Edge Directed Filter based Error Concealment for Wavelet-based Images

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ABSTRACT

Edges in a natural image have important effects on the subjective visual quality. During the transmissions of wavelet-compressed images such as JPEG2000, errors in high frequency subbands will result in the effects like ring or ripple artifacts around edges. In this paper, we propose an error concealment algorithm to remove these annoying artifacts. This algorithm requires an edge directed filter. Although some known filters can be employed, we tailor-make a new edge directed filter which fits well in our algorithm. The proposed scheme firstly enhances the received damaged image using the edge directed filter. Then the recovered wavelet coefficients are rectified using two constraint functions, which are based on the statistical characteristics in the wavelet domain, and the observation that correctly received data must remain unchanged. Simulation results show that the image quality has been significantly improved in terms of both objective and subjective evaluation.

1. INTRODUCTION

Recently, the rapid growth of Internet and Wireless communications has led to the increasing interest towards robust transmissions of compressed images. However, errors always exist in these unreliable transmissions, and compressed images are sensitive to these errors. Thus, error control techniques are necessary for image transmissions. But even with strong error protection, residual error may still exist in the received images, which results in severe degradation on image quality. Error concealment techniques aim to conceal errors without modifying source or channel coding schemes.

JPEG2000 is a newly issued image coding standard based on wavelet, which provides some basic error resilience tools, such as data partitions combined with resynchronization and error detection by entropy coding [1]. However, JPEG2000 does not standardize any error concealment methods, but simply replaces the damaged wavelet bitplane data with zeros [1].

A variety of error concealment methods have been proposed for media transmissions, most of which deal with lost blocks caused by errors [2]. These methods are not directly suitable for wavelet-based images as the errors in high frequency subbands or resolutions have effects like ring or ripple artifacts (Fig.1b). In [3], the authors proposed an error concealment approach for JPEG2000 images using residual wavelet coefficient correlations. In that paper, they estimate those damaged bitplane data according to the undamaged bitplane information of the cross subband and undamaged bitplane data. However, the performance of this method is not good enough, since WT nearly removes the correlations among different coefficients.

In this paper, we propose an error concealment scheme based on a new edge directed filter for wavelet-based images. It makes use of the redundancy residuals in spatial domain combined with those in wavelet domain. The major difference that distinguishes this paper from our previous work [4] is the new designed edge directed filter, which can recover the damaged wavelet coefficients better than the filters used in [4]. These recovered coefficients are then rectified by two constraint functions to ensure that the correctly received coefficients keep unchanged, and comply with WT statistical characteristics. By this proposed algorithm, edges of the damaged image get enhanced, details preserved, and edge continuity achieved using edge directed filter.

2. PROPOSED ALGORITHM

2.1 Problem analysis

The effects of errors in wavelet-based images depend on which parts of wavelet coefficients are corrupted. In this paper, we aim to conceal errors which result in the loss of a bitplane of the wavelet coefficients of the affected subband [5]. The LL subband can be considered as a subsampled version of the original image, so errors in the LL coefficients are similar to the lost blocks. Therefore, recovery of LL coefficients can be achieved by some error concealment techniques developed for block-based image [2]. In this paper we only focus on concealing the errors of the high frequency coefficients.

In Wavelet domain, the energies of high frequency coefficients are mainly concentrated around edges in image (Fig.1a). When errors occur in these subbands, errors have effects like ring or ripple artifact around edges (Fig.1b) in the damaged image. However, edges in a natural image have important effects on the subjective visual quality,

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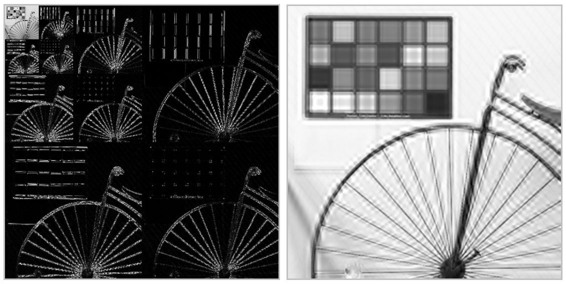
since edges are always associated with the boundary of an object, or with marks on the object. An image with blurred edges is always annoying to the spectator. Our proposed algorithm aims to remove the noises around edges and then to make the image quality improved.



