost data and then works to make the presentation more pleasing to the human eye. The EC algorithm proceeds through two steps to conceal the lost blocks. First, for a correctly received block A that contains an approximation copy of the lost block B , the LSB bit plane of block A is retrieved and the inserted 64 bits BDI of the block B are extracted. Subsequently, when both block A and block B are broken at the same time, it is impossible to restore the loss of block A and block B using the BDI. In such a case, a spatial interpolation EC method that uses the surrounding correctly received or restored image information is applied [2]. The extracted BDI is the 16 quantized approximation coefficients of the 8×8 DWT block. To reconstruct the image, we allocate these coefficients to the LL band in the DWT block where the other coefficients in the HL, LH, and HH

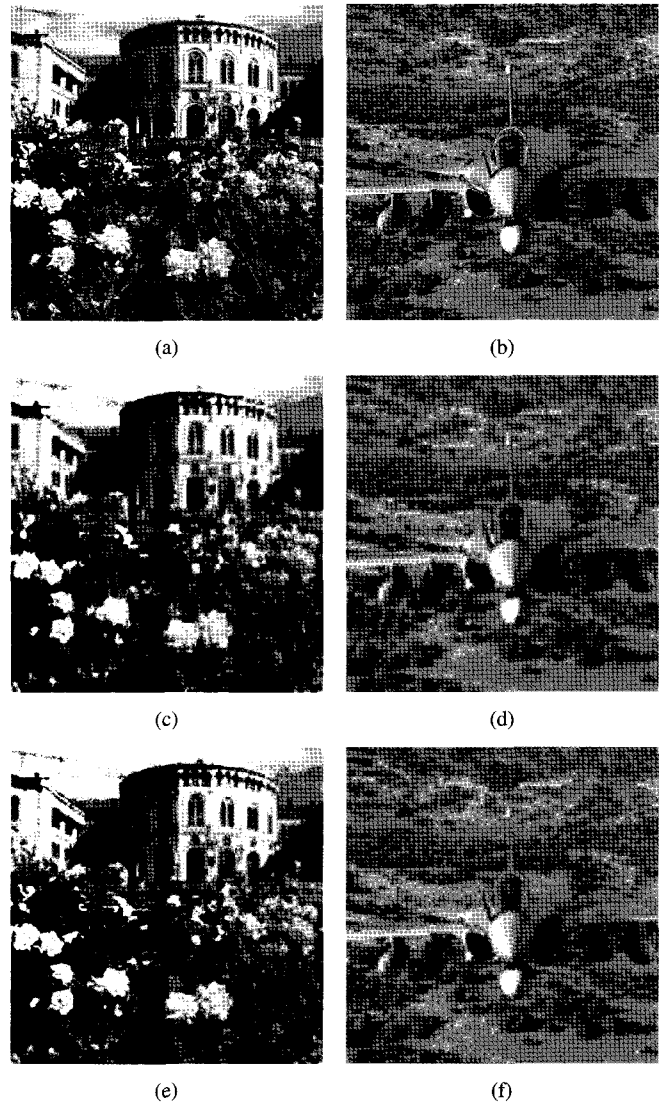


Fig. 2. (a) and (b) are original images of CASTLE and JET, respectively. (c) and (d) are reconstructed images using DCT. (e) and (f) are reconstructed images using DWT.

bands are all zeros. Finally, the approximation close I' of the original image is restored by applying inverse wavelet transform following de-quantization.

III. EXPERIMENTAL RESULTS

For a performance evaluation of the proposed EC technique, 100 grayscale images of 256×256 pixels were used in a comparison with the interpolation-based EC method [2] and the DCT-based EC method [10]. The PSNR, which is most commonly used as a measure of quality of reconstruction, was employed as the performance metric. The base wavelet used for the DWT was the Haar wavelet. Following an error-prone channel model proposed in a recent study [2], losses of blocks during transmission with a percentage ranging from 5% and 50% were simulated. In order to show the performance of the proposed EC algorithm using DWT without spatial interpolation, the simulation stipulated that one of the block pairs should survive. The BDI of each block was inserted into another block that was lo-



Fig. 3. (a) Original Barbara, (b) BDI-inserted Barbara, (c) erroneous image received with 50% block loss, (d) restored image from spatial interpolation, PSNR=20.03 dB, (e) restored image from DCT coefficients, PSNR=29.89 dB, (f) restored image from DWT coefficients, PSNR=31.05 dB, and (g) restored image from the hybrid scheme, PSNR=30.92 dB.

cated at half the image height. In addition, it was assumed that the locations of errors can be determined by simply searching for blocks consisting of all zeros.

