Block and Region Based Image Error Concealment Using Fragile Watermarking in the Spatial Domain

Razieh Keshavarzian[1] and Ali Aghagolzadeh[2]

*[1]Department of Electrical Engineering,
Heris Branch, Islamic Azad University, Heris, Iran
[2]Faculty of Electrical and Computer Engineering, Babol University of Technology, Babol, Iran
keshavarzian@herisiau.ac.ir, aghagol@nit.ac.ir*

Abstract

Transmission of block-coded images over wireless channels results in lost blocks. These losses may occur in region-of-interest (ROI) of images which contain important information of images. In this paper, we propose a new error concealment method for covering up the high packet losses of an original image after its transmission through an error-prone channel. In this scheme, Discrete Wavelet Transform (DWT) is applied to each block of the original image in order to produce a lower resolution copy of the block. Then, we choose approximation coefficients of each block as replica of the block and embed it into a remote block (called masking block) of the image in the spatial domain. We use a new algorithm to find the masking block for embedding the replica. The advantage of this algorithm is that it avoids losing simultaneously the information of the block and its masking block. It is shown that the proposed scheme provides significant improvement over existing algorithms in terms of both subjective and objective evaluations. This technique can be implemented for wireless channels to combat degradations in a backward-compatible scheme. It is also shown that this scheme can efficiently restore the lost blocks in the ROI of images.

Keywords: *Error Concealment, Image Transmission, ROI, Watermarking*

1. Introduction

The transmission of images over wireless channels introduces multiple losses into the transmitted data and degrades severely the quality of the received image [1]. Up to now, many approaches have been proposed to combat the transmission errors in these channels. Examples of such schemes include forward error correction (FEC), automatic retransmission request (ARQ) and error concealment (EC) [2]. Today error concealment techniques have received particular attention as effective mechanisms to recover the packet losses in multimedia data transmission without increasing the bandwidth demand [3]. The main purpose of error concealment is to obtain a close approximation of the original image or attempt to make the output image at the decoder least objectionable to human eyes [2].

Error concealment techniques are categorized into three groups, forward error concealment, error concealment by post processing and interactive error concealment, depending on whether the encoder or decoder plays the primary role or both are involved in cooperation. EC by post processing includes techniques in which the decoder fulfills the task of error concealment. The decoder estimates some features of lost information and then interpolate the lost information from the estimated features [4]. In general, post processing methods attempt to recover the lost information by estimation and interpolation without relying on additional information from the encoder [2]. EC at the decoder requires error detection. Some of the error concealment techniques have the capability of detecting damaged blocks before recovering them while the others must be supported by an appropriate transform format and/or an error detection algorithm that helps to identify damaged blocks [5].

In past years, various error concealment methods have been proposed [5-8]. Sun and Kwok proposed an interpolation algorithm for recovering the lost blocks in the spatial domain based on projections onto convex sets (POCS) [6]. They used spatially correlated edge information obtained from a large number of surrounding pixels to recover the lost blocks. Wang et al. [5] introduced a new error concealment algorithm called best neighborhood matching (BNM) to recover lost blocks in still images. They used a spatial kind of information (blockwise similarity within the image) obtained from not only neighboring pixels, but also remote regions in the image. Li and Orchard [7] presented an orientation adaptive interpolation technique for reconstruction of the pixels in a missing block using sequential recovery. In the sequential approach, the pixels in a missing block are recovered such that the previously recovered pixels can be used in the recovery process afterwards. An error concealment technique based on optimized directional decision and extrapolation in the spatial domain proposed in [8]. The authors in this technique used the accurately estimated direction of the edges, which determined by using Sobel operator and Hessian matrix, to recover the lost blocks in image by directional extrapolation.

These EC methods may obtain good restoration results but include high computational complexity at the decoder and often do not work well in the complex loss models. To solve these problems, a watermarking based error concealment technique is proposed that uses data hiding methods. In error concealment using watermarking, some significant information is extracted from the original image and embedded into the image itself. Then, the watermarked image is coded and transmitted over the network. At the receiver, the embedded data are extracted and the original image is restored based on the extracted hidden data along with some other post processing methods. In this technique, feature extraction is performed at the encoder side and so major computational complexity is shifted to the encoder. In watermarking based EC methods, the more information of the lost data is at hand, the more perfect reconstruction of the lost data can be achieved. On the other hand, more information embedding results in more quality degradation [9]. Therefore, embedding capacity is an important and restricting issue.

So far, several watermarking based EC methods have been proposed [4], [10-12]. EC using data hiding was first introduced by Liu and Li [10]. They embedded the DC coefficient of each 8x8 block into one of its neighboring blocks. At the receiver, the extracted DC coefficients were used to reconstruct the lost data. Yin et. al., [4] extracted edge directions from the content block of original image and embedded them into Discrete Cosine Transform (DCT) coefficients of its companion block. Due to limited embedding capacity, only one edge is embedded even if the content block has more than one edge. So their method cannot give good results when the lost block has a complex texture. In [11] error concealment was done by embedding BNM (best-neighborhood-matching) information into DWT detail coefficients of original image. In this method, the domain block address was found for each block of the image by the BNM algorithm and embedded into the wavelet detail coefficients. At the receiver, the domain block address for each lost block was extracted and then the original image was reconstructed by replacing each lost block with domain block of the extracted address. Since detail coefficients are not robust against attacks, if a packet is lost during transmission, the domain block address is wrongly extracted. The reconstructed image by replacing the lost block with wrong domain block will be splotchy. Gür et. al., [12] used robust watermarking for embedding downsized replicas of original image into wavelet coefficients. The replicas are embedded in the sub bands of the original image, excluding LL sub bands, in order to limit the visual degradation. In robust watermarking, embedded watermark is expected not to be altered in severe transmission conditions. Although this algorithm has used this type of watermarking for embedding watermark, it cannot recover all lost blocks.