(a) Wavelet decomposition; (b) High frequency errors

Fig. 1: Wavelet-based image (*Bike*) error pattern

2.2 Proposed error concealment scheme

The process of proposed error concealment scheme can be summarized as:

$$I^{n+1} = \mathrm{W}^{-1} \circ \mathrm{C} \circ \mathrm{W} \circ \mathrm{F}\left(I^{n}\right) \tag{1}$$

where I^{n+1} is the recovered image after the n+1 iterations, and I^0 is the received image. "∘" is concatenation operation of two functions. F is edge directed filter in the spatial domain to remove artifacts around edges. W is Wavelet Transform, and W^{-1} is the inverse Wavelet Transform. C is a function that rectifies the recovered results, taking in information regarding which bit-planes are lost, and I^0 as input. Details of C will be discussed in Section 2.4

In other words, the damaged image is firstly filtered using edge directed filter F (detailed in Subsection 2.3), and then transformed into WT domain (W). The recovered WT coefficients are then constrained to their statistical characteristics in WT Domain by using function C. These recovered wavelet coefficients are then transformed into the image domain again (W^{-1}) to get a valid image I^{n+1}. The constraint function C comprises the known WT coefficient values constraint function C_1 and the WT statistical characteristics constraint function C_2 (detailed in Subsection 2.4). That is, $\mathrm{C} = \mathrm{C}_1 \circ \mathrm{C}_2$.

Let ψ be the set of images comprised by those which satisfy the two WT constraints discussed in Subsection 2.4. The above algorithm can be viewed as an attempt to find a recovered image I in ψ that minimizes the distortion between I and the image $\mathrm{F}(I_0)$, that is, find the I which,

$$\begin{cases} \min\limits_{I_c} \left(\mathrm{F}(I_0) - I\right) \\ s.t. \quad I \in \psi \end{cases} \tag{2}$$

2.3 Edge directed filter

Based on the error pattern of the wavelet-based images, we can construct an edge directed filter to remove the noises around edges caused by errors in damaged images. Anisotropic diffusion techniques have been widely used in image processing for its efficiency of smoothing the noisy images while preserving the sharp edges [6]. When proper function is constructed in anisotropic diffusion, it can form direction diffusion or edge directed filter to remove the ring or ripple artifacts around edges of damaged images caused by errors in high frequency subbands. An edge directed filter using a new diffusion function is proposed in this section.

2.3.1 Anisotropic diffusion

The original anisotropic diffusion equation is presented by Perona and Malik [7], which can be written as a Partial Differential Equation (PDE):

$$\begin{cases} \dfrac{\partial I}{\partial t} = div\left(f\left(\left|\nabla I\right|\right)\nabla I\right) \\ I\left(t = 0\right) = I_0 \end{cases} \tag{3}$$

where I_0 is the initial image, and ∇ is the gradient operator:

$$\nabla I = \frac{\partial I}{\partial x}\vec{x} + \frac{\partial I}{\partial y}\vec{y} \tag{4}$$

The gradient magnitude is used to detect an image edge or boundary as a step discontinuity in intensity. In our scheme, *Sobel* operator is adopted to generate the gradient for the damaged image. The *div* is the divergence operator and *f(x)* is a decreasing positive diffusion function. Perona and Malik suggested two diffusion functions:

$$f\left(x\right) = \frac{1}{1 + \left(x/K\right)^2} \tag{5}$$

$$f\left(x\right) = \exp\left(-\left(x/K\right)^2\right) \tag{6}$$

K is a constant with fixed value. The function (5) privileges wider regions over smaller ones, while the function (6) privileges high-contrast edges over low-contrast ones [7].

2.3.2 Proposed diffusion function

In this paper we adopt the anisotropic diffusion as a direction diffusion operation, and design a new diffusion function for error concealment. Since we only aim to construct edge directed filter to remove the ring or ripple artifacts caused by errors, in our solution the diffusion function *f(x)* is:

$$\begin{cases} f\left(\nabla I\right) = \dfrac{k\exp\left(-\left|\nabla I\right|/M\right)}{\max\left(\exp(\Delta I),\ 1 + \left|\nabla I\right|\right)} \\ M = \max\limits_{P \in \mathbf{\Gamma}}\left(\left|\nabla I_P\right|\right) \end{cases} \tag{7}$$

where $\mathbf{\Gamma}$ is the $N \times N$ pixels block which the damaged pixel belongs to (N = 16, k=1 in this paper), and $\left|\nabla I\right|$ is the magnitude of ∇I. ΔI is the *Laplacian* of image I, which is a second order derivative of I, defined as:

$$\Delta I = \nabla\left(\nabla I\right) = \frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2} \qquad (8)$$

If $|\nabla I|$ is close to M, then the conduction coefficient $f(\nabla I)$ is approximate to zero, and then we have direction filter along with the direction of edges. If $|\nabla I|$ is very small, then $f(\nabla I)$ is approximate to one, and now we could achieve isotropic diffusion (like Gaussian filter).

