An Error Concealment Algorithm Using Discrete Wavelet Transform

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Abstract

A new algorithm for error concealment of a completely lost blocks using the 1-D discrete wavelet transform is proposed in this paper. The transmission of block-coded images, fading in wireless channels can cause errors in entire blocks and consequently causes the loss of information of the block. Instead of using common retransmission query protocols, the error block is substituted for pixel values of the neighborhood of the lost block.

The proposed algorithm does not require a DC estimation method. While most of the previously error concealment methods assume that the DC value is available or DC estimation is required.

الخلاصة

تم في هذا البحث اقتراح خوارزمية جديدة لأخفاء الأخطاء المؤدية الى فقدان الأجزاء كلياً من الصور باستخدام مجال المويجة ذي البعد الواحد. عندما يتم نقل كتل الصورة المرمزة، فانها تتعرض للاضمحلال في القنوات اللاسلكية، مما يؤدي الى حدوث الأخطاء في بعضها، ومن ثم الى فقدان المعلومات المتوفرة في هذه الأجزاء. فبدلاً من استخدام بروتوكولات إستفسار إعادة الإرسال المشتركة، فان اجزاء الصور المفقودة يتم تعويضها من قيم النقاط المجاورة للجزء المفقود.

الخوارزمية المقترحة لا تحتاج الى طريقة تخمين DC. بينما طرق التعويض السابقة تفترض توفر قيمة DC أو أنها تحتاج الى طريقة لتخمين DC.

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1.Introduction

In common wireless scenarios, the image is transmitted over the wireless channel block by block. So, the image is tiled into blocks. Due to severe fading, entire image blocks can be lost. E. Chang reports that average packet loss rate in a wireless environment is 3.6 % and occur in a bursty fashion [2].

Error resilient channel coding schemes (e.g., Forward Error Correction) Automatic Retransmission Query Protocols (ARQ). ARQ lowers data transmission rates and can further increase the network congestion, which can aggravate the packet loss [3]. Instead, it was shown that it is possible to satisfactorily substitute the lost blocks by using the available information surrounding them. The location of lost data, i.e., lost image blocks, is known in common wireless scenarios. The proposed scheme is tested with a variety of images and simulated block losses. It was shown that the substitution has an acceptable visual quality while high SNR is obtained.

2. Related Work

Purely decoder-based error concealment in baseline JPEG coded images has been demonstrated in the use Reed Solomon codes or convolutional codes to reconstruct the lost portion of the bit stream, sacrificing some useful bandwidths in the process. This method, which is designed for a fixed bit error rate (BER), cannot completely prevent loss of data when the BER is unknown, as in most practical cases [2].

The common techniques to recover the lost block are grouped under image domain and in the DCT domain. Various studies have successfully used the wavelet framework for texture synthesis [4], substitution of edges, which are distorted during compression [5], and enhancement of edges, which are blurred during interpolation [6].

V. DeBrunner, et al, provided a survey of commonly used error control and concealment methods in image transmission [7]. Image domain methods use interpolation [8], or separate substitution methods for structure and texture [9]. Most transform-based methods, notably those described for MPEG-2 video [10] and earlier for DCT-JPEG images [8], assume a smoothness constraint on the image intensity. These methods define an object function, which measures the variation at the border between the lost block and its neighbors, and then proceed to minimize this object function. Z. Alkachouch and M. Bellanger describe a different DCT-based interpolation scheme, which uses only 8 border pixels to reconstruct the 64 lost DCT coefficients [11].

3. The Concept Of Transform

The concept of transform is familiar to mathematicians and engineers. It is a standard mathematical tool used to solve problems in many areas. The idea is to change a mathematical quantity into another form, where it may look unfamiliar but may exhibit useful features [12].

The conventional transform is the Fourier theory in that a signal can be expressed as the sum of, possibly infinite, a series of sines and cosines. This sum is also referred to as Fourier expansion. The big disadvantage of a Fourier expansion, however, is that it has only frequency resolution and no time resolution. This means that although one might be able to determine all the frequencies present in a signal, it is not known when they are present. To overcome this problem, over the past decades, several solutions have been developed which are more or less able to represent a signal in the time and frequency domain at the same time [13].

