AN IMPROVED EDGE-MODEL BASED REPRESENTATION AND ITS APPLICATION IN IMAGE POST-PROCESSING

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ABSTRACT

Images can be represented using as locations and parameters of edges based on an edge mode. The representation was shown to be effective to reduce coding errors of images coded using SPIHT in an image post-processing method. However, the representation results several artifacts which include "smudge and halos" artifacts and stripping artifacts. We have found the causes of these artifacts and propose a revised representation that has these artifacts significantly suppressed. Also, we shall demonstrate that the revised representation can further improve the performance of the image post-processing algorithm.

1. INTRODUCTION

Images contain a vase amount of data. Therefore, a lot of works have been performed to find new representations of images that will lead to reduction of computation requirements of image processing or reduction of storage requirements. For example, images are often converted into frequency domain so that linear and shift-invariant operations can be implemented using the efficient FFT. JPEG coded images and MPEG1 and MPEG2 coded video are converted into DCT domain for efficient representation. Also, wavelet transforms have been shown to be most effective to reduce both computation and storage requirements [1,2]. As edges are the most important structures in images, therefore representations of images using edges have been proposed. For example, [3] provides a good representation of images. However, no direct method is suggested to estimate the model parameters. Instead, they are estimated by an iterative method that requires a long computation time.

van Beek [4] investigated the use of a normalized error function to represent edges in an image. He developed effective and accurate methods to estimate edge parameters as well as an algorithm to generate a synthesized version of the image from the locations and parameters of edges. The representation has been shown to be effective to reduce coding errors of images coded using SPIHT [2,5]. However, it is observed that the synthesized images often contain artifacts which include "smudge and halos" artifacts and stripping artifacts.

In this paper, we shall reveal the causes of these artifacts and propose methods to suppress them. We shall demonstrate that the revised representation that incorporates these methods suppressed these artifacts significantly. We also demonstrate that the revised representation can improve the performance of the post-processing for SPIHT coded images. Section 2 will give a brief review of the edge model and the post-processing algorithm reported in [6]. And then in section 3, we shall identify the causes of these artifacts and suggest methods to suppress them. Also, the experimental results will be given to show how these artifacts are suppressed. In section 4, the experimental result will be given to show how the performance of the post-processing algorithm [6] is improved.

2. THE EDGE MODEL AND EDGE RECONSTRUCTION

2.1. The Edge Model

van Beek suggests a 1-D edge model that is a unit step $U(x)$ convolved with a Gaussian function $g(x;w)$. It models the grey level of a pixel at a distance $x-x_0$ away from the edge center at x_0 to be:

$$s(x-x_0;b,c,w) = b + \frac{c}{2}\left(1 + erf\left(\frac{x-x_0}{w\sqrt{2}}\right)\right) \qquad (1)$$

where b is the basis, c is the contrast, w is the edge width, and $erf(.) \in [-1,1]$ is the normalized error function. By means of the Canny edge detector [7], we can find the edge location. Here, the edge detection is described by:

$$d(x) = s(x-x_0;b,c,w) \otimes g'(x;\sigma) \qquad (2)$$

where $g'(x;\sigma)$ is the first derivative of a Gaussian function with variance σ^2. By multi-point estimation, the model parameter can be found as:

$$w^2 = \frac{a^2}{\ln(d_1 d_1 / d_2 d_3)} - \sigma^2$$
$$x_0 = {a \ln(d_2 / d_3)} \Big/ {2 \ln(d_1 d_1 / d_2 d_3)} \qquad (3)$$
$$c = d_1 \sqrt{\frac{2\pi a^2}{\ln(d_1 d_1 / d_2 d_3)}} \left(\frac{d_2}{d_3} \right)^{\frac{1}{4a}}$$

where
$$d_1 = d(0; c, w, \sigma)$$
$$d_2 = d(a; c, w, \sigma)$$
$$d_3 = d(-a; c, w, \sigma)$$

By choosing a = 1, we can easily find the model parameters. With these parameters and extending the model to 2-D, we can reconstruct the regions near edges and then the whole image by a regularization process.

2.2. Reconstruction Artifacts

van Beek proposed a representation of images using this edge model, which represents images using locations and parameters of edges. The representation is a useful tool in computer vision and image processing. However, the representation has several types of artifacts. "Smudge and halos" artifact or diffusion artifact is the most noticeable type of artifact. This type of artifacts appears as unusually bright (or dark) regions near edges. Examples of such artifacts can be found in Lena's hat in Fig. 1(b). Other artifacts, such as jagged lines and stripped artifacts may also be observed in some images. In this paper, we will identify the causes of these artifacts and propose methods to minimize or eliminate them.

