Projection Onto Convex Sets with Watermarking for Error Concealment

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Abstract. Transmission of images and video over unreliable channels produces visual artifacts due to either loss or corruption of bit streams. Error concealment schemes aim at reducing such degradation and improving the visual quality. Error concealment schemes usually conceal errors of a specific type. This points towards the possibility of combining more than one scheme, for efficient error concealment and better visual effects. In this paper, we propose a scheme for error concealment using a combination of watermarking and Projection Onto Convex Sets (POCS). Watermarking an image using the information derived from the host data itself conceals errors initially and those which are prominent even after this stage are concealed through POCS. The proposed method can be used for concealing errors in images and intra coded video by preserving average values through watermarking and edge information through POCS. Simulation results of POCS, watermarking and watermarking with POCS are given in the paper to show the advantage of combining both the methods.

1 Introduction

Data transmitted over channels are vulnerable to transmission errors. Imperfect transmission of block coded images and video results in loss of blocks. Error correction, error control and error concealment techniques have been developed for reducing these visual artifacts [1]. Error concealment techniques reduce image distortions through post processing at the decoder side. Hence error concealment techniques do not have access to the original information and are usually based on estimation and interpolation procedures that do not require additional information from the encoder.

Digital watermarking is basically a means of inserting some content into the original data which can be later recovered to prove authentication or copyright. Of late it has also been proposed for error concealment of images and video [2]. In this case some important information derived from the image itself is chosen as the watermark and is retrieved at the decoder as in the case of a blind watermarking scheme and used for concealing errors. The scheme proposed in [3] conceals block errors of various sizes by replacing the lost blocks with their average value. This is performed by embedding some important information

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extracted from the original image itself to introduce sufficient redundancy in the transmitted image. When there are too many losses, blockiness may become visible and some blocks may remain unconcealed. Thus it would be a good idea to combine this method with another method to remove this blockiness.

Projection onto Convex Sets (POCS) [4] utilizes correlated edge information from local neighborhood in images and intra frames of video to restore missing blocks. It is an iterative algorithm satisfying spatial domain and spectral domain constraints. Thus POCS method preserves edge, but is computationally complex and non real time as it requires much iteration to extrapolate missing pixels from the available correctly received surrounding blocks.

This paper proposes a combined error concealment algorithm using both watermarking and POCS. Watermarking ensures that each block is replaced by its average value. But this has disadvantage of high blockiness effect as the number of error blocks increases. This can be improved through POCS by recovering coefficients extrapolated from the neighboring correctly received blocks. POCS is an efficient algorithm to maintain edge continuity. Moreover, it gives superior concealment for blocks in smooth regions by exploiting the local texture information. POCS being a computationally expensive method, is applied after replacing error blocks with their DC values using watermarking method. This reduces the number of iterations for POCS. Most of the erroneous blocks are concealed using watermarking based method. So a low complexity error measure is worked out to select blocks on which POCS will be applied. This ensures better performance with reduced complexity. We have chosen Peak Signal to Noise Ratio (PSNR) and Structural Similarity (SSIM) [5] as two performance indices for evaluating our method. To show the superiority of the algorithm we have performed 8×8 and 16×16 block errors on three different images. The performance with POCS, watermarking and combined watermarking and POCS are tabulated to show the advantage of combining both the methods.

The paper is organized as follows. Section 2 gives a detailed description of the algorithm and the performance indices. Section 3 includes the simulation results. Section 4 gives conclusion.

2 Proposed Method

Error concealment of the corrupted image using watermarking is explained in the first part of this section. Second part gives the implementation of POCS in the subsequent stage of concealment on selected blocks. At the end of this section the performance indices chosen are explained.

2.1 Error Concealment Through Watermarking

We have used a wavelet based algorithm for this purpose and the gray level values of the approximate band is hidden in two selected sub-bands of the image. Before hiding these values, they are encrypted using a pseudo random sequence generated by using a key. So only a person who has the key can decrypt the

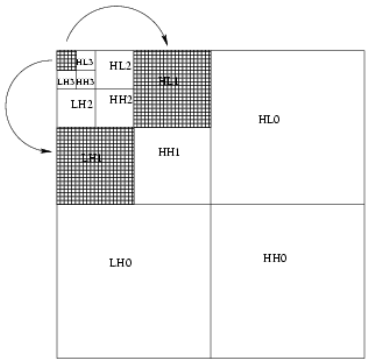


Fig. 1. 4-level Wavelet transform

hidden information for concealment purpose. Four level wavelet decomposition of the original image is taken and the approximate band is selected as the information to be hidden for error concealment as in Fig 1. Consider a general case of 4-level DWT which gives an approximate band of size $N \times N$. Then bands LH1 and HL1 would be of size $4N \times 4N$. If we use 8-bit representation of each coefficient in approximate band, we can have four copies of the bit stream embedded into the horizontal and vertical detail bands which give redundancy.