The idea behind these time-frequency joint representations is to cut the signal of interest into several parts and then analyze the parts separately. It is clear that analyzing a signal in this way will give more information about the time and place of different frequency components occurrence. If anyone wants to know exactly all the frequency components present at a certain moment in time, he must cut out only this very short time, using a pulse, and transform it to the frequency domain.

The problem here is that cutting the signal corresponds to a convolution between the signal and the cutting pulse. Since convolution in the time domain is identical to multiplication in the frequency domain and since the Fourier transform of a pulse contains all possible frequencies, the frequency components of the signal will be spread out all over the frequency axis. In fact, this situation is the opposite of the standard Fourier transform since now there is time resolution but no frequency resolution.

The principle of the phenomena just described is due to Heidelberg's uncertainty principle, which in signal processing terms, states that it is impossible to know the exact frequency and the exact time of occurrence of this frequency in a signal. In other words, a signal can simply not be represented as a point in the time-frequency space.

The wavelet transform or wavelet analysis is probably the most recent solution to overcome the shortcomings of the Fourier transform.

In wavelet analysis, the use of a fully scalable modulated window (pulse) solves the signal-cutting problem, the window is shifted along the signal and for every position the spectrum is calculated. Then, this process is repeated many times with a slightly shorter (or longer) window for every new cycle. At the end, the result will be a collection of time-frequency representations of the signal, all with different resolutions, and because of this collection of representations one can speak of a multiresolution analysis. In the case of wavelets, one normally does not speak about time-frequency representations, but about time-scale representations, scale being in a way the opposite of frequency, because the term frequency is reserved for the Fourier transform. The scale may be defined here as follows: the large scale is the big picture, while the small scales show the details or zooming.

4. The Wavelet Transform

The term "Wavelet" as it implies means a little wave. This little wave must have at least a minimum oscillation and a fast decay to zero, in both the positive and negative directions, of its amplitude. This property is analogous to an admissibility condition of a function that is required for the wavelet transform.

Sets of "Wavelets" are employed to approximate a signal and the goal is to find a set of daughter wavelets constructed by a dilated (Scaled or Compressed) and translated (shifted) original wavelets or mother wavelets that best represent the signal. So, by "traveling" from the large scales toward the fine scales, one "zooms in" and arrives at more and more exact representations of the given signal. The wavelet transform is an operation that transforms a function by integrating it with modified versions of some Kernel function. The Kernel function is called the mother wavelet, and the modified version is its daughter wavelet. The mother wavelet can be any real or complex function that satisfies the following properties [14]:

1) The total area under the curve of the function is zero, i.e.

$$\int_{-\infty}^{\infty} h(t)\,dt = 0 \qquad (1)$$

(the wavelet must integrate to zero "its *D.C.* or zero frequency component is zero", this means that for a function to be a wavelet it must be oscillatory and decays fast towards zero (wave)).

2) The total area of $|h(t)|^2$ is finite, i.e.

$$\int_{-\infty}^{\infty} |h(t)|^2\,dt < \infty \qquad (2)$$

This condition implies that a function $h \in L^2(R)$ (the set of all square integrable or a finite energy function).

3) The admissibility condition, with properties 1 and 2, a function $h(t)$ is admissible if

$$C_h = \int_{-\infty}^{\infty} \frac{|H(w)|^2}{|w|}dw < \infty \qquad (3)$$

Here $H(W)$ is the Fourier transform of $h(t)$. The constant C_h is the admissibility constant of the function $h(t)$, and the requirement that it is finite allows for inversion of the wavelet transform. Any admissible function can be a mother wavelet, for a given $h(t)$, the condition $C_h < \infty$ holds only if $H(0) = 0$ i.e., the wavelets are inherently band pass filters in the Fourier domain [14].

The wavelet transform of a function $f \in L^2(R)$ with respect to a given admissible mother wavelet $h(t)$ is defined as:

$$W_f(a,b) = \int_{-\infty}^{\infty} f(t).h^*{}_{a,b}(t)dt \qquad (4)$$

where * denotes the complex conjugate. However, most wavelets are real valued. The daughter wavelets are generated from a single mother wavelet $h(t)$ by dilation and translation:

$$h_{a,b}(t) = \frac{1}{\sqrt{a}} h(\frac{t-b}{a}) \qquad (5)$$

where $a > 0$ is the dilation factor (the scaling factor that controls the dilation or compression) and b is the translation factor (the translation factor which determines the shift in time) [15].