Most of these EC methods utilize fragile watermarking techniques (due to high embedding capacity) and transform domain methods (DWT, DCT). In transform domain techniques, since the watermark is embedded into transform coefficients, if a packet is lost during transmission, the broken watermark cannot be detected. The use of the broken watermark for error concealment causes the quality degradation of the reconstructed image. Therefore, better performance can be obtained via developing a method that detects the broken watermarks. In [13] a number of thumbnail images of the original image were embedded into the Least Significant Bits (LSB) of the image. At the receiver, the best thumbnail image was extracted from the received watermarked image and estimated the lost blocks of the image using the best thumbnail. The authors considered a condition in which the upper part of the watermarked image is completely lost due to erroneous channel but the lower part is not affected by channel problems. Since we cannot consider restriction for error-prone channels (such as wireless channels) due to their fading dynamics, such condition for these channels is impractical. Another error concealment technique based on the fragile watermarking has been proposed in [14]. In this technique, DWT is used to produce a lower resolution copy of the original image. Then some of DCT coefficients of this downsized replica of the original image are embedded into the original image in the spatial domain as watermark. The embedding algorithm is such that it causes the quality degradation of the watermarked image. Also there is high computational complexity because of utilizing two transforms including DWT and DCT.

In this paper a new algorithm is proposed to conceal errors in the spatial domain. This scheme is based on wavelet transform and fragile watermarking. We apply DWT to each block of the original image and embed its approximation coefficients into masking block in the spatial domain. Our scheme use fragile watermarking techniques which are more susceptible to attacks. So, it is possible that the block and its masking block are lost due to attacks. Hence, to avoid simultaneously losing of information in the both blocks we use a new algorithm in which embedding is done circularly. Furthermore, watermark embedding is done in the spatial domain and so the broken watermarks can be detected. Our proposed algorithm can be used for wireless channels that usually have high error rates. Also it is based on block image processing; so it can be adopted by most existing image compression standards. This technique has shown higher efficiency and lower computational complexity over the existing techniques. It is also shown that this scheme can efficiently restore the lost blocks in the ROI of images.

The rest of the paper is organized as follows: In Section 2, the proposed EC algorithm is described in details. Section 3 presents the process of restoring lost blocks in the ROI of images. The simulation results and discussions are shown in Section 4. Finally, the conclusion is provided in Section 5.

2. The Proposed Algorithm

In the proposed algorithm, approximation coefficients of each block are used as a replica of the block and embedded into another block called masking block. To find the masking block of a block, we use a new method that prevents simultaneously losing of information in the both blocks. At the receiver, the embedded watermark is extracted and used to reconstruct lost blocks after transmission through error prone channels. Figure 1 illustrates the block diagrams of the proposed error concealment algorithm at the encoder and decoder.

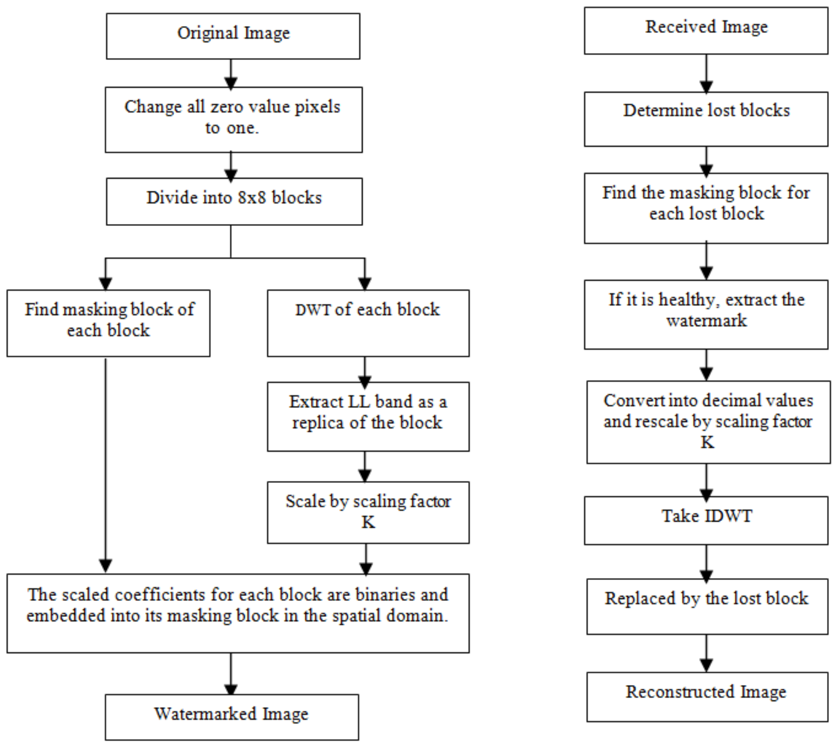


Figure 1. Block Diagram of the Proposed Algorithm at the Encoder and Decoder

2.1. Watermark Generation and Embedding

To generate watermark, the original image is first divided into non-overlapping 8x8 blocks. Then, we apply DWT to each block to produce a lower resolution copy of the block. We choose approximation coefficients of each block as its replica and embed into another block as a watermark. Consider a case of 2-level DWT which gives an approximation band of size 2x2. In this case, there are 4 coefficients of each block to be embedded. If we use 8-bit binary representation, we will have the replica with length of 32 bits. Since a large number of bits are necessary to embed the coefficients, a scaling factor K is used to reduce the coefficients values. This scale factor should be known at the receiver side to extract the watermark exactly. Thus we can use this factor as a network security aspect. After applying the scale factor K to the replica of each block, we convert to 8-bit binary representation. We generate a one dimensional array of binary numbers, obtaining a bit stream. Then, this generated bit stream is embedded into its masking block in the spatial domain by a pseudorandom key generated at the encoder. Choosing pixels from the masking block for embedding the bit stream is done by the pseudorandom key after zigzag scanning of the pixels. If we are aware of watermarking algorithm at the receiver, watermark extraction needs the knowledge of the pseudorandom key and scaling factor K. Since the watermarks are embedded in the spatial domain, if a packet is lost during transmission, its watermark cannot be used and the intended watermark is extracted as zero. So, the broken watermark is useless and not used for error concealment.

