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 technique is significant because of the growing interest in imagery transmission over error-prone channels. In this paper, we present a spatial error concealment technique for losslessly compressed images using 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 and embedded into the LSB plane of the original image itself at the encoder. At the decoder, this BDI is used for concealing the missing blocks which have occurred during transmission. Although the original image is modified a little by message embedding, no perceptible artifacts are introduced and the visual quality is enough for analysis and diagnosis. By comparing with previous methods in various loss rates, we show that our technique is promising and has good performance for the loss of isolated and continuous blocks.**

Index Terms: **Error concealment, data hiding, 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 with 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 3 major categories as follows [1].

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

2) Post-processing at the decoder: Most image contents have spatial redundancy and locality. Without communication with 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.

In here, 1) and 3) require the sufficient available bandwidth for (re)transmission and have problems such as the high possibility of the loss again, high propagation delay, and the low efficiency of transmission operation. Alternatively, post-processing at the decoder does not suffer from the burden of retransmissions and increases the transmission bandwidth [2]. For example, satellite images are transmitted through error-prone satellite links and hence have high error possibility. In satellite links, retransmission has various difficulties from the channel bandwidth, the satellite visiting time, the complex protocol among satellite, mission control system, and 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 pixel. It is simple, but causes over blurring [3]-[5]. As a method of post-processing at the decoder, we propose an approach to use a data hiding based EC algorithm for corrupted images. Data hiding technique hides information directly into an original media itself without any perceptual distortion. When it is used for error concealment, it provides the same bit rate as the media to be transmitted (i.e., no extra channel needs).

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 these features were hidden in DCT domain of the original image. Although their method has relatively low computational complexity, the lost block including the strong edge or the complex texture could be restored insufficiently due to limited embedding capacity. Wang and Ji [7] classified the image into two regions, region of interest (ROI) and region of background (ROB). The coded bitstream of ROI was embedded into the wavelet coefficients of ROB by data hiding. When data loss occurred in ROI, the embedded data was extracted from ROB for reconstruction. This technique can give better results when perception-based encoding is employed. However, if the loss rate in ROB is increasing more than that in ROI, the ability to conceal the lost ROI is weakened. Another EC method by data hiding was proposed by Yilmaz and Alatan [8]. They embedded 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

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hidden into other blocks. Basically, the data was always embedded into the frames by even-odd signaling of DCT coefficients.

These EC methods that was designed for lossy channels should modify low frequency coefficients to survive against lossy compression such as JPEG or JPEG2000 and hence have a limited capacity for message embedding which was used for recovery. Therefore, they cannot be efficiently applied to the applications where contents are stored or transmitted in a lossless fashion. For examples, medical imaging, military images, precious artworks, and remote-sensing images, where the images are subject to further processing and also are obtained at great cost, are all candidates for lossless processing [9]. When the loss occurs over whole image areas in lossless compression applications, it is not easy to reconstruct the original images because these EC methods mentioned above do not have enough capacity to embed all the required data for concealing errors.

Lee *et al.* [11] proposed EC technique of satellite imagery transmission using LSB-based data hiding. However, it caused visible artifacts between blocks since it employed a few DCT coefficients which have only frequency characteristics. We propose an improved EC algorithm for corrupted images using LSB-based data hiding. After we split an image into blocks, block description information (BDI) of each block is calculated from quantization following wavelet decomposition and then inserted in the LSB planes of the image itself. Each BDI represents the low-quality copy, namely approximation coefficients, of the block itself. Using this BDI, we conceal loss of blocks caused by transmission errors. In experiment, we measure the improvements in visual quality as well as peak signal-to-noise ratio (PSNR) with comparing spatial interpolation and DCT-based EC methods [11].

Our algorithm uses LSB planes for the quality issue of original contents. Although we have some limit for applying in lossy compression applications, there are various lossless compression applications such as satellite and surveillance images that are valuable and expensive.

The paper is organized as follows. Sec. 2 describes the proposed EC algorithm using data hiding and experimental results are shown in Sec. 3. Finally, we conclude in Sec. 4.

II. PROPOSED EC ALGORITHM

This section proposes an EC algorithm where BDI is generated and inserted into the LSB bit-plane of the image itself at encoder. At decoder, BDI is extracted and used for concealing missing blocks during transmission. Fig. 1 illustrates the proposed EC algorithm.