The constant a $^{-1/2}$ is the energy normalization factor, included so that $\|h\| = \|h_{a,b}\|$. (i.e., keeps the energy of the daughter wavelet equal to the energy of the original mother wavelet, independent of a and b). To reconstruct the original function from its integral wavelet transform, the expression for the inverse wavelet transform is: [16]

$$f(t) = \frac{1}{C_h} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} W_f(a,b) h_{a,b}(t) \frac{dadb}{a^2} \quad (6)$$

To constitute a frame, the discrete wavelet transform is generated by sampling the wavelet parameters (time/scale) on a grid or lattice, which is not equally spaced, must satisfy the admissibility condition and the lattice points must be sufficiently close to satisfy basic information-theoretic needs. The family of basic functions $\{h_{a,b}(t)\}$ is said to be a frame if it satisfies the property that there exist two frame bounds $A > 0$ and $B < \infty$ where $A \text{ and } B$ are independent of f(t) such that for all the functions $f \in L^2(R)$, the sum of square moduli of $W_f(a,b)$ must lie between the two positive bounds:

$$A\|f\|^2 \leq \sum_{a,b} |< f, h_{a,b} >|^2 \leq B\|f\|^2 \quad (7)$$

5. The Proposed Algorithm

Once the missing block has been detected which has a size of (m x m), the substitution of the lost blocks includes the following steps:-

1) The nearest row above the lost block has been taken (which has the same size of the column of the lost block, i.e., 1 x m) as shown in Fig.(1), and denoting it (N).
2) The nearest row below the lost block has been taken (which has the same size of the column of the lost block, i.e., 1 x m) as shown in Fig.(1), and denoting it (S).
3) The nearest column to the right of the lost block has been taken (which has the same size of the row of the lost block, i.e., m x 1) as shown in Fig.(1), and denoting it (E).
4) The nearest column to the left of the lost block has been taken (which has the same size of the row of the lost block, i.e., m x 1) as shown in Fig.(1), and denoting it (W).
5) The 1-D discreate wavelet transform for all N,S,R, and L that gives us the approximate (low frequency component) and details (high frequency component) coefficients of N,S,R, and L with each has a dimension equals to one-half of its original, i.e., m/2.

   [Na,Nd]=dwt(N),

   [Sa,Sd]=dwt(S),

[Ea,Ed]=dwt(E),

[Wa,Wd]=dwt(W).

where Na,Nd,Sa,Sd,Ea,Ed,Wa, and Wd each of them has a dimension of m/2.

6) The values of the detail elements are translated as an additional elements in their approximate elements.

Nna=[Na,Nd],

Sna=[Sa,Sd],

Ena=[Ea,Ed],

Wna=[Wa,Wd].

where each of the new low frequency components has a dimension of m.

7) Nnd, Snd, End, and Wnd have been given zero values with a dimension of m.

Nnd=zeros(1,m),

Snd=zeros(1,m),

End=zeros(1,m),

Wnd=zeros(1,m).

8) By taking the 1-D inverse discreate wavelet transform for the new values of approximation and details gives us the new values of N,S,E, and W with the double size of m.

Nn=idwt(Nna,Nnd),

Sn=idwt(Sna,Snd),

En=idwt(Ena,End),

Wn=idwt(Wna,Wnd).

9) The substitution of the first half of the top of the lost block is done by averaging the nearest values indicated in Fig.(2), i.e., N and W.

$T_1=(W_1+N_1)/2$,

then $T_2=(T_1+N_2)/2$, and so on.

10) The substitution of the second half of the top of the lost block is done by averaging the nearest values indicated in Fig.(2), i.e., N and E.

$T_m=(E_1+N_1)/2$,

then $T_{m-1}=(T_m+N_2)/2$, and so on.

11) Step (9) is repeated for the first halves of the bottom (by using S and W), right (by using E and N), and left (by using W and N) respectively.

12) Step (10) is repeated for the second halves of the bottom (by using S and E), right (by using E and S), and left (by using W and S) respectively.

13) Now the size of the lost block is decreased by (2).

14) Repeat steps (1-13) until the whole lost block is found.

The flowchart of the proposed algorithm is shown in Fig.(3).

