Error Concealment for JPEG2000 Images Based on Orthogonal Edge Directed Filters

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Abstract

In this paper, we propose an error concealment algorithm for JPEG2000 image transmissions over *unreliable channels. Firstly, the local principal edge information in the damaged area is detected in the spatial domain. Then the proposed Orthogonal Edge Directed Filters (OEDFs) are applied to remove the ring or ripple artifact errors due to the loss of some Wavelet Transform (WT) bitplane data. Two kinds of constraints in WT domain are used for rectifying the recovered WT coefficients got from OEDFs, namely WT known-value constraint and empirical statistical constraint of WT coefficients. Finally, this filtering-and-rectifying procedure is iterated until convergent. Simulation results have shown that both objective and subjective image quality have been improved by our proposed algorithm.*

1. Introduction

Internet and Wireless communications have grown astronomically recently, which lead to the increasing interest towards multimedia transmissions. Errors always exist in these transmissions, and compressed multimedia data are particularly sensitive to errors. Naturally error resilient techniques are used for media transmissions. However, even with strong protection from error resilient techniques, residual errors may still exist [1]. Error concealment techniques aim to conceal those residual errors without modifying source or channel coding schemes.

A variety of error concealment methods have been proposed for media transmissions, which mainly focus on recovering the lost blocks [1]. These methods are not directly suitable for JPEG2000 images, since errors in JPEG2000 images result in different visual effects like ring or ripple artifacts around edges (Fig. 1), but not lost blocks.

Though JPEG2000 has already specified some error resilience tools [2], such as data partitions combined with hierarchical resynchronization, and error detection by entropy coding, it does not standardize any error concealment methods. Instead it simply replaces the damaged wavelet bitplane data with zeros [2].

Only a few error concealment algorithms have been proposed for JPEG2000 images. In [3], the authors proposed an error concealment approach for JPEG2000 images using residual wavelet coefficient correlations. 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. It therefore motivates us to discover the spatial residual in this paper to improve images quality better.

In this paper, we proposed an error concealment algorithm based on Orthogonal Edge Directed Filters (OEDFs) under two WT domain constraints. The basic idea is to remove ring or ripple artifact noises around edges by OEDFs, under the wavelet domain constraints that these filters cannot alter the correct coefficients, and those recovered coefficients which do not comply with WT statistical properties must keep unchanged. Our algorithm makes use of the residual redundancy in spatial domain, as well as in WT domain. Edges of the damaged image get enhanced and details are preserved. Objective and subjective image qualities are improved, which show that our proposed algorithm can achieve good error concealment effect.

2. Proposed error concealment scheme

The proposed algorithm is enlightened by how experts repair damaged images, which contain determining the areas to be corrected, examining the boundary of these regions, continuing lines into these regions, gradually filling in, and painting small details [4]. In [4], the authors propose an algorithm for image inpaint by imitating this procedure, and then extend it to recover the lost blocks of damaged images [5]. However, it can not be applied to conceal errors in JPEG2000 images directly, because the errors here do not result in lost blocks. But the idea of how an expert repair damaged images can be applied to construct a set of filters (OEDFs) to conceal these errors.

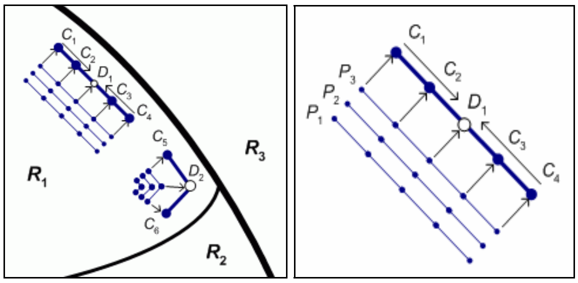
Fig. 1: Typical error pattern of JPEG2000

Edges in a natural image play a key role on the subjective visual quality. An image with blurred edges is always annoying to the spectators. Unfortunately, errors occurring in JPEG2000 images always result in the so-called ring or ripple artifacts (Fig. 1) around edges. Edge enhancement techniques are not suitable for concealing errors here, since some strong edges in images are caused by errors. Corresponding to these observations, we propose a set of Orthogonal Edge Directed Filters (OEDFs) to enhance edges and remove artifacts caused by errors, and then rectify the results by the constraints in WT domain.

Note that in [6], the authors proposed an edge directed interpolation to obtain high-resolution image from a low-resolution image. They explore the local covariance from a low-resolution image to estimate the edge direction in high-resolution image. The proposed OEDFs here share the term of "edge directed", but our algorithm and application are totally different.