A. BDI GENERATION

DWT provides powerful insight into spatial and frequency characteristics of an image as opposed to other transforms such as DFT and DCT revealing only frequency attributes. Since human eyes tolerate a certain degree of high-frequency distortion in an image [10], we generate the BDI by using low frequency coefficients in wavelet domain and use for concealing the block artifacts caused by transmission errors. Also, in order to reduce the visual distortion after embedding the BDI, the length of the BDI is limited to 64 bits. To generate BDI, the image first splits into 8×8 blocks and then each block is decomposed four bands by applying level-1 DWT and denoted by LL, HL, LH, and HH. We use the approximation coefficients in LL band as the BDI to embed into LSB bit-plane of another block. Since the size of the LL coefficients in level-1 of 2-D DWT will grow by a factor of 2, we make the coefficients be 4-bits representation using quantization process.

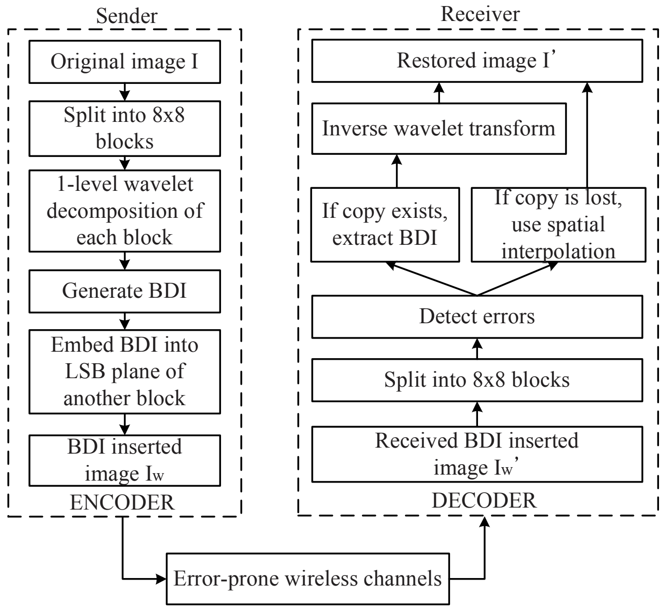


Fig. 1. Block diagram of the proposed EC technique.

B. BDI INSERTION

We introduce BDI insertion algorithm using LSB-based data hiding technique. Since the resolution of LL band is 4×4 in level-1 DWT, the length of the BDI is $4 \times 4 \times 4$ bits = 64 bits. Note that 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 base 2 polynomial as follows:

$$A = a_{k-1}2^{k-1} + a_{k-2}2^{k-2} + \cdots + a_1 2^1 + a_0 2^0 \qquad (1)$$

We denote a set of a_0 by A_0 and employ only single bit plane to embed the BDI. This is because we should maintain quality of the original image. To increase the robustness against lossy compression applications, higher bits plane can be used, but degrade the perceptual quality of the original image.

Let I be the original image to be transmitted and I_w be the BDI inserted image. First, we divide I into 8×8 blocks. For each block, we apply quantization following DWT and select all 16 quantized coefficients of the approximation band. These 16 quantized coefficients are our BDI explained in Sec. 2.1. This BDI information $B(i, j)$ is then encrypted by using a symmetric key. That is, we combined the binary random sequences $W(i, j)$ generated by the key with $B(i, j)$ using the bit-wise XOR operation. The encrypted version $E(i, j)$ to be inserted is obtained as follows. So restoration process is possible only with the same key.

$$E(i,j) = B(i,j) \oplus W(i,j), \quad 0 \le i,j \le 7 \tag{2}$$

Next, we pair two blocks called block A and block B. The distance between these two blocks should be as far as possible because continuous blocks have the possibility to include errors at the same time. This distance is also known at the receiver. Then, 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 BDI. Then, the BDI inserted image is transferred from the sender to the receiver through error-prone wireless channels.

C. BDI EXTRACTION AND ERROR CONCEALMENT

This section explains how to extract the inserted BDI and conceal error during transmission at the receiver. For BDI extraction, we divide the received BDI inserted image I'_w into 8×8 blocks. In order to detect block losses, we simply search the blocks consisting of all zeros. When the block loss is detected, the location of the block B that contains the BDI of the lost block A is determined. As mentioned before, the receiver and the encoder share the information that 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, the spatial interpolation technique is adopted. To achieve the BDI information $B(i,j)$, we performed the bit-wise XOR operation 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.