Since the information of a block is embedded into its masking block, we should try to avoid losing both them. To this end, we choose these blocks in such a way that they have the largest possible distance from each other. Furthermore, if B is the masking block of block A, A might also be the masking block of block B. In this case, if we embed the information of block A into B and vice versa, the probability of recovery is low when both block A and B are lost. Therefore, in this paper, we use a new algorithm in order to find masking block for a block, for circular embedding. If B is the masking block of block A, C is the masking block of block B. It means that the information of block A and block B is embedded into block B and block C respectively. Suppose block A at position (n, m) in the original image. Its masking block B at position (p, q) can be found using the following algorithm.

- Let m_1 and m_2 represent the number of blocks in each row and column of the original image, respectively.
- If $n \le m_1/2$, find $p > n$ such that $|p-n| = m_1/2$, where || denotes absolute value.

  Else, find $p < n$ such that $|p-n| = m_1/2-1$. If $p > m_1/2$, let $p = p - m_1/2$.
- Let $q = m_2 + 1 - m$.

Figure 2 shows the masking block B of block A and the masking block C of block B, when $m_1 = m_2 = 10$.

A									
C									
									B

Figure 2. Masking Blocks in an Image, B is the Masking Block of Block A, C is the Masking Block of Block B

In order to apply the error detection algorithm, before embedding the watermark, we change the value of all zero value pixels to one. Thus, at the receiver we determine the lost blocks by searching blocks consisting of all 0's.

The steps of watermark generation and embedding can be summarized as follows:

1. Read the original image, Y, of size N_1xN_2 pixels.
2. Change the value of all zero value pixels to one. This stage is done for error detection. This procedure does not introduce objectionable distortion since there are usually few pixels of zero value in normal images.
3. Divide the original image into 8x8 blocks.
4. Apply l^{th} level DWT to each block of image Y and then choose approximation coefficients of each block as its replica.

5. Scale the replica of each block by scaling factor K, and then convert to 8-bit binary representation. The generated bit stream is stored as watermark for the intended block.
6. Assign a masking block for each block of image Y using the former algorithm.
7. Generate a shared-key dependent pseudorandom sequence which determines embedding process in each block. The embedding algorithm is as follows:

```
If W (j) = = 1
    If P (i): odd
        P (i) = P (i) + 1
    End
Else
    If P (i): even
        P (i) = P (i) + 1
    End
End
```

where P (i) is the i^{th} pixel of zigzag ordering in block, and i is j^{th} element of A (j), the shared key dependent pseudorandom permutation of the pixels. W(j) is the j^{th} element of the watermark.

After embedding watermarks, the image is transmitted through the channel and blocks are lost according to the block loss patterns.

2.2. Watermark Extraction and Error Concealment

At the receiver, we first determine the lost blocks by searching blocks consisting of all 0's. Then, we find the masking block for the each lost block using the explained algorithm. If it is healthy, the embedded watermark is extracted by the pseudorandom key generated at the encoder. This key is equally applied to all blocks. After extracting the watermark of the lost block from its masking block, we convert groups of 8 consecutive bits into decimal values and multiple them by scaling factor K to get the replica of the lost block. This replica is coefficients in the LL sub band of the lost block. We take inverse wavelet transform of the obtained coefficients by setting the coefficients in the other sub bands to zero, obtaining an approximation of the lost block. Finally, we replace the lost block with its obtained approximation.

The steps of watermark extraction and error concealment are as follows:

1. Read the corrupted image, Y_1, and determine the lost blocks by searching blocks consisting of all 0's.
2. Find the masking block for each lost block using the explained algorithm. If it is healthy, the embedded watermark is extracted by the pseudorandom key generated at the encoder. The watermark extraction algorithm is as follows:

```
If PR (i): odd
    WR (j) = 0
Else
    WR (j) = 1
End
```

Where PR (i) is the i^{th} pixel of zigzag ordering in block, and i is j^{th} element of A (j), WR (j) is the j^{th} element of the watermark.

3. Convert groups of 8 consecutive bits into decimal values and rescale them by the scaling factor K to get the LL sub band of the lost block.
4. Take inverse DWT of the obtained coefficients by setting the coefficients in the other sub bands to zero, obtaining an approximation of the lost block.
5. Replace the lost block with its obtained approximation.
6. If all lost blocks are replaced, the error concealment process is finished.
7. If there are still blocks consisting of all 0's, then replace them with the median value of non-zero values of neighboring blocks' corresponding pixel.

3. Capability of Restoring Lost Blocks in ROI

The ROI in an image contains human-interested information and is usually the most important region of an image. When errors occur in the ROI of an image, perfect error concealment is needed and the reconstruction of the real missing bits is expected. Therefore, many techniques have been proposed to recover the missing blocks in the ROI of images. For example, Wang and Ji [15] proposed an error concealment scheme to reconstruct missing data of ROI of images using data hiding. They truncated embedded data from the coded bit stream of the ROI and embedded into the wavelet coefficients of region of background (ROB). When a data loss occurs in bit stream of the ROI, embedded data are extracted for reconstruction.