2.1 Orthogonal Edge Directed Filters (OEDFs)

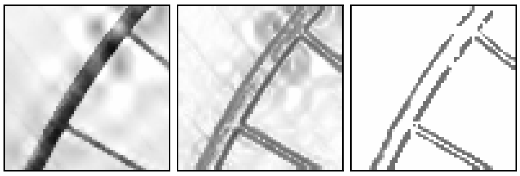
The proposed OEDFs comprise two orthogonal filters, which are perpendicular and parallel to the local principal edge respectively, for removing ring or ripple artifacts around edges. OEDFs are designed to conceal the errors in such a way that it mimics the procedure of repairing the damaged images by experts. As shown in Fig. 2, a filter whose orientation is perpendicular to the edge is applied firstly, following with another filter which is parallel to the edge. Both filters are done in the same region divided by the local principal edges. The perpendicular filter acts as filling in, and the parallel filter acts as directional filter. Note that we are only interested in concealing the errors in edge areas in this paper because human eyes are very sensitive to those areas. As to conceal errors in smooth areas, we simply adopt a linear interpolation to improve the image visual quality.



(a) OEDFs illustration; (b) OEDFs details

Fig. 2: Orthogonal Edge Directed Filters

Firstly, local principal edges are detected by the gradient angle histogram of a small block (64×64 in this paper). We assume local principal edges always exist in the damaged area. Sobel operator is used to calculate the edges of the damaged image. Fig. 3 shows the damaged image, edge image, and the detected local principal edges. The angle histogram of the edge image is shown in Fig. 4. Principal edges are detected by evaluating the maxima of the angle histogram.



(a) Original; (b) edges; (c) principal edges

Fig. 3: Local principal edges detection

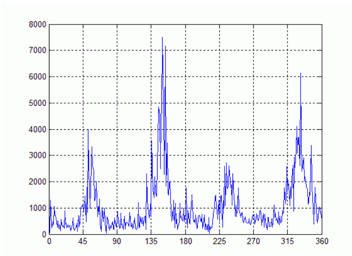


Fig. 4: Gradient angle histogram

Furthermore, from the distribution of the angle we can also detect the ranges for the principal edge directions. If an edge pixel is in these ranges, it is kept unchanged, otherwise removed from the edge image. Then the principal edge image is generated (Fig. 3c).

After local principal edges are detected, these edges partition the 2D plane into several regions (e.g., $\boldsymbol{R}_1$, $\boldsymbol{R}_2$, and $\boldsymbol{R}_3$ in Fig. 2a). Firstly, a filter perpendicular to the edge acts on pixels around the edge. This filter is used with small weights, since it results in pixel diffusion. The perpendicular filter is a one dimension (1D) second derivative smooth filter as follows:

$$C_1 = (1-\alpha)\, C_1 + \alpha\,(3P_3 + P_1 - 3P_2) \quad (1)$$

where C_1, P_1, P_2, and P_3 are pixels as shown in Fig. 2b, and α ($\alpha \in [0,1]$) is a weight number determined by the distance between C_1 and the edge.

Then the pixel which is only around one edge, such as D_1 in Fig. 2, is filtered using its neighboring pixels (C_1, C_2, C_3, and C_4) along the edge in the same region $\boldsymbol{R_1}$ by:

$$D_1 = (1-\beta)\, D_1 + \beta\,(4C_2 + 4C_3 - C_1 - C_4)/6 \quad (2)$$

where the weight β ($\beta \in [0,1]$) is determined by the distance from D_1 to the edge. This parallel filter is also a 1D second derivative smooth filter. The pixel around the intersection of two edges, such as D_2 in Fig. 2a, is filtered based on weighting their neighboring pixels along each edge, such as C_5 and C_6 in Fig. 2a.

The pixels on the detected edges are only filtered by their neighboring pixels on the edge, which is a similar process as parallel filtering described in Equation (2), i.e. the perpendicular filtering is skipped.

2.2 Wavelet coefficients rectification

Two WT domain constraints are applied in our scheme: statistical constraint, and known-value constraint to rectify the recovered results.

WT almost decorrelates WT coefficients, however, the distribution of one coefficient conditioned on its parent *P* usually is a linear function of *P* [7]. It means that even though the coefficients are uncorrelated, they 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, WT coefficients also show their statistical dependency across their neighborhoods in spatial domain. Therefore, these statistical properties are used to construct a rule to discard the recovered WT bitplane data which are not satisfying these statistical properties.

Furthermore, when the damaged WT bitplane data are recovered by OEDFs, the correct WT bitplane data will be changed at the same time. We discard these changes of the correct WT coefficients with this so-called known-value constraint.

The rectification procedure can be described as finding an image I_w in an image set *C* to minimize its distortion *D* to $OEDF(I_d)$, as shown below:

$$D = (\,OEDF(I_d) - I_w\,),\ where\ I_w \in C \quad (3)$$

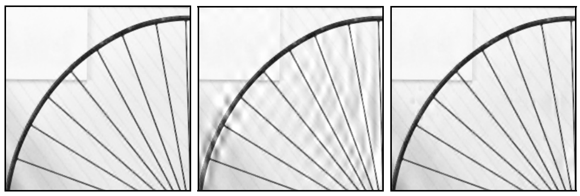
I_d is the received damaged image, and *C* is a convex set constructed by images which satisfy the two WT domain constraints discussed above. $OEDF(I_d)$ means apply OEDFs on the damaged image I_d.