To hide the approximate band, the transformed coefficients are first scaled to 0-255 gray scale. This scale factor should be known at the receiver side to retrieve the approximate band exactly. Then 8×8 blocks from approximate band are selected row wise and zig-zag scanned to get a one dimensional array. Converting these gray levels to 8-bit binary representation, we generate a one dimensional array of binary numbers. This generated bit stream is Ex-ORed with a pseudo random sequence generated using a key to get the watermark. The bands LH1 and HL1 are also divided into 8×8 blocks row wise and then zig-zag scanned. Each coefficient pixel from LH1 and HL1 would carry a single watermark bit. A block error in LH1 would implicate the same error in HL1 also in the same location. This may lead to loss of the same watermark bit in the redundant streams. The bit streams embedded in LH1 and HL1 are spatially displaced from one another so as to minimize the effect of same bits being affected by an error. We have given a shift of 50 bits while embedding in LH1. A reversed stream is embedded in HL1.

For embedding the watermark there are four different cases to be considered. The watermark bit can be either 0 or 1 and the coefficient on which embedding is to be performed can be positive or negative. We have followed the following strategy for embedding under these four conditions.

- If watermark bit is 0 and the coefficient I is positive
  $I' = 8(floor(I/8)) + 1$
- If watermark bit is 0 and the coefficient I is negative
  $I' = 8(ceil(I/8)) - 1$

- If watermark bit is 1 and the coefficient I is positive
  $I' = 8(floor(I/8)) + 5$
- If watermark bit is 1 and the coefficient I is negative
  $I' = 8(ceil(I/8)) - 5$

Here I' is the watermarked coefficient. After the embedding, inverse transform is performed to get the watermarked image.

For retrieving the watermark, decompose the received image using wavelet transform. Then select HL1 and LH1 from the decomposed image. Group 8×8 blocks and then zig-zag scan each of these blocks. After that for each coefficient Y in the scanned pattern, we decide if a 0 or a 1 is embedded.

- If $(mod(Y, 8) \geq -2)$ or $(mod(Y, 8) \leq 2)$,
  the recovered bit is 0
- Else, the recovered bit is 1.

The range specified in the above case eliminates round off errors. We get 4 copies of the embedded stream from HL1 and LH1. The shift given to the bit stream is considered while reconstructing the four copies. Then out of the four bits representing a single bit in the watermark, we choose the one which occurs maximum number of times. The extracted stream is Ex-ORed with the pseudo random sequence generated using the key to get the bit stream corresponding to the approximate band. Convert groups of 8 consecutive bits into decimal values and place them in 8×8 blocks as in zig-zag scanning. The approximate band is recovered by multiplying this entire band by the scale factor chosen while embedding.

Once the approximate band is retrieved, the blocks in error are to be reconstructed using these values. The 4-level wavelet decomposition of the error image is performed. The error coefficients of the approximate band of the received image are replaced by the corresponding coefficients from the retrieved approximate band. After wards, we zoom in the approximate band to the original size. Zooming in at every stage is performed by simple replication of row and column at every level and averaging the four neighbors of each of the pixel. Once the zoomed in image is obtained, its 4-level wavelet decomposition is taken. Comparing the transformed coefficients of the zoomed in image and error image at every resolution,the error blocks are replaced from the transformed coefficients of the zoomed in image. Then inverse transform is performed to get the error corrected image.

2.2 Implementation of POCS

Watermarking based error concealment gives good performance when the number of blocks in error is less. As more number of blocks are lost during transmission, it becomes difficult to retrieve the correct copy of the embedded data. This affects the quality of the error concealed image. Thus, with a large number of error blocks, it is better to combine another method for further improvement in the image quality. In the proposed method, POCS is implemented after the previous stage of error concealment. So the first step to be performed is to identify those blocks which are still in error. The selection of error blocks is separately performed if it is an 8×8 or 16×16 block error.