For the interpolation-based EC method, we replaced each pixel in the lost block with the mean value of the non-zero values of the corresponding pixels in the neighboring blocks. For the DCT-based EC method, 64 bits of BDI were extracted by selecting 8 quantized coefficients in a zigzag order around the DC component following the DCT process. The 64 bits of the BDI of each block were embedded into the LSB plane of the other block and it was extracted to reconstruct the corrupted images [10].

We achieved an average PSNR value of 51 dB between the image with the BDI inserted. The average PSNR value of the

DCT-based EC method was also close to 51 dB. Without a loss of blocks, there was no PSNR difference between the proposed EC algorithm and the DCT-based EC method. However, when a loss of a block occurred, the DCT-based EC method caused blocking artifacts in the restored images and showed low PSNR values.

To analyze the quality of the proposed BDI, the inserted BDI was extracted and images were reconstructed using only this BDI. Some of the results are shown in Fig. 2. The average PSNR between the original images and the reconstructed images was 25 dB for DWT and 23.5 dB for DCT. As the LL of DWT has spatial characteristics, the reconstructed images from DWT have fewer block artifacts compared to those from DCT.

Fig. 3 shows the error concealment results at a 50% loss rate

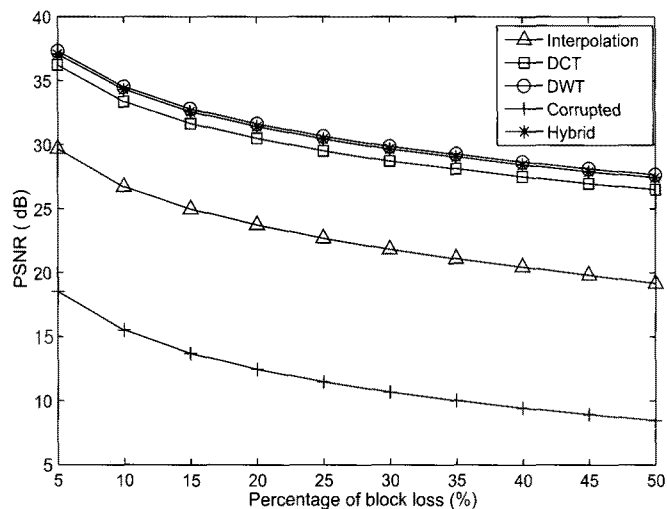


Fig. 4. Average PSNR values between original images and restored images with different loss rates.

from the proposed DWT-based EC algorithm, the DCT-based EC method, and the interpolation-based EC method. Although the DWT-based EC algorithm led to quantization errors in some flat areas, it showed improvements not only in the PSNR values but also in the perceptual quality, especially reducing the discontinuities between blocks and enhancing the visualization of the texture areas, of the corrupted images considerably compared to the interpolation-based EC method and the DCT-based EC method.

To reduce the quantization errors in these flat areas and maintain the visual quality in the edge and texture areas, additional experiments were performed using a hybrid approach. That is, 64-bit BDI represented the DCT coefficients or the DWT coefficients including a 1-bit flag for the decoder. If block A is a uniform region, the BDI of block A describes the DCT coefficients and is then inserted into the LSB plane of block B. Otherwise, the BDI of block A describes the DWT coefficients. A simple means of determining whether a current block is a uniform region or not is described as follows: For each block, the sample variance is computed. This variance is then normalized with respect to the maximum of all block variances, i.e.,

$$D = \frac{\sigma_{\text{block } i}^2}{\max(\sigma_{\text{block } 1}^2, \dots, \sigma_{\text{block } n}^2)}. \quad (4)$$

Using (4), if D is higher than the fixed value of α , the current block i is considered as a non-uniform block; otherwise, it is considered as a uniform block. In this experiment, α was set to 0.13. The result of the hybrid scheme is depicted in Fig. 3(g).

