A SPATIAL-DOMAIN ERROR CONCEALMENT METHOD WITH EDGE RECOVERY AND SELECTIVE DIRECTIONAL INTERPOLATION

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ABSTRACT

A low complexity spatial-domain error concealment method is proposed to reconstruct still images and intra-coded (I) frames in video when they are transmitted through unreliable channels in this work. The proposed concealment algorithm works with the following steps. First, missing edges in a lost macroblock (MB) are detected and recovered using gradient data. Then, the lost MB is implicitly divided into several segments along the recovered edges. Finally, each pixel in a segment is directionally interpolated from boundary pixels adjacent to the segment. Experimental results show that the proposed algorithm can recover high as well as low frequency information in lost MBs and provide better visual quality in comparison with the conventional spatial domain interpolation.

1. INTRODUCTION

Data loss is a severe problem in transmitting image and video signals through the wired and/or wireless Internet for applications with a high quality of service (QoS) requirement. Error concealment techniques attempt to conceal erroneous macroblocks (MBs) without modifying source and channel coding schemes. They are employed at the decoder to conceal residual transmission errors that cannot be corrected by other resilience tools. The underlying idea of error concealment is to fill in missing MBs using temporal or spatial correlation existing in video data. The temporal error concealment is basically achieved by motion vector estimation and temporal replacement. However, in still images or intra frames in video, no temporal information is available and missing MBs should be reconstructed with the spatial-domain error concealment technique.

In this work, we propose a low complexity spatial-domain error concealment method that can restore edge components as well as low frequency information. The proposed algorithm first detects edge components in neighboring boundary pixels, and connects broken edges in a lost MB via linear approximation. Then, the lost MB is partitioned into segments based on the recovered edge information. Finally, each pixel in a segment is directionally interpolated from boundary pixels adjacent to the segment. Simulation results demonstrate that the proposed algorithm is a simple yet efficient method for the spatial concealment of images.

The rest of this paper is organized as follows. Previous related work is reviewed in Section 2. The proposed error concealment algorithm, which includes edge recovery and selective directional interpolation, is presented in Section 3. Section 4 provides the experimental results and discussion. Finally, some concluding remarks are given in Section 5.

2. REVIEW OF PREVIOUS WORK

Various algorithms have been proposed for spatial-domain error concealment. A typical method is to interpolate each pixel p in a lost MB from four intact pixels in adjacent MBs [1]. Let p_i $(i = 1, 2, 3, 4)$ denote the closest pixel to p in the upper, lower, left, and right MBs, respectively. Then, the reconstruction value $\hat{p}$ of p is given by

$$\hat{p} = \frac{\sum_{i=1}^{4} p_i(W - d_i)}{\sum_{i=1}^{4} (W - d_i)}, \tag{1}$$

where W is the horizontal or the vertical size of a MB, and d_i is the distance between p_i and p. This spatial interpolation is one of the simplest methods and yet effective for smooth images. Note that the weighting coefficient $W - d_i$ is selected so that the pixel with smaller distance d_i has more influence on the pixel to be interpolated. A more advanced technique was proposed in [2] to assign weighting coefficients adaptively to achieve the maximum smoothness.

Generally speaking, these methods attempt to reconstruct a lost MB as a smooth interpolated surface from its neighbors. However, they may result in a blurred image if the lost MB contains high frequency components such as object edges. More sophisticated methods were proposed to recover high as well as low frequency components. For example, the fuzzy logic reasoning approach [3] uses vague relationships and similarities between a lost MB and its neighbors to recover high frequency information. It first recovers the low frequency information with surface fitting. Then, it uses fuzzy logic reasoning to coarsely interpret high frequency information such as complicated textures and edges. Finally, a sliding window iteration is performed to integrate results in the previous two steps to get the optimal output in terms of surface continuity and a set of inference rules. This method is however computationally expensive for real-time applications.

For the multi-directional filtering scheme proposed in [4, 5], a block classifier is used to determine the directions of edges based on the gradient data. Then, instead of imposing the smoothness constraint, an iterative procedure called projections onto convex sets (POCS) is adopted to restore lost MBs with an additional directional constraint. On one hand, this approach provides satisfactory results when a missing MB is characterized by a single dominant edge direction. On the other hand, POCS-based optimization also demands a heavy computational load. Computationally simple schemes such as the work in [4, 6] attempt to retrieve the edge information from neighboring intact MBs so that the concealed MB is smoothly connected to its neighborhood with consistent edges.

3. PROPOSED ERROR CONCEALMENT METHOD

3.1. Edge Recovery

Edges, which mean sharp changes or discontinuities in luminance values, play an important role in human perception of images. Generally, an image with blurred edges is annoying to human eyes. In this work, edges in missing MBs are recovered by the scheme illustrated in Fig. 1.