Another error concealment technique for recovering lost blocks in the ROI of images using data hiding was proposed in [16]. It is based on the robust watermarking technique to restore the lost blocks in ROI and BNM technique to restore the lost blocks in ROB of images. In that work, some important information was extracted from the ROI using DCT and embedded into the ROB of image. In both of these schemes, since the ROI information is embedded into the ROB, if the defined ROI size increases, the embedded information value into the ROB will decrease. This implies that the lost blocks are not perfectly recovered due to not providing proper estimate.

In [17], some key information was extracted from the ROI and embedded into the DCT high frequency coefficients of the original image. Since the watermark is embedded into the DCT coefficients, if a packet is lost during transmission, the broken watermark cannot be detected. The use of the broken watermark for error concealment causes the quality degradation of the reconstructed image. The lost blocks in the ROB of image were restored with a spatial interpolation algorithm. Our proposed algorithm, unlike the former techniques which use BNM algorithm or interpolation in order to reconstruct the lost blocks in the ROB, utilize fragile watermarking technique which has lower computational complexity over BNM algorithm. Furthermore, the interpolation technique may fail for images with contiguous block losses. Also, our scheme gives good results for larger ROIs due to embed the ROI information into all blocks of image.

In this paper, we first define the ROI of image and determine the set of ROI and ROB blocks. Then, we perform the algorithm proposed in Section 2 on these blocks. We apply 2-level and 3- level wavelet transform from each block in the ROI and ROB, respectively. Since the error in significant bits has far more serious effect on the quality of the reconstructed image, the more information of the ROI is embedded into the image. To this end, we embed two copies of the watermark for each ROI block into different blocks of the image. Suppose A is a block of the ROI. We find the masking block of A called block B and the masking block of B called block C using the explained algorithm and embed one copy of watermark for block A into the block B and another copy into the block C.

In embedding process, we first embed watermark of each ROB block and one copy of watermark for each ROI block into their masking block. After all ROB information and one copy of ROI information is embedded into the image, we embed the second copy of stored watermark for each ROI block. Since we have already done embedding into all blocks, we start the embedding process of the second copy of watermarks after the last embedded pixel of each block.

At the receiver, we find the masking blocks B and C for each lost block in the ROI using the explained algorithm. If they are errorless, two collections of watermarks are extracted. Converting into decimal values and applying the scaling factor K to them, we obtain two matrices w_1 and w_2 of approximation coefficients for the lost block in the ROI. We form new matrix w in which any zero value element of matrix w_1 is replaced with corresponding non-zero value element of matrix w_2. This new matrix is approximation band of the lost block. We take inverse wavelet transform of matrix w and replace the lost block with it. The reconstruction process of the lost blocks in the ROB is the same as the reconstruction procedure proposed in Section 2.2.

4. Simulation Results and Discussion

In our simulations, we have used gray scale “Lena”, “Pepper”, “Baboon”, “Barbara” and “Elaine” images of size 512x512 pixels. The blocks used for watermark embedding and the lost blocks during transmission have the size of 8x8 pixels. Thus, there are 4096 blocks in image. We have used various block loss patterns to evaluate our proposed algorithm and compare with the existing algorithms. The patterns are isolated block loss, consecutive block loss and contiguous block loss. The base wavelet used for DWT is Haar wavelet. Peak-signal-to-noise-ratio (PSNR) is employed as the performance metric. PSNR for the reconstructed image is defined as follows:

$$PSNR = 10\log_{10} \frac{(255)^2}{\frac{1}{N_1 \times N_2} \sum_{i=1}^{N_1} \sum_{j=1}^{N_2} (X(i,j) - Y(i,j))^2} \quad (1)$$

Where N_1 and N_2 is the number of pixels in each row and column of the image, respectively; X and Y is the original image and the reconstructed image, respectively.

4.1. The Order of DWT and Scaling Coefficient Effect

In our proposed algorithm, as mentioned before, the approximation coefficients of each block are selected as a replica of the block and embedded into the image for error concealment. In order to evaluate the effect of the order of DWT on the quality of the reconstructed image, we have used 2-level and 3-level DWT. If we apply 2-level DWT to an 8x8 block, the approximation sub band will be of size 2x2 pixels. In other word, 4 coefficients are selected as the replica of the intended block. If we apply 3-level DWT, the approximation sub band will be of size 1x1 pixel. In this case, one coefficient is selected as the replica of that block. Since 4 coefficients carry more information about the block, the block recovery using the 4 coefficients will be better due to providing better estimate.

Another factor which affects the quality of the reconstructed image is the scaling coefficient K. The greater the scaling coefficient, the less the embedded information value. On the other hand, some of information may be lost due to lessen embedded information and cannot be restored. Therefore, the greater coefficient K, the less quality of the reconstructed image. The numerical results of our simulation for "Lena" with 2-level and 3-level DWT and three different scaling coefficients are shown in Table 1. Comparing the results shown in this table reveals that the PSNR value of the reconstructed image for 2-level DWT and scaling factor 15 is the highest.

Table 1. PSNR Performance for Different Scaling Coefficients and 2-level and 3-Level DWT with 10% Contiguous Block Loss

The order of DWT	Scaling coefficient	The PSNR value of the corrupted image with 10% block loss(dB)	The PSNR value of the reconstructed image (dB)	Enhancement on the PSNR (dB)
2	100	15.3045	32.9053	17.6008
	50	15.4825	36.0122	20.5297
	15	15.3322	36.7985	**21.4663**
3	100	15.0909	33.6709	18.58
	50	15.2303	33.9473	18.717
	15	15.1433	34.0093	18.866

4.2. Performance Evaluation using Various Block Loss Patterns

The visual results of our simulation for "Lena" for 2-level DWT and scaling coefficient 15 are shown in Figures 3 through 6. The original and watermarked "Lena" images are shown in Figure 3(a) and Figure 3(b), respectively. It can be seen that there is no visual difference between them and our embedding algorithm causes no quality degradation. The corrupted image with 50% (PSNR=8.0473 dB) and 10% contiguous block loss (PSNR=15.3322 dB) are shown in Figure 4(a) and Figure 4(c), respectively. Figure 4(b) and Figure 4(d) show the reconstructed images by the proposed algorithm. The PSNR of these images are 27.0097 dB and 36.7985 dB, respectively.