6. Experimental Results

Since there is no control over the fading channel, there is no prior information about the relative locations and number of blocks that can be received with errors and causing the information to be lost in the process. It is noted that before transmission of the blocks, a packetization scheme is applied so that a bursty packet loss during transmission is scattered into a pseudorandom loss in the image domain. Therefore, consecutive image blocks are rarely being with errors and the substitution scheme can use the neighborhood of the lost block for substitution. Figures (4), (6), and (8) show simulated losses for three blocks of size 8 x 8 for the images clown, tree and Lena. While their substitutions are shown in Figures (5), (7), and (9) respectively using the proposed algorithm. The substitution of the lost blocks of the clown image gives an SNR of 27.5041dB. While the substitution of the lost blocks of the tree image gives an SNR of 30.6202 dB. Finally, the substitution of the lost blocks of the Lena image gives an SNR of 34.8115 dB.

To make a comparison between the proposed algorithm and the previously related work, it is worth to note that the newest algorithm to substitute lost blocks is the algorithm presented by A. H. Hadi [17]. It had been shown in that algorithm that it is the best to substitute lost blocks in terms of SNR values and easiest to get the nearest original values. But that algorithm assumed that the DC value must be received correctly or a DC estimation technique is required which make the algorithm spent more time. While the algorithm presented in this paper does not require a DC estimation technique which makes it spend less time than the algorithm presented in [17], and if the DC value is received correctly, then the proposed algorithm gives better performance than the previously algorithms in terms of SNR values.

7. Conclusions

An algorithm for substitution of a completely lost blocks using the 1-D discrete wavelet transform is presented. The algorithm takes only one raw above and below the lost block and with the same size of the lost block. It also takes only one column to the right and left of the lost block with the same size of the lost block. Then proceeding with the procedue given in part (5), the whole lost block is reconstructed. The proposed algorithm does not require a DC estimation method. While most of the previuosly substitution methods assume that the DC value is available or a DC estimation is required.

References

1) D. Taubman and M. Marcellin, "**JPEG 2000 Image Compression, Fundamentals, Standards, and Practice**", Kluwer Aczdemic Publishers, 1st edition, 2002.
2) E. Chang, "**An Image Coding and Reconstruction Scheme for Mobile Computing**", in Proceedings of the 5th IDMS, pp.137-148, Oslo, Norway, September 1998.
3) S. Shirani, F. Kossentini, and R. Ward, "**Reconstruction of Baseline JPEG Coded Images in Error Prone Environments**", IEEE Transactions on Image Processing, vol. 9, pp. 1292–1299, July 2000.
4) D. J. Heeger and J. R. Bergen, "**Pyramid-Based Texture Analysis/Synthesis**", in SIGGRAPH 95 Conference Proceedings, pp.229–238, Addison Wesley, 1995.
5) G. Fan and W. Cham, "**Model-Based Edge Reconstruction for Low-Bit-Rate Wavelet Transform Compressed Images**", IEEE Transactions on Circuits System Video Technology, vol. 10, February 2000.
6) S.-H. G. Chang, Z. Cvetkovi´c, and M. Vetterli, "**Resolution Enhancement of Images Using Wavelet Transform Extrema Extrapolation**", in Proceedings ICASSP-95, vol. 4, pp.2379–2382, 1995.
7) V. DeBrunner, L. DeBrunner, L.Wang, and S. Radhakrishnan, "**Error Control and Concealment for Image Transmission**", IEEE Communications Society Surveys and Tutorials, vol. 3, no. 1, 2000.
8) S. S. Hemami and T. H.-Y. Meng, "**Transform Coded Image Reconstruction Exploiting Inter-block Correlation**", IEEE Transactions on Image Processing, vol. 4, pp. 1023–1027, July 1995.
9) S. Rane, G. Sapiro, and M. Bertalmio, "**Structure and Texture Filling-in of Missing Image Blocks in Wireless Transmission and Compression Applications**", Submitted to IEEE Transactions on Image Processing (available at www.ima.umn.edu), 2001.

10) J. W. Park, J. W. Kim, and S. U. Lee, "**DCT Coefficients Recovery-Based Error Concealment Technique and its Application to The MPEG-2 Bit Stream Error**", IEEE Transactions on Circuits and Systems for Video Technology, vol. 7, pp. 845–854, Dec. 1997.