M and ΔI are used to make the conduction coefficients of the ring or ripple artifacts small compulsively, because the errors are concentrated around edges and the gradient values are always smaller than those of edges. Thus the artifacts are made to be filtered smoothly, but edges are kept sharp.

A discrete form of Equation (3) is given by:

$$I^{n+1} = I^n + \frac{\Delta t}{N}\sum_{i=1}^{N} f\left(\nabla I_i^n\right)\cdot \nabla I_i^n \qquad (9)$$

This process constructs edge directed filter served as edge directed filter F in Equation (1).

2.4 Wavelet domain constraint functions

Two WT domain constraint functions are applied in wavelet domain: known-value constraint function C_1, and WT statistical constraint function C_2 to rectify the recovered coefficients.

After the damaged image is filtered by edge directed filter, the lose WT coefficients are recovered. However, the correctly received WT coefficients (denoted as $\mathbf{\Phi}$) may also be altered at the same time. We should discard these changes, with known-value constraint function:

$$C_1(x) = \begin{cases} x_0, \text{ if } x \in \mathbf{\Phi} \\ x, \text{ else} \end{cases} \qquad (10)$$

where x_0 is the original wavelet coefficients of x before edge directed filtering.

Furthermore, although WT almost decorrelates WT coefficients, the distribution of one coefficient conditioned on its parent P usually is a linear function of P [8]. It means that the coefficients are still statistically dependent. For high-amplitude coefficients, if the parent is less than some threshold (e.g., one standard deviation) then the child also is mostly likely to be less than the threshold [8]. Moreover, wavelet coefficients also show their statistical dependency across their neighborhoods in spatial domain. After using the function C_1, such characteristics may not be kept anymore. Thus, the image set $\mathbf{\Omega}$ within statistical characteristics is used to construct a function to discard the recovered wavelet coefficients which violate these statistical characteristics constraint function:

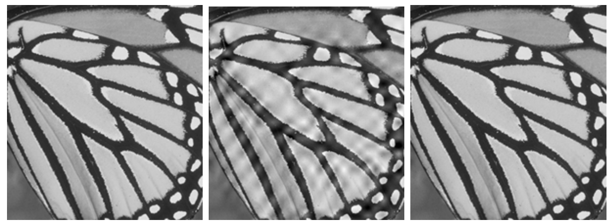
$$C_2(x) = \begin{cases} x, \text{ if } x \in \mathbf{\Omega} \\ 0, \text{ else} \end{cases} \qquad (11)$$

Then we get $\boldsymbol{\psi}$ ($\boldsymbol{\psi} = \mathbf{\Omega} \cap \mathbf{\Phi}$), and C ($C = C_1 \circ C_2$).

3. SIMULATION RESULTS

The proposed algorithm has been evaluated on a number of JPEG and JPEG2000 test images. In our simulations, the error detection can be done by the error resilience tools issued in JPEG2000 [1]. We use five-level wavelet decomposition and *Daubechies* 9/7 filter.

The details of improvement of the damaged image *Monarch* by our proposed algorithm is shown in Fig. 2. We can see that the annoying noises around edges are almost removed. And the recovered areas have high continuity, which visually makes the spectators much comfortable. The cost is the decreasing of the contrast. But such change is not easy to be caught by human eyes.



(a) Original; (b) Damaged; (c) Recovered

Fig. 2: Edges enhanced of image *Monarch*.

The *PSNR* results are listed in Table 1. The bit error rate (BER) is set to 10^{-4}. In terms of *PSNR,* the improvement on the quality of the damaged images is significant, though the improvement varies from image to image. For example, Image *Monarch* contains much more clear edges and in stronger contrast than *Lake*, so it can get better result than *Lake*.