(a) (b)

Figure 3. (a) Original Lena, (b) Watermarked Lena

(a) (b) (c) (d)

Figure 4. (a) Corrupted image with 50% Contiguous block loss (PSNR=8.0473), (b) Error concealed image by our algorithm (PSNR=27.0097), (c) Corrupted image with 10% contiguous block loss (PSNR=15.3322), (d) Error concealed image by our algorithm (PSNR=36.7985)

The error concealment results for isolated and consecutive block loss patterns are given in Table 2. The visual results of "Lena" with both block loss case are shown in Figure 5 and Figure 6. It can be seen that our proposed algorithm improves the quality of the distorted image for high packet losses and various block loss patterns.

We have conducted similar experiments for "Elaine", "Barbara", "Baboon" and "Pepper" images. The corresponding results for Barbara are shown in Figure 7.

Table 2. PSNR Performance of our Algorithm for Different Block Loss Patterns

Image	Block loss pattern		
	25% isolated block loss	25% consecutive block loss	50% consecutive block loss
Lena	33.5161	31.6567	27.8159
Pepper	32.8081	30.1204	27.4269
Baboon	26.4838	25.4169	22.7797
Barbara	28.8572	27.4529	24.7014

(a) (b)

Figure 5. (a) Corrupted Image with 25% Isolated Block Loss (PSNR=11.6673), (b) Error Concealed Image by our Algorithm (PSNR=33.5161)

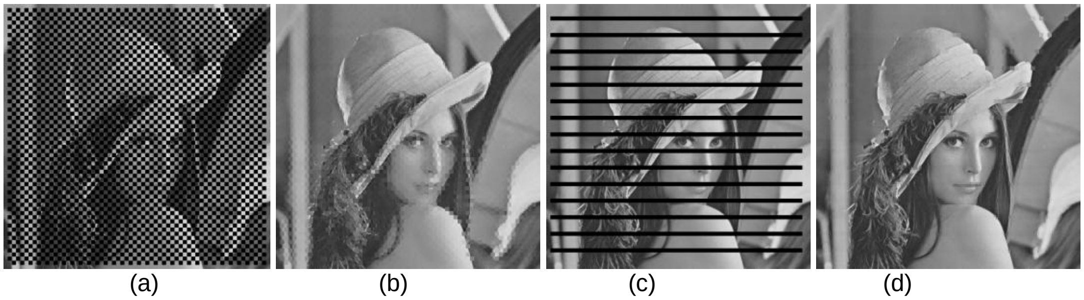


Figure 6. (a) Corrupted Image with 50% Consecutive block loss (PSNR=8.9180), (b) Error concealed image by our algorithm (PSNR=27.8159), (c) Corrupted image with 25% consecutive block loss (PSNR=11.8592), (d) Error concealed image by our algorithm (PSNR=31.6567).

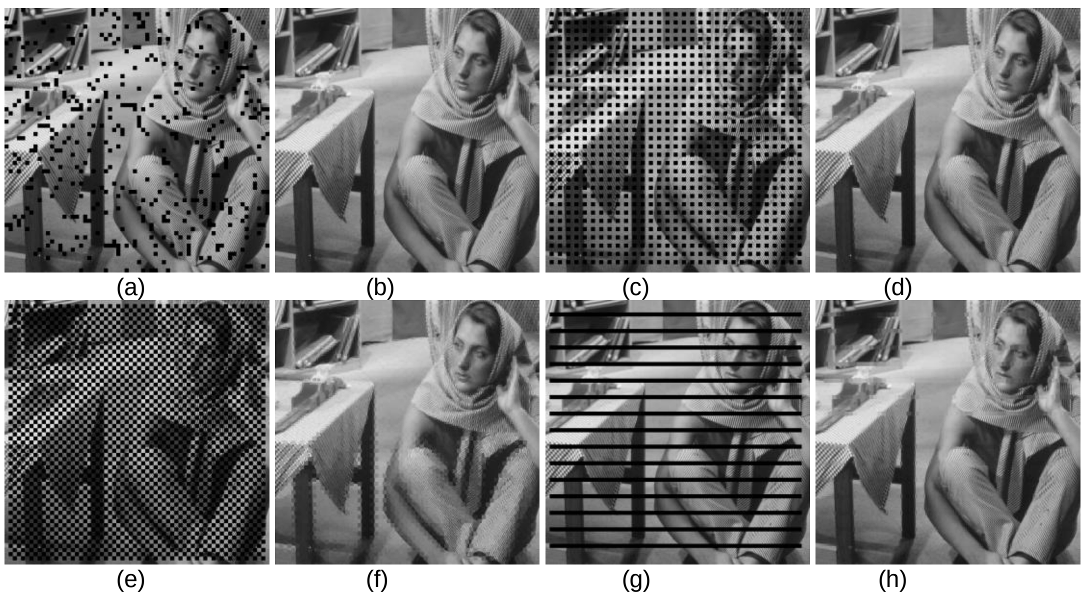


Figure 7. (a) Corrupted image with 10% Contiguous block loss, (b) Error concealed image by our algorithm, (c) Corrupted image with 25% isolated block loss, (d) Error concealed image by our algorithm,(e) Corrupted image with 50% consecutive block loss, (f) Error concealed image by our Algorithm, (g) Corrupted image with 25% Consecutive Block Loss, (h) Error Concealed Image by our Algorithm

4.3. Comparison with Related Works

To compare the proposed algorithm with the algorithms given in [11] and [12], we have obtained the PSNR values of the reconstructed image with different contiguous block loss rates ranging from 10% to 75% for 2-level DWT and scaling factor 15. The PSNR performance of our scheme for Lena, Baboon and Pepper images is depicted in Figure 8. Figure 9 shows the PSNR performance of the algorithms [11] and [12]. These results reveal that our proposed algorithm performs better and even at the high block loss levels provides significant improvement over both them in terms of PSNR. This profound improvement comes from the watermark embedding in the spatial domain. In this case, if a packet is lost during transmission, the broken watermark can be detected simply. Furthermore, due to circular embedding, the probability of simultaneously losing of a block and its masking block is small.