11) Z. Alkachouch and M. Bellanger, "**Fast DCT-Based Spatial Domain Interpolation of Blocks in Images**", IEEE Transactions on Image Processing, vol. 9, pp. 729–732, Apr. 2000.

12) Haidar Tarish Al-Haajy, **"Evaluation of Information Hiding for Still Image**", M.Sc. Dissertation, University of Baghdad, 2001.

13) Salwan Khalid, "**Computing of Wavelet Transform Using DSP Technology**", Higher Diploma Dissertation, Iraqi Commission For Computer and Information, the Institute of Postgraduate Studies, Computer and Information Education, 2002.

14) D. Salomon, "**Data Compression: The Complete Reference**", Prentice Hall PTR, 2nd edition, 2000.

15) Y. Hill, and D. V. Thiel, "**An Investigation of Wavelet Design Using Genetic Algorithms**", Microelectric Engineering Research Conference, Oslo, Norway, 2001.

16) S. Al-Shabkaan, "**Wavelet Neural Network Approach for Recognition of Arabic Handwritten Character**", M.Sc. Dissertation, University of Technology, Baghdad, 2004.

17) A. H. Hadi, "**Wavelet-Domain Reconstruction of Lost Blocks for Transmission in Computer Networks**," M.Sc. Dissertation, University of Technology, Baghdad, 2004.