POCS for 8×8 Blocks. Sum of Absolute Difference (SAD) of the boundary pixels with the surrounding good ones is taken as a measure for selection of 8×8 block errors. POCS is applied to only those blocks which are above some threshold. The threshold value has been decided by varying the number of erroneous blocks and considering the perceptual quality improvement.

The damaged block with correctly received 8 surrounding blocks is used to form a larger search area. This search area is classified as a monotone block or edge block. This is done using a Sobel edge detector. The local gradient components g_x and g_y for each pixel $x(i,j)$ in the correctly received pixels in search area is computed as follows.

$$\begin{aligned} g_x &= x_{i+1,j-1} - x_{i-1,j-1} + 2x_{i+1,j} - 2x_{i-1,j} + x_{i+1,j+1} - x_{i-1,j+1} \\ g_y &= x_{i-1,j+1} - x_{i-1,j-1} + 2x_{i,j+1} - 2x_{i,j-1} + x_{i+1,j+1} - x_{i-1,j-1} \end{aligned} \quad (1)$$

The magnitude of gradient, G and angular direction, θ are computed as follows.

$$\begin{aligned} G &= \sqrt{g_x^2 + g_y^2} \\ \theta &= tan^{-1}(\frac{g_y}{g_x}) \end{aligned} \quad (2)$$

For each pixel in the surrounding block, the actual edge direction is estimated with Sobel edge detector. The slope at each pixel is then determined as $slope = tan(\theta + 90)$. After wards, a line is drawn from the pixel with the calculated slope. If this line intersects the boundaries of the error block, θ is quantized to one of the eight directions in $0 - 180^0$ and the corresponding accumulator is incremented by the gradient value. If the line drawn is not touching the boundary pixels of the error block, classification process is shifted to the next pixel. This process is repeated exhaustively to all pixels in the neighborhood and the accumulator with highest value is compared against a threshold. This completes the classification of a particular error block as a monotone block or an edge block.

Once the classification process is performed, two projection operations are applied to restore the missing block. The first projection operation is adaptive to local image characteristics and it imposes smoothness and edge continuity constraints. In monotone areas of the image, the spectrum is nearly isotropic and has very low bandwidth. So for restoring missing blocks, classified as monotone areas, a low pass band-limited spectrum is imposed. Specifically, in the Fourier transform domain, all high frequency coefficients outside a particular radius are set to zero. In edge areas of the image, the spectrum has a bandpass characteristic in which energy is localized in transform coefficients that lie in a direction orthogonal to the edge. The remaining coefficients are usually very small. Thus for missing blocks classified as edge areas, we can impose the constraint that any

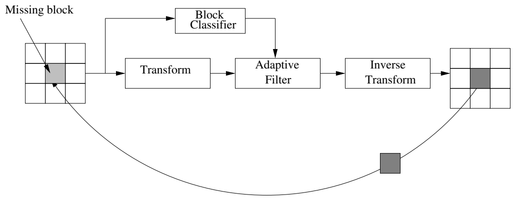
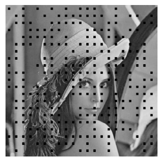


Fig. 2. Adaptive POCS iterative restoration process



(a) Error image

(b) Watermarking method

(c) POCS

(d) Proposed method

Fig. 3. Error Image (8 × 8 block error) and Error Concealed Images

feasible restoration must have a bandpass spectrum oriented orthogonal to the classified edge. All the coefficients located outside this spectrum are set to zero.

The second projection operation imposes a range constraint and restricts the output values after the first projection to a range of 0–255. For neighboring blocks that are correctly received, the values are maintained unaltered. These two projection operations are iteratively applied until the block does not change anymore under further projections.

Selection of 16 × 16 Blocks for Applying POCS. With larger block sizes of errors, POCS does not give a very good result. Emphasis should be given to texture information while selecting the blocks to apply POCS. We choose three different criteria for deciding this.