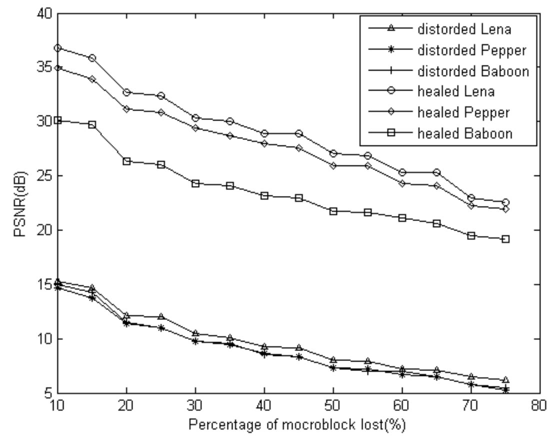
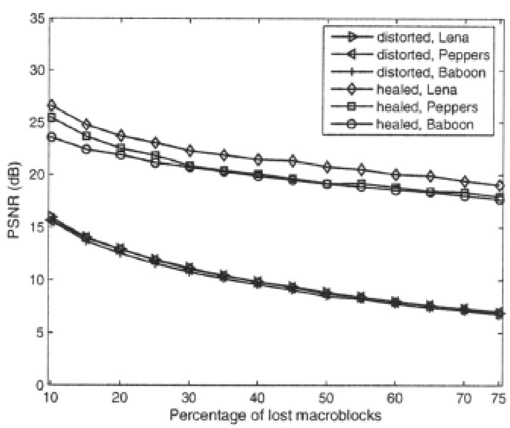
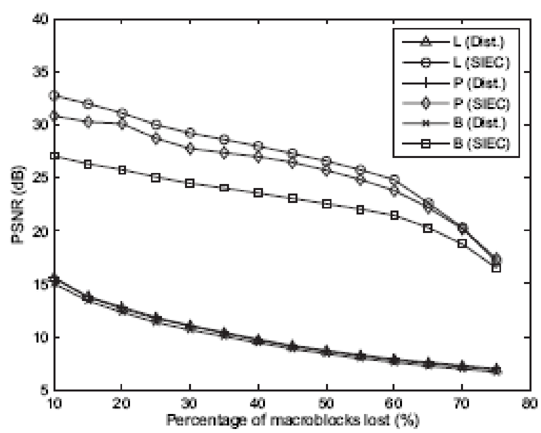


Figure 8. PSNR for Lena, Baboon and Pepper Images with Various Packet Loss Levels for 2-level DWT and Scaling Factor 15 by our Proposed Algorithm



(a)



(b)

Figure 9. (a) PSNR for Lena, Baboon and Peppers images with various packet loss levels [11], (b) PSNR for Lena, Baboon and Peppers images with various packet loss levels [12]

To compare the proposed algorithm with the algorithm given in [14], the PSNR values of the damaged and the reconstructed images with different block loss rates ranging from 2.5% to 30% for our scheme and the algorithm proposed in [14] for Lena and Elaine are given in Table 3. Comparing the results shown in Table 3 reveals that our scheme performs better. It can be seen that in our algorithm, the enhancement on the PSNR for all block loss rates is more than [14]. In our algorithm, the quality of the watermarked image is higher due to used embedding technique compare with the algorithm given in [14]. This causes higher reconstruction image quality for our scheme.

Table 3. PSNR Performance for our Algorithm and the algorithm given in [14] with different block loss rate ranging from 2.5% to 30%

Image	Block Loss Rate (%)	Proposed Algorithm			Algorithm [14]		
		Damaged Image (dB)	Error Concealed Image (dB)	Enhancement on the PSNR	Damaged Image (dB)	Error Concealed Image (dB)	Enhancement on the PSNR
Lena	2.5	31.45	52.36	**20.91**	20.85	31.15	**10.30**
	5.0	20.71	42.33	**21.62**	18.62	30.90	**12.28**
	7.5	18.32	40.21	**21.89**	16.58	30.72	**14.14**
	10.0	15.33	36.79	**21.46**	15.52	30.59	**15.07**
	15.0	14.65	35.89	**21.24**	13.72	29.15	**15.43**
	20.0	12.07	32.71	**20.64**	12.54	28.20	**15.66**
	30.0	10.49	30.33	**19.84**	10.76	25.29	**14.53**
Elaine	2.5	29.38	50.79	**21.41**	20.27	33.01	**12.74**
	5.0	19.29	41.86	**22.57**	17.83	32.73	**14.90**
	7.5	18.00	39.83	**21.83**	16.00	32.30	**16.30**
	10.0	14.61	37.12	**22.51**	15.00	32.03	**17.03**
	15.0	13.82	36.31	**22.49**	13.12	31.24	**18.12**
	20.0	11.42	33.55	**22.13**	12.00	30.06	**18.06**
	30.0	9.69	30.91	**21.22**	10.35	27.91	**17.56**