2.3. The edge model based reconstruction

Fan proposed an efficient method [6] to improve the visual quality as well as the PSNR of images coded using SPHIT [2] at low bit rates by means of the edge model. It successfully removes the artifacts of the wavelet-based coded images at very low bit rates. The method reconstructs distorted edges using van Beek's edge model and removes the ringing effect by a Gaussian low pass filter. The two operations are combined together by a confident function that allows pixels closer to the edge center depending more on the edge model while pixels further away from the edge center depending more on the low pass operator. Finally the resultant image is ensured to be in the same quantization space of the coded image by a projection operation in wavelet domain. This algorithm improves not only the visual quality but also the fidelity (i.e. PSNR) of the image.

3. IMPROVED EDGE MODEL BASED REPRESENTATION

"Smudge and halos" artifacts occur because the reconstruction range is not wide enough. It is suggested in [4] that the reconstruction range is 2 times the edge width. In cases where the edge width is just 0.4 pixels or narrower, the reconstruction range does not include the pixels adjacent to the edge center. This causes the diffusion artifact during the regularization process. In Fig. 1(b), it is shown that "halo" occurs near Lena's hat because of the sharp edge of her hat. This artifact can be removed by simply setting the minimum reconstruction range to be 2 pixels such that all pixels adjacent to edge pixels are reconstructed. In Fig. 1(c), a well-bracketed edge region improves the reconstructed image. Fig. 2 shows a close up of Lena's. It shows that the minimum reconstruction range successfully eliminates the diffusion artifact.

To reconstruct an image from the locations and parameters of edges [4], we need to estimate the distance between a pixel (that is not a member of an edge) and its nearest edge pixel. Vector distance transform [8] is adopted because of its high efficiency. However, vector distance transform assumes all pixels rest on a discrete grid and so error is introduced in the estimation. On the other hand, an edge is a sharp change of intensity and the intensity may change dramatically over a small distance such as 0.5 pixel. Therefore, a small error in distance may result a large error in intensity. Furthermore, the regularization process will spread this error out. This error can be easily observed in an image with an edge that makes a small angle, say a few degrees, with the grid.

This problem can be solved by sub-pixel estimation. In van Beek's image representation, we need to find the distance d between a pixel (that is not an edge pixel), say A in Fig. 3, and its closest edge point. First, the closest edge pixel (i.e. P_2) is found by vector distance transform and then the edge pixels (i.e. P_1 and P_3) adjacent to it. From the edge model, we can obtain the sub-pixel edge centers which are C_1, C_2 and C_3 as shown in Fig. 3. In van Beek's method, the locus of an edge is represented by edge pixels at the grid. Here, we propose to represent the locus of an edge by straight lines that connect all these sub-pixel edge centers C_1, C_2 and C_3 together. Since these edge centers are of sub-pixel accuracy and are about one pixel apart on average, the approximation is more accurate than the original representation. This edge representation also allows distance d to be found easily.

In general, as shown in Fig.4, given two points $C_1(x_1,y_1)$ and $C_2(x_2, y_2)$, and the distance of the third point $A(x_A, y_A)$ to the segment joining C_1 and C_2 is d, we can simply translate the origin to C_1 and then rotate the coordinate system such that C_1C_2 lies with the x-axis. From now on, all the coordinates will be referring to the new coordinate system ($X'Y'$) and let the coordinates of A and C_2 in this system be (x_A', y_A') and (x_2', y_2'). The coordinates of A in the new coordinate system becomes:

$$\begin{bmatrix} x_A' \\ y_A' \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x_A - x_1 \\ y_A - y_1 \end{bmatrix}$$

where $$\tan\theta = \frac{y_2 - y_1}{x_2 - x_1}.$$

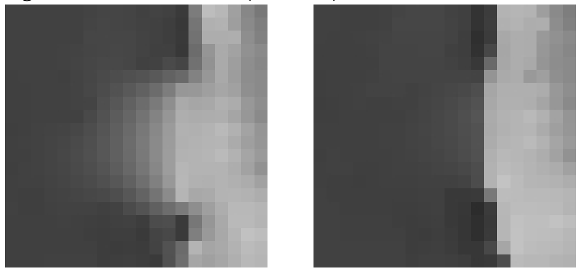
As a result, d is the absolute value of y_A'. Since the edge parameters are interpolated from the parameters at C_1 and C_2, we must ensure that point E in Fig. 4 falls on the line segment C_1C_2 where E is an edge center that has the shortest distance from point A. This can be easily verified by checking if x_A' is within [0, x_2'].