The two procedures of OEDFs and WT rectification will affect each other. Therefore, iterations must be carried out to make them convergent, i.e., to minimize distortion *D*. Common constraints, such as edge continuity and known-value bound, are known to be convex sets, and projections between convex sets are said to be convergent [9]. In our scheme, two convex sets are constructed based on edge continuity ($\boldsymbol{S}_1$), or consistency within known values in WT domain ($\boldsymbol{S}_2$). The iterations in our scheme can be treated as projections between $\boldsymbol{S}_1$ and $\boldsymbol{S}_2$, and are convergent actually in our simulations.

3. Simulation Results

The proposed algorithm is evaluated on a number of JPEG2000 testing images. Error detection can be done by the error resilience tools provided in JPEG2000. After the errors are detected, the whole relevant bitplane data of the received images will be set to zeros by the error resilience tools of JPEG2000 [2]. The BER in this paper is 10^{-4}. Image coding was done with five level wavelet decomposition and two channel filter banks with a *Daubechies* 9/7 wavelet filter.

The details of improvement of the damaged image *Bike* by our proposed algorithm are shown in Fig. 5. The target bit rate is 1.0 bits/pixel. We can see that those annoying noises around the edges are removed. However, we also found that our solution lowers the contrast compared with the original image though such change is not easy to be caught by human eyes.



(a) Original; (b) damaged; (c) recovered

Fig. 5: Details of concealment for image *Bike*

Fig. 6 shows the error concealment results of image *Hotel*. We can observe that the proposed algorithm can achieve quite good subjective visual quality (Fig.6c), compared with the annoying noises around edges in the damaged image (Fig.6b). Visually the recovered image is very close to the original image (Fig.6a).

The PSNR results for different images (Fig. 7a, 1bpp) and various bitrates (Fig. 7b, image *Lena*) are also measured. The improvement of PSNR of the damaged images of this proposed algorithm is about 3~10 dB (with average about 5.0 dB), compared with

0.6~3 dB improvements of JPEG2000 images with error resilient tools (BER 10^{-3}) in paper [3]. It is because we remove ring or ripple artifacts by OEDFs using spatial redundancy, besides of WT coefficient correlations. For different images, the proposed scheme achieved different improvements, depending on the image contents. For example, Image *Bike* contains much more edges in high contrast than image *Woman*, so it can get better improvement than *Woman*. From Fig. 7b, we can find that in different bitrates, different objective improvements are obtained, more in high bitrate than in low bitrate.

4. Conclusions

We propose an algorithm of error concealment for JPEG2000 images based on OEDFs under WT domain constraints in this paper. The local principal edges in the erroneous areas are detected and enhanced by OEDFs, and those recovered WT coefficients are rectified with two WT domain constraints. Simulations show our algorithm achieves a good performance on objective quality as well as subjective quality. Further work may focus on how to improve the concealment effect for damaged texture areas.

5. References

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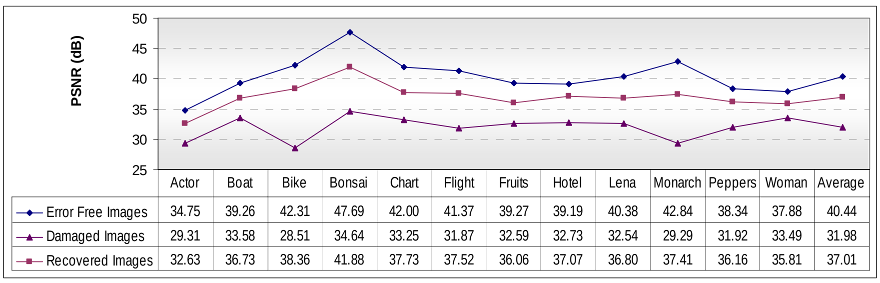
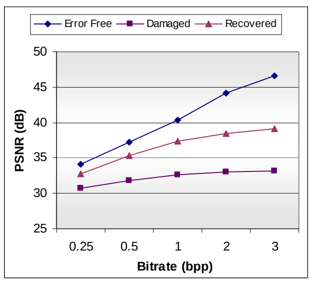
(a) Original image; (b) damaged image; (c) recovered image

Fig. 6: Concealed result of image *Hotel*



	Actor	Boat	Bike	Bonsai	Chart	Flight	Fruits	Hotel	Lena	Monarch	Peppers	Woman	Average
Error Free Images	34.75	39.26	42.31	47.69	42.00	41.37	39.27	39.19	40.38	42.84	38.34	37.88	40.44
Damaged Images	29.31	33.58	28.51	34.64	33.25	31.87	32.59	32.73	32.54	29.29	31.92	33.49	31.98
Recovered Images	32.63	36.73	38.36	41.88	37.73	37.52	36.06	37.07	36.80	37.41	36.16	35.81	37.01



(a) Different Images (bitrate=1bpp); (b) Various bitrates (*Lena*)

Fig. 7: PSNR results