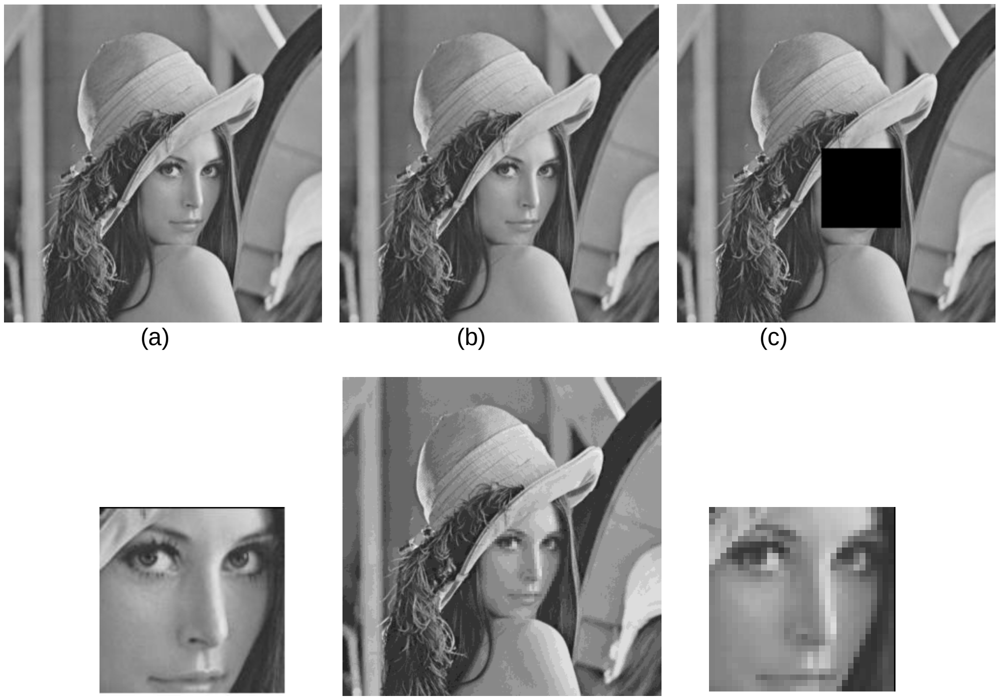
We have also compared our algorithm with the other techniques which are not based on watermarking. Table 4 shows the PSNR comparison between our proposed algorithm and the techniques in [6, 7] and [8] for Lena image. It can be seen from this Table that our proposed algorithm has achieved significant improvements over these techniques in both isolated and consecutive block loss case. Our proposed algorithm against the techniques given in [6, 7] and [8] which use interpolation in order to reconstruct the lost blocks in image, utilize fragile watermarking technique which has lower computational complexity and better reconstruction results. Furthermore, the interpolation technique may fail for images with contiguous block losses while our scheme has better performance in these cases.

Table 4. Performance Comparison in PSNR for Lena Image

Recovery Method	Block loss pattern	
	25% isolared block loss	25% consecutive block loss
[6]	23.93	20.14
[7]	28.25	23.55
[8]	33.24	-
Ours	**33.52**	**31.66**

4.4. Performance Evaluation in the ROI

The error concealment results for lost blocks in the ROI are shown in Figure 10 and Figure 11. The original and watermarked "Lena" images are shown in Figure 10(a) and Figure 10(b), respectively. The corrupted ROI image is shown in Figure 10(c). The corresponding ROI of Lena, with size 128x128 pixels, is shown in Figure 10(d). The reconstructed image by the proposed algorithm and its ROI image are shown in Figure 10(e) and Figure 10(f), respectively. The whole PSNR value for the reconstructed image and the corresponding PSNR value for the ROI are 39.8121 and 27.8101, respectively. It can be seen that when ROI image is damaged, the error concealment can be done perfectly.



(a) (b) (c)

(d) (e) (f)

Figure 10. Error concealment results of Lena image by the proposed algorithm when ROI image is damaged: (a) Original Lena, (b) Watermarked Lena, (c) The corrupted ROI image (with the whole PSNR=17.1949), (d) The ROI of Lena with size 128×128 pixels, (e) Error concealed image from (c) (with the whole PSNR=39.8121), (f) The ROI of error concealed image (PSNR= 27.8101)

The simulation results, when errors occur both in the ROI and ROB, are shown in Figure 11. In this case, the corrupted image with 10% block loss is seen in Figure 11(a) (PSNR=15.5251). Figure 11(b) shows the reconstructed image by the proposed algorithm. The PSNR values of the reconstructed ROI and ROB are 40.1546 and 31.6749, respectively. These results show that error concealment in the ROI is done better due to embedding more information of this region.

We have compared the PSNR performance of our algorithm with the algorithm given in [17] when the ROI image is damaged. The results for Lena image are reported in Table 5. This table shows that the PSNR performance over [17] is about 0.4 dB. In order to evaluate the effect of the ROI size on the quality of the reconstructed image, we have obtained the PSNR values of the reconstructed image and of its ROI with the different sizes for the ROI. These results for "Lena" are given in Table 6. It shows that when the ROI size increases, the PSNR values of the reconstructed image and of its ROI are satisfactory while the algorithm proposed in [16] does not show this capability.