- SAD of boundary pixels with surrounding good ones with a threshold value that removes the blocking effect
- SAD of boundary pixels with the surrounding good ones with a lower threshold, and finding only one strong edge

Table 1. PSNR and SSIM after concealment of 8 × 8 block errors

Image	Error blocks	before conceal	PSNR POCS	PSNR WM	PSNR WM+POCS	SSIM original	SSIM POCS	SSIM WM	SSIM WM+POCS
Lena	50	24.59	42.42	40.94	43.21	0.9998	0.994	0.9941	0.9957
	100	21.70	38.55	37.32	40.68		0.9855	0.9848	0.9903
	150	19.73	37.14	36.04	38.33		0.9829	0.9821	0.9869
	200	18.83	36.50	35.28	37.56		0.9794	0.9782	0.9839
	250	17.77	35.30	34.13	36.47		0.9734	0.9719	0.9796
Aerial	50	21.84	36.37	37.78	38.17	0.9999	0.990	0.9920	0.9924
	100	19.15	33.55	34.85	35.35		0.9817	0.9846	0.9855
	150	16.84	31.21	32.80	33.06		0.9691	0.9743	0.9755
	200	16.13	30.50	31.93	32.29		0.9635	0.9693	0.9710
	250	14.88	29.29	30.69	31.04		0.9518	0.9590	0.9615
Couple	50	24.90	39.91	40.28	40.66	0.9998	0.9925	0.9926	0.9933
	100	22.36	37.11	37.76	37.86		0.9864	0.9869	0.9879
	150	20.69	35.53	36.20	36.45		0.9807	0.9815	0.9830
	200	18.93	33.54	34.40	34.53		0.9699	0.9719	0.9740
	250	18.34	33.28	33.84	34.17		0.9664	0.9680	0.9709

– SAD of boundary pixels with surrounding good ones with higher threshold and four strong edges

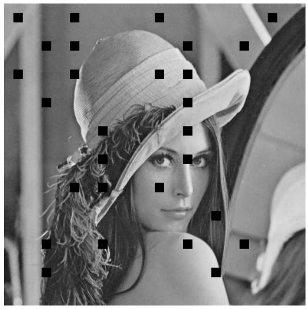
This classifies the image texture and POCS has been applied to them. In case of multiple strong edges, bandpass filtering in three directions are applied in spectral domain.

2.3 Performance Measures

We have used two performance measures namely, Peak Signal to Noise Ratio and Structural Similarity (SSIM) in this work. PSNR is one of the simplest and most widely used full reference quality metrics. However, it is not very well matched to perceived visual quality. SSIM is a measure that compares local patterns of pixel intensities that have been normalized for luminance and contrast. It is based on extraction of structural information by Human Visual System [5]. This measure gives better consistency with perceived quality.

3 Simulation Results

In this section, the results of simulations are included and discussed. We have chosen three test images of size 512 × 512. We have considered block errors of size 8 × 8 and 16 × 16. Number of lost blocks was varied from 50 to 250 and 10 to 35 in case of 8 × 8 and 16 × 16 block errors respectively. The results of error concealment with POCS, watermarking and watermarking with POCS are tabulated to have a comparative study of all three methods.



(a) Error image

(b) Watermarking method (c) POCS (d) Proposed method

Fig. 4. Error Image (16 × 16 block error) and Error Concealed Images

Table 2. PSNR and SSIM after concealment of 16 × 16 block errors

Image	Error blocks	before conceal	PSNR POCS	PSNR WM	PSNR WM+POCS	SSIM original	SSIM POCS	SSIM WM	SSIM WM+POCS
Lena	10	27.60	42.25	44.33	45.09	0.9999	0.994	0.9954	0.9955
	20	22.34	36.57	38.72	39.02		0.9878	0.9899	0.9904
	30	21.08	34.56	36.97	37.13		0.9833	0.9857	0.9872
	35	20.04	33.79	36.62	36.29		0.9792	0.9839	0.9845
Aerial	10	22.89	36.53	39.71	39.74	0.9999	0.9923	0.9938	0.9939
	20	19.31	32.53	35.85	36.05		0.9825	0.9857	0.9859
	30	18.13	31.60	34.89	34.98		0.9770	0.9818	0.9819
	35	17.49	31.96	35.94	35.53		0.9734	0.9789	0.9791
Couple	10	25.91	38.33	41.32	41.68	0.9998	0.9932	0.9944	0.9945
	20	23.37	37.69	39.56	39.76		0.9872	0.9891	0.9893
	30	21.32	34.85	38.31	38.61		0.9796	0.9831	0.9832
	35	20.75	34.58	37.46	37.50		0.9772	0.9812	0.9813

4 Conclusion

In this paper, we propose to use a combination of watermarking and POCS for error concealment of images. Watermarking method conceals most of the errors in the first stage of concealment. The error blocks which degrade the quality of the image even after this preliminary stage will be concealed using POCS in the successive stage. This minimizes computational complexity due to POCS. Both improvement in performance and reduced complexity depend on the threshold values chosen which in turn depend on the content.

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