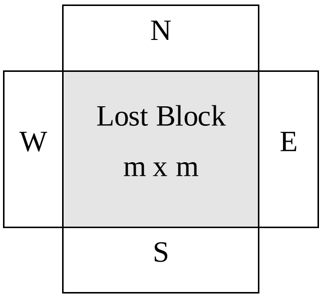

Fig.(1). The Demonstration of N,S,E, and W

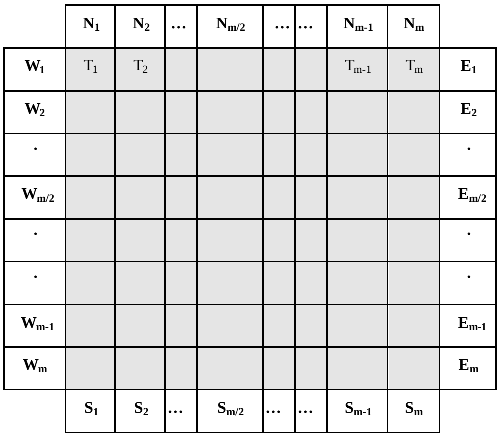

Fig.(2). The Reconstruction of The Top of The Lost Block

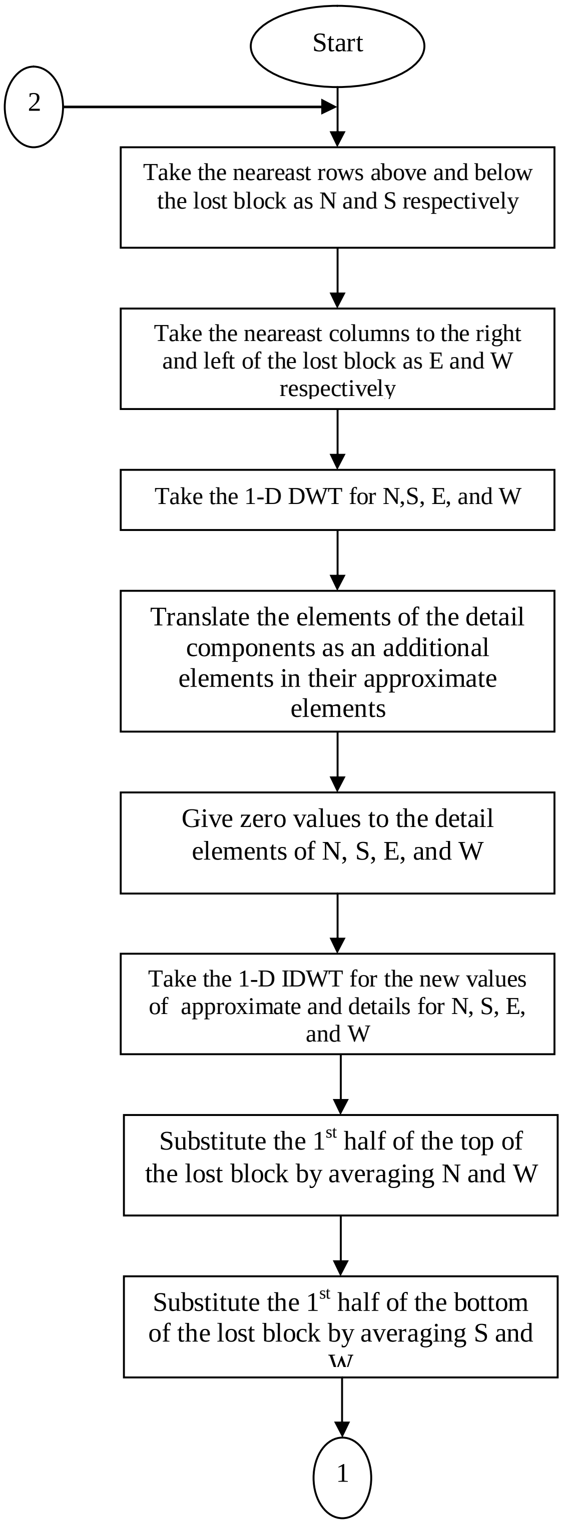

Fig.(3). The Flowchart of the Proposed Algorithm

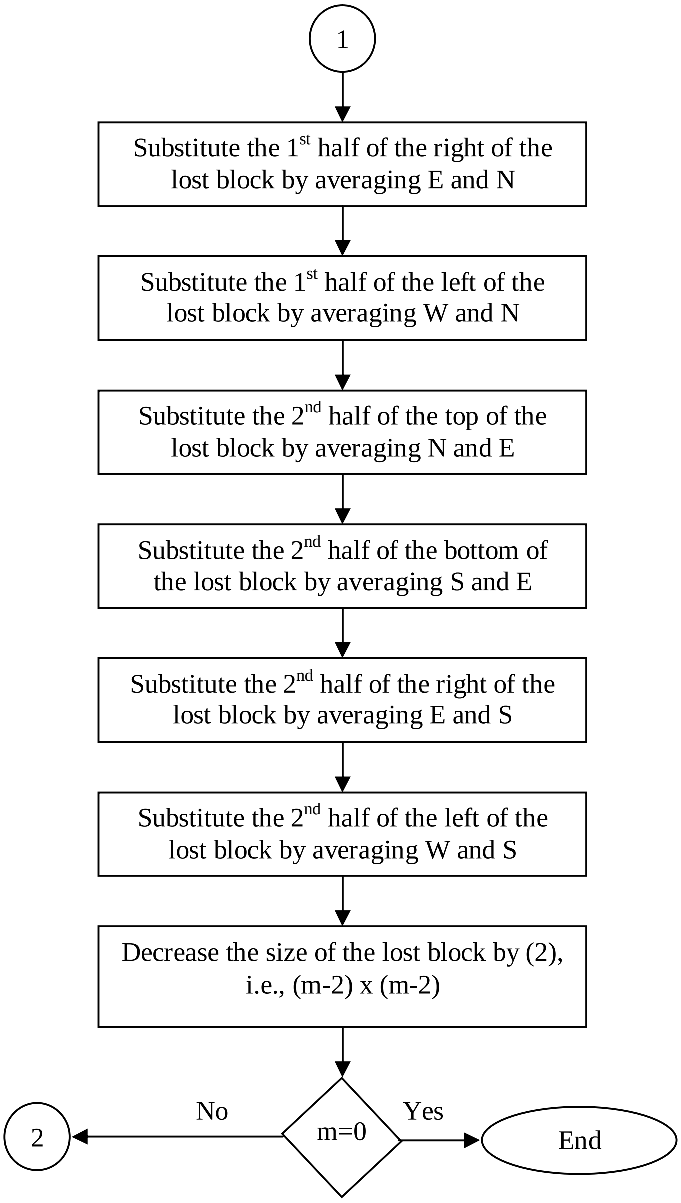

Fig.(3). Continued

Fig.(4) The Simulated Lost Blocks. The Black Squares Represent The Lost Blocks

Fig.(5) The Reconstructed Image

Fig.(6) The Simulated Lost Blocks. The Black Squares Represent The Lost Blocks

Fig.(7) The Reconstructed Image

Fig.(8) The Simulated Lost Blocks. The Black Squares Represent The Lost Blocks

Fig.(9) The Reconstructed Image