Considering that the criterion of *PSNR* does not always provide an accurate measure of the visual quality for natural images. To evaluate the performances on edge preservation of the proposed algorithm, we further use *Figure of Merit* (*FoM*) defined [9] by:

$$FoM = \frac{1}{\max\left(N_O,\ N_C\right)}\sum_{i=1}^{N_C}\frac{1}{1+\lambda\times d_i^2} \qquad (12)$$

where N_C and N_O are the number of detected and original edge pixels, respectively. The d_i is the *Euclidean* distance between the detected edge pixel and the nearest original edge pixel, and λ is a constant typically set to 0.1. In this paper, we use *Canny* edge detector, and the standard deviation of the *Gaussian* kernel in the *Canny* detector is set to 0.4.

The *FoM* values of the results are also listed in Table 1. We can see that the *FoM* values of the recovered images are close to 1, which shows high edge preserving ratios are achieved by the proposed error concealment algorithm.

The efficiency of our proposed diffusion function (Equation (7)) is illustrated in Fig. 3, compared with classic *Laplacian* edge enhancement filter (detailed in [10]), and the two anisotropic diffusion functions proposed by

Perona and Malik (Equation (5) and (6), K = 25). These filters are all used in the same error concealment scheme defined by Equation (1).

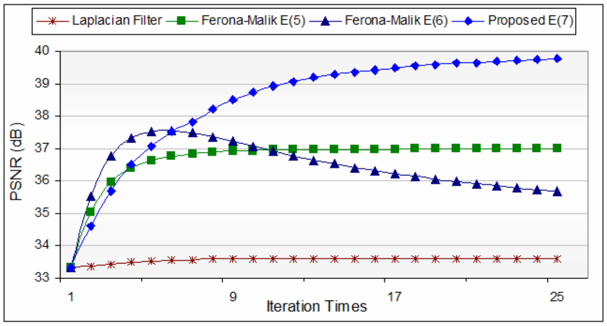


Fig. 3: Diffusion functions compared (*Lena*)

Fig. 4 shows the progressive visual results of image *Lena*, done by our proposed error concealment algorithm. We can see that after a few iterations (5 to 10 times), the noises around edges are almost removed.

4. CONCLUSIONS

This paper proposed an error concealment algorithm for wavelet-based images using a new edge directed filter, combined with the constraints in wavelet domain. The annoying noises around edges in the damaged images are removed by edge directed filter, and those recovered wavelet coefficients are rectified using two constraints in wavelet domain. Our algorithm exploits the residual redundancy not only in spatial domain but also in wavelet domain. Simulation results show our error concealment algorithm can get significant improvement in terms of the objective quality as well as the subjective quality.

5. REFERENCES

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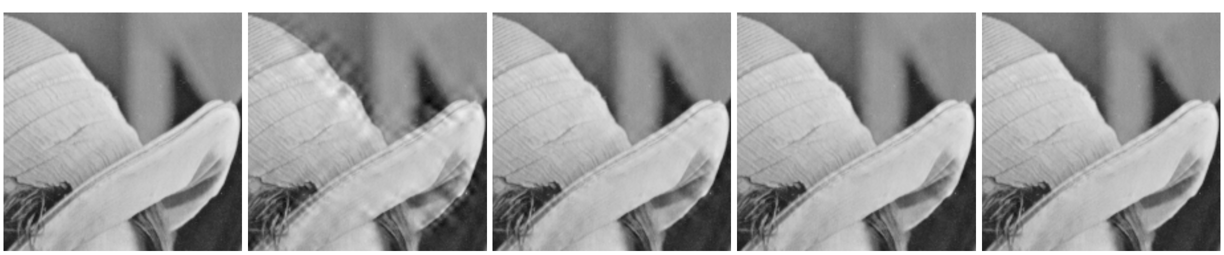
Table 1: Image quality evaluation of simulation results

Image Quality		*Actor*	*Bike*	*Chart*	*Fruits*	*Hotel*	*Lake*	*Lena*	*Monarch*	*Peppers*	Average
Damaged Images	*PSNR* (dB)	30.76	30.34	33.85	33.63	33.83	31.37	33.31	29.49	33.05	32.18
	FoM (%)	88.5	88.0	91.3	88.7	88.0	89.1	89.0	89.2	87.3	88.8
Recovered Images	*PSNR* (dB)	38.24	38.55	40.13	39.21	41.79	38.37	40.02	39.57	40.77	39.63
	FoM (%)	94.5	95.2	96.3	94.2	95.5	93.9	93.7	94.2	91.2	94.3



(a) Original; (b) Damaged; (c) After 5 iterations; (d) After 10 iterations; (e) Recovered

Fig. 4: The process of proposed error concealment results for image *Lena*