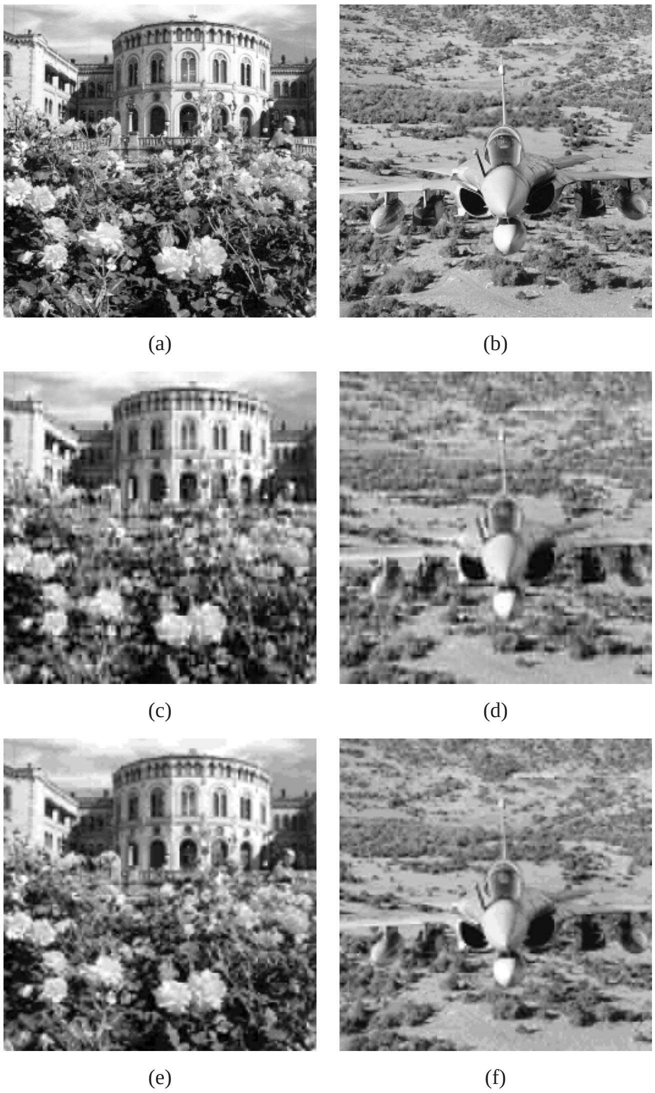
$$B(i,j) = E(i,j) \oplus W(i,j), \quad 0 \le i,j \le 7 \tag{3}$$

After that, the decoder begins with employing our EC algorithm to restore the lost data and then makes the presentation more pleasing to human eyes. Our EC algorithm has two steps to conceal the lost blocks. First, if there is the correctly received block A which contains the approximation copy of the lost block B, we retrieve the LSB bit plane of block A and extract the inserted 64 bits BDI of the block B. Next, when both block A and block B are broken at the same time, it is impossible to restore the loss of the block A and the block B using the BDI. In that case, we apply the spatial interpolation EC method that uses the surrounding correctly received or restored image information [2]. The extracted BDI is the 16 quantized approximation coefficients of 8×8 DWT block. To reconstruct the image, we allocate these coefficients to LL band in DWT block where other coefficients in HL, LH, and HH bands are all zeros. Finally, we restore the approximation close I' of the original image by applying inverse wavelet transform following de-quantization.

III. EXPERIMENTAL RESULTS

For the performance evaluation of our EC technique, we used 100 grayscale images of 256×256 pixels and compared with the interpolation-based EC method [2] and the DCT-based EC method [11]. PSNR (Peak Signal to Noise Ratio), which is most commonly used as a measure of quality of reconstruction, is employed as the performance metric. The base wavelet used for DWT was Haar wavelet. According to the error-prone channel model proposed by [2], we simulated the loss of blocks during transmission whose percentage was ranged from 5% and 50%. In order to show the performance of our EC algorithm from DWT without spatial interpolation, we simulate that one of block pair should be survived. The BDI of each block is inserted into the other block that is located in half image heights. Also, we assume that the locations of errors are known by simply searching the blocks consisting of all zeros.

For the interpolation-based EC method, we replaced each pixel in the lost block by the mean value of the non-zero values of corresponding pixels in neighboring blocks. For the DCT-based EC method, 64 bits BDI is extracted by selecting 8 quantized coefficients in zigzag order around DC component following DCT. We embedded 64 bits BDI of each block into LSB plane of the other block and extracted it to reconstruct the cor-



(a) (b) (c) (d) (e) (f)

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.

rupted images [11].