With the proposed sub-pixel estimation, the image can be represented more accurately as shown in Fig. 1(d). Fig. 5 shows clearly the effect of the proposed method. It shows that, without sub-pixel estimation, the jagged artifacts degrade Lena's forehead (Fig. 5(a)) while the proposed method eliminates this artifact (Fig. 5(b)) because the edge center is estimated more accurately. As a result, the proposed edge-model based image representation can represent the image "Lena" more accurately with a PSNR improvement of 2.5dB.

(a) (b)

(c) (d)

Figure 1. (a) The original "Lena" image. (b) The image reconstructed with original method (27.33dB). (c) The image reconstructed only with MRR (29.46dB). (d) The reconstructed image with MRR and SPE (29.83dB).



(a) (b)

Figure 2. (a) The close up of Lena's hat without minimum reconstruction range (MRR) (Figure 1(b) magnified by 6). (b) The close up of Lena's hat with MRR (Figure 1(c) magnified by 6).

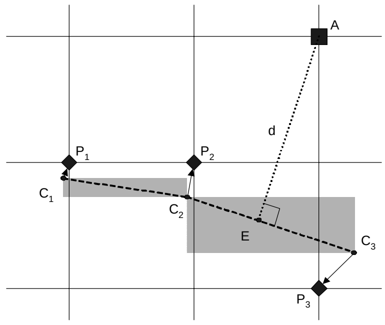


Figure 3. Estimation of the edge center by sub-pixel estimation.

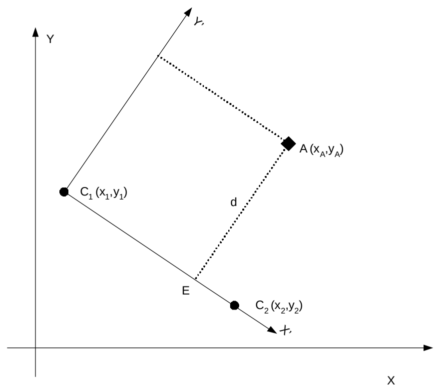
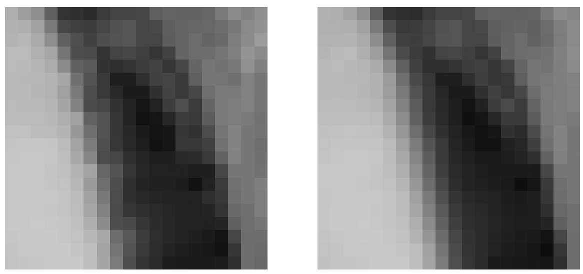


Figure 4. Quick estimation of the distance between the edge center and the interpolation ratio.



(a) (b)

Figure 5. (a) The close up of Lena's forehead without SPE (Figure 1(c) magnified by 6). (b) The close up of Lena's forehead with SPE (Figure 1(d) magnified by 6).

4. APPLICATION IN IMAGE POST-PROCESSING

We apply the proposed edge-model based representation to the image post-processing of edge reconstruction [6]. With minimum reconstruction range and sub-pixel estimation, the artifacts present before are removed and hence the edge region can be better reconstructed.

A total of twenty-eight sample images coded by the efficient wavelet-based codec-SPIHT [2]. The result shows that on average the modified process gives further improvement of 0.051, 0.021, 0.017 and 0.011dB to the images coded at 0.20, 0.15, 0.10 and 0.08 bits per pixel respectively (As shown in Table 1). Among the 28 sample images, 27, 26, 25 and 23 images are further improved their fidelity by means of the proposed edge model representation at the code rate of 0.2, 0.15, 0.1 and 0.08 bits per pixel respectively.

Code Rate	Average PSNR Gain (dB)		
	Edge model Representation	Improved Edge model Representation	Gain
0.08	0.222	0.232	0.011
0.10	0.224	0.242	0.017
0.15	0.100	0.121	0.021
0.20	-0.065	-0.014	0.051

Table 1. The comparison between the PSNR gain of the reconstructed images with and without proposed representation.

5. CONCLUSION

We have revealed the causes of artifacts in an edge-based image representation [4] and propose methods to suppress them. The revised representation that incorporates these methods has these artifacts significantly suppressed. We also demonstrate that the revised representation can improve the performance of the post-processing [6] for SPIHT coded images.

6. REFERENCES

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