Fig. 4 reveals the average PSNR values between the original images and the restored images; the x axis represents the block loss rate and the y axis represents the PSNR values. For most block loss percentages, the proposed EC algorithm using DWT outperformed the interpolation-based EC method and the DCT-based EC method. Moreover, the hybrid scheme using the DCT and DWT coefficients showed better PSNR values than those two methods. For example, the PSNR value of the DWT-based algorithm demonstrates an improvement of approximately 1.5 dB compared to DCT-based method; and 8 dB compared to

interpolation-based method for a block loss of 50%. In all cases, the proposed EC algorithm achieves satisfactory concealment performance at all distortion levels.

IV. CONCLUSION

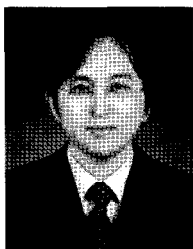
This study proposed a spatial error concealment technique using LSB data hiding that can be used to recover high block losses over error-prone channels such as satellite links. As these types of satellite images use lossless compression during transmission, LSB planes were utilized to insert the BDI. After transmission through error-prone channels, any loss of blocks is restored by extracting the inserted BDI. In an experiment, the performance of the proposed EC algorithm was compared to that of an interpolation-based EC method and a DCT-based EC method. The experimental results indicate that the proposed technique is a promising method for lossless compression. Currently, the authors are conducting research pertaining to resistance against lossy compression environments.

REFERENCES

- [1] Y. Wang and Q. F. Zhu, "Error control and concealment for video communication: A Review," *Proc. IEEE*, vol. 86, pp. 974–997, May 1998.
- [2] G. Gur, Y. Altug, E. Anarim, and F. Alagoz, "Image error concealment using watermarking with subbands for wireless channels," *IEEE Commun. Lett.*, vol. 11, pp. 179–181, Feb. 2007.
- [3] W. Zeng and B. Kiu, "Geometric structured based error concealment with novel applications in block-based low-bitrate coding," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 9, pp. 648–664, June 1999.
- [4] W. Zhu, Y. Wang, and Q. F. Zhu, "Second-order derivative-based smoothness measure for error concealment," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 8, pp. 713–718, Oct. 1998.
- [5] S. S. Hemami and T. H. Y. Meng, "Transform coded image reconstruction exploiting interblock interpolation," *IEEE Trans. Image Process.*, vol. 4, pp. 1023–1027, July 1995.
- [6] P. Yin, B. Liu, and H. H. Yu, "Error concealment using data hiding," in *Proc. IEEE Int. Conf. Acoust., Speech, Signal Process.*, vol. 3, May 2001, pp. 1453–1456.
- [7] J. Wang and L. Ji, "A region and data hiding based error concealment scheme for images," *IEEE Trans. Consum. Electron.*, vol. 47, no. 2, pp. 257–262, May 2001.
- [8] A. Yilmaz and A. A. Alatan, "Error concealment of video sequences by data hiding," in *Proc. Int. Conf. Image Process.*, vol. 2, Sept. 2003, pp. 679–682.
- [9] B. Carpentieri, M. J. Weinberg, and G. Seroussi, "Lossless compression of continuous-tone images," *Proc. IEEE, Special Issue on Lossless Data Compression*, vol. 88, no. 11, pp. 1797–1809, Nov. 2000.
- [10] H. Y. Lee, D. H. Im, and H. K. Lee, "Error concealment technique of satellite imagery transmission through information hiding," *IEICE Trans. Inf. Syst.*, vol. E90-D, no. 11, pp. 1881–1884, Nov. 2007.
- [11] I. J. Cox, M. L. Miller, and J. A. Bloom, Chap. 10 in *Digital Watermarking*. Morgan Kaufmann Publishers, San Francisco, CA, 2002.



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