We achieved the average PSNR value of 51 dB between the original images and the BDI inserted images. The average PSNR value of the DCT-based EC method was also around 51 dB. Without the loss of blocks, there was no PSNR difference between the proposed EC algorithm and DCT-based EC method. However, when the loss of block occurred, the DCT-based EC method caused blocking artifacts in the restored images and also showed low PSNR values.

To analyze the quality of our BDI, we extracted the inserted BDI and reconstructed images using only this BDI. Some 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. Since LL of DWT has spatial characteristics, reconstructed images from DWT have less block artifacts than those from DCT.

Fig. 3 shows the error concealment results at 50% loss rate from our DWT-based EC algorithm, the DCT-based EC method, and the interpolation-based EC method. Although our DWT-based EC algorithm caused quantization errors in some flat areas, it shows the improvements not only PSNR values but also the perceptual quality, especially reducing discontinuities between blocks and enhancing visualization of texture areas, of the corrupted images considerably to the interpolation-based EC method and the DCT-based EC method.

In order to reduce the quantization errors in those flat areas and maintain the visual quality in edge and texture areas, we performed additional experiments using hybrid approach. That is, 64-bits BDI could represent the DCT coefficients or the DWT coefficients including a 1-bit flag for decoder. If block A is a uniform region, the BDI of the block A describes the DCT coefficients and then is inserted the LSB plane of the block B. Otherwise, the BDI of the block A describes the DWT coefficients. A simple way of determining whether the current block is a uniform region or not is here described: for each block the sample variance is computed. This variance is then normalized with respect to the maximum of all block variances, i.e.,

$$D = \frac{\sigma^2_{block\ i}}{max(\sigma^2_{block\ 1,\ \ldots\ ,\ block\ n})} \tag{4}$$

By the means of Eq. (4), if D is higher than the fixed α, the current block i is considered the non-uniform block, otherwise it is considered the uniform block. In this experiment, α was set to 0.13. Consequently, 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. In most of the percentage of the block loss, the proposed EC algorithm using DWT outperformed the interpolation-based EC method and the DCT-based EC method. Also, the hybrid scheme using DCT and DWT coefficients showed the 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 to DCT-based method, 8 dB to interpolation-based method for 50% block loss. In all cases, our EC algorithm achieves satisfactory concealment performance at all distortion levels.

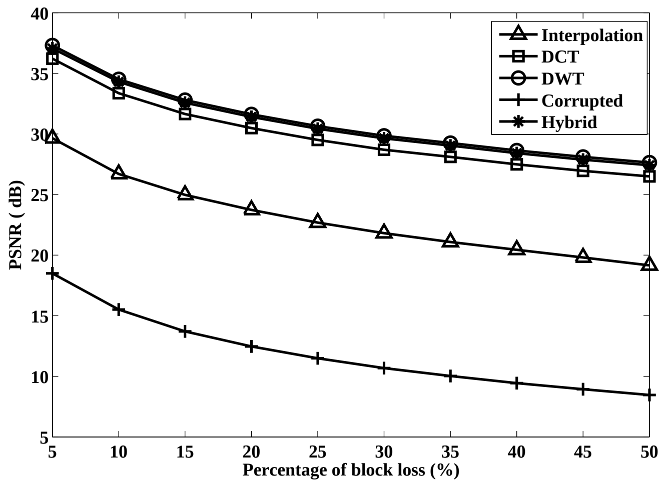


Fig. 4. Average PSNR values between original images and restored images on a variety of the loss rate.

IV. CONCLUSION

We have proposed a spatial error concealment technique using LSB data hiding for recovering up high block losses over error-prone channels such as satellite links. Since this kind of satellite images use lossless compression during transmission, we have utilized the LSB planes to insert BDI. After it is transmitted through error-prone channels, the loss of blocks is restored by extracting the inserted BDI. In this paper, we have compared the performance of our EC algorithm to an interpolation-based EC method and DCT-based EC method. The experimental results indicate that the proposed technique is a promising in lossless compression. Currently, we are working to research for resisting against lossy compression environments.

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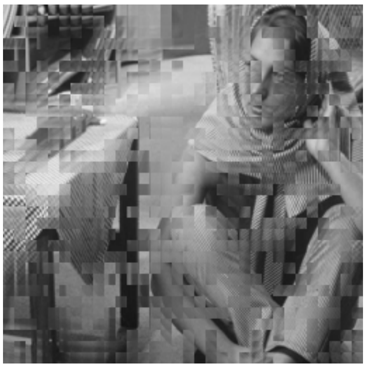
(a) (b) (c)



(d) (e) (f)

(g)

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

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