(a) (b)

Figure 11. Error concealment results of Lena image by the proposed algorithm when both ROI and ROB are damaged. (a) The corrupted image with 10% block loss (PSNR=15.5251). (b) Error concealed image (PSNR=34.2866)

Table 5. Performance Comparison in PSNR Values for Lena Image

Recovery Method	ROI-PSNR(dB)	Full-PSNR(dB)
[17]	27.42	39.46
Our proposed method	**27.81**	**39.81**

Table 6. PSNR Performance for Different Sizes of ROI by the Proposed Algorithm with 10% Block Lost Rate

ROI size	Damaged Image (dB)	Damaged ROI (dB)	Restored Image (dB)	Restored ROI (dB)	Restored ROB (dB)
136x136	15.5251	15.4619	34.2866	40.1546	31.6749
200x200	15.7499	15.4335	34.7444	36.1161	31.1696
248x248	15.5250	15.9063	35.0052	35.5745	30.1137

5. Conclusion

In this paper a new error concealment scheme based on fragile watermarking and wavelet transform was proposed. This scheme is based on block image processing; so it is adopted by most existing image compression standards. We embedded the replica (approximation band) of each block into its masking block. To find the masking block, we used a new algorithm that avoids simultaneously losing of information in a block and its masking block. The lost blocks during transmission were reconstructed using their extracted replicas. In order to add to the security aspect of the proposed scheme, besides a pseudorandom sequence generated by a key, we have also used a scaling factor for embedding watermarks. Our proposed algorithm can be used for wireless channels that have high error rates. Simulation results indicate that the proposed scheme provides significant improvement over the existing algorithms in terms of both subjective and objective evaluations. Also this scheme has the capability of restoring the lost blocks in the ROI of images and can improve the quality of the reconstructed ROI image in comparing with the similar algorithms.

References

[1] C. B. Adsumilli, M. C. Q. Farias, S. K. Mitra and M. Carli, "A Robust Error Concealment Technique Using Data Hiding for Image and Video Transmission Over Lossy Channels", IEEE Transaction on circuits and systems for video technology, vol. 15, no. 11, **(2005)** November.
[2] Y. Wang and Q.-F. Zhu, "Error Control and Concealment for Video Communication: A Review", Proceedings of the IEEE, vol. 86, no. 5, **(1998)** May.
[3] W. M. Lam and A. R. Reibman, "An Error Concealment Algorithm for Images Subject to Channel Errors", IEEE Trans. on Image Processing, vol. 4, no. 5, **(1995)** May.
[4] P. Yin, B. Liu and H. H. Yu, "Error concealment using data hiding", in Proc. IEEE Int. Conf. On Acoustic, Speech and Signal Processing, vol. 3, **(2001)** May, USA, pp. 1453-1456.
[5] Z. Wang, Y. Yu and D. Zhang, "Best Neighborhood Matching: An Information Loss Restoration Technique for Block-Based Image Coding Systems", IEEE Transaction on Image Processing, vol. 7, no. 7, **(1998)** July.
[6] H. Sun and W. Kwok, "Concealment of damaged block transform coded images using projection onto convex set," IEEE Trans. on Image Processing, vol. 4, **(1995)** April, pp. 470–477.
[7] X. Li and M. T. Orchard, "Novel sequential error-concealment techniques using orientation adaptive interpolation", IEEE Trans. on Circuits Systems for Video Technology, vol. 12, no. 10, **(2002)** October, pp. 857–864.
[8] Y. Zhao, Q. Chen, H. Chen and M. Rupp, "Spatial Error Concealment Using Optimized Directional Decision and Extrapolation", The 5th International Conference on Visual Information Engineering (VIE 2008), **(2008)** July 29-Auguat 1, China, pp. 658-661.
[9] S. D. Lin and C. W. Tsai, "An Effective Data Embedding for Error Concealment", The 3rd IEEE International Conference on Innovative Computing Information and Control, (ICICIC'08), **(2008)**.
[10] Y. Liu and Y. Li, "Error concealment for digital images using data hiding", presented at the 9th DSP Workshop, Hunt, TX, **(2000)** October.
[11] G. G¨ur, F. Alag¨oz and M. abdel-Hafez, "A Novel Error Concealment Method for Images Using Watermarking in Error-Prone Channels", in Proc 16th Annual IEEE International symposium on personal Indoor and Mobile Radio communications (PIMRC'05); **(2005)**.
[12] G¨. G¨ur, Y¨. Altu˘g, E. Anarim, and F. Alag¨oz, "Image Error Concealment Using Watermarking with Sub bands for Wireless Channels", IEEE Communication Letters, vol. 11, no. 2, **(2007)** February.
[13] F. Alagoz and M. Abdel-Hafez, "A New Error Concealment Algorithm Utilizing Thumbnail Images and LSB Data Hiding Techniques", in Proc. IJt. Conference on Electronics, Circuits and Commun. (ELECO2003), Bursa, Turkey, **(2003)** December.
[14] D. Bashiri, A. Aghagolzadeh, J. Museviniya and M. Nooshyar, "A Novel Still Image Error Concealment Using Fragile Watermarking in Wireless Image Transmission and Packet-Switched Networks", International Journal of Information and Communication Technology (IJICT), vol. 1, no. 3, **(2009)**.
[15] J. Wang and L. Ji, "A Region and Data Hiding Based Error Concealment Scheme for Images", IEEE Transactions on Consumer Electronics, vol. 47, no. 2, **(2001)** May, pp. 257-262.
[16] S. D. Lin, S. Shie and J. Chen, "Image Error Concealment Based on Watermarking", in Proc. 7th Int. Conf. on Digital Image Computing: Techniques and Applications, Sydney, Australia, **(2003)** December.
[17] S.-C. Hsia, S.-H. Wang and M.-H. Chen, "High-Performance Region-of-Interest Image Error Concealment with Hiding Technique", Journal of Electrical and Computer Engineering, vol. 2010, **(2010)** January.

Authors

Razieh Keshavarzian received the B.Sc. and M.Sc. degrees, both in Electrical Engineering, from University of Tabriz, Tabriz, Iran, in 2005 and 2009, respectively. He is currently a member of the faculty of electrical engineering, Islamic Azad University, Heris Branch. His research interests include Image Processing, watermarking and communication systems.

Ali Aghagolzadeh received Ph.D. degree from Purdue University, West Lafayette, IN, USA, in 1991 in electrical engineering. He is currently professor of electrical engineering in Babol University of Technology, Babol, Iran. His research interests include image processing, video coding and compression, information theory, computer vision.