Consider a missing MB that is surrounded by four correctly decoded MBs. First, edges are detected by calculating the gradient field on the boundary pixels in the neighboring MBs. The gradient at pixel (j,k) is denoted by $G(j,k) = (G_R(j,k), G_C(j,k))$, where G_R and G_C can be computed by the convolution of image $F(j,k)$ with row and column impulse arrays as

$$G_R(j,k) = F(j,k) \bigotimes H_R(j,k), \tag{2}$$

$$G_C(j,k) = F(j,k) \bigotimes H_C(j,k). \tag{3}$$

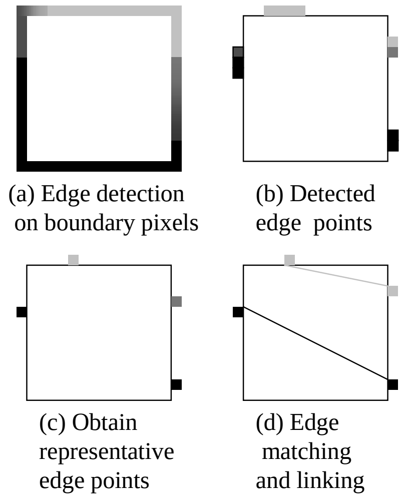


Fig. 1. The edge recovery process.

The following Sobel operator is adopted in this work:

$$H_R = \frac{1}{4}\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}, \tag{4}$$

$$H_C = \frac{1}{4}\begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}. \tag{5}$$

The amplitude and the angle of the gradient at point (j,k) are then defined as

$$A(j,k) = \sqrt{G_R^2(j,k) + G_C^2(j,k)}, \tag{6}$$

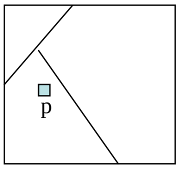
$$\theta(j,k) = \arctan \frac{G_R(j,k)}{G_C(j,k)}. \tag{7}$$

If the amplitude $A(j,k)$ is larger than a pre-specified threshold, pixel (j,k) is said to lie on an edge. The threshold is set to the variance of pixel values in this work.

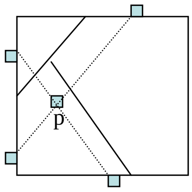
Several consecutive pixels are often detected as edge points as shown in Fig. 1(b). Among them, only one pixel with the largest gradient amplitude is selected as the true edge point as shown in Fig. 1(c).

It is assumed that there are two cases when an edge enters a lost MB through an edge point. The first case is that this edge exits the MB via another edge point. The second case is that the edge meets another edge within the MB and does not exit the MB as a result. Thus, in the final step, we should compare edge points to find the matched pairs. The attribute vector of the ith edge point is defined as

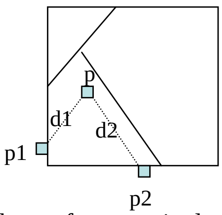
$$\left(\frac{A_i}{255\sqrt{2}}, \frac{\theta_i}{180}, \frac{lum_i}{255}\right), \tag{8}$$



(a) A lost MB with two edges linked



(b) Two reference pixels are determined along each edge direction



(c) Select reference pixels within the same region of p

Fig. 2. Illustration of selective directional interpolation where $p = \frac{\frac{p_1}{d_1}+\frac{p_2}{d_2}}{\frac{1}{d_1}+\frac{1}{d_2}}$

where A_i and θ_i denote the amplitude and the angle of the gradient of the edge point, respectively, and lum_i is the luminance of the edge point. Then, the attribute distance between every two edge points are calculated. A pair of edge points is deemed as a match if their attribute distance is the smallest among all. Thus, we label them as a pair and treat the remaining edge points as a new group. The same matching process can be performed iteratively until all points are matched or the distance of two edge points is over a certain threshold. After the above step, each matched pair is linked together to recover a broken edge. After edge linking of all pairs, if there is still an unmatched edge point, it is extended into the lost MB along its gradient until it reaches an edge line.

3.2. Selective Directional Interpolation

After edges are recovered in a missing MB, these edge lines partition the 2D plane into several regions. As shown in Fig. 2, a pixel p in the missing MB is interpolated using only the boundary pixels in the same region to smoothly recover the lost information in that region.

Let us assume that there are n edges in a missing MB. Each edge can be represented by a line equation, *i.e.*

$$y - y_{0,i} - m_i(x - x_{0,i}) = 0, \tag{9}$$

where m_i is the edge slope and $(y_{0,i}, x_{0,i})$ is the coordinate of a point on the edge. If this edge is recovered by a matching pair of edge points $(x_{1,i}, y_{1,i})$ and $(x_{2,i}, y_{2,i})$, we have $m_i = \frac{y_{2,i}-y_{1,i}}{x_{2,i}-x_{1,i}}$. Otherwise, $m_i = \frac{G_{R,i}}{G_{C,i}}$. In other words, it is determined by the gradient of the unmatched edge point.

For each lost pixel $p = (x, y)$, we find the reference pixels to be used in the interpolation. Along each edge direction i, the boundary pixels in neighboring MBs are retrieved as shown in Fig. 2(b). Note that only those reference points within the same region as p are reliable due to the discontinuities caused by edges. Thus, an elimination algorithm is applied to each retrieved boundary pixel to determine whether it is within the same region as $p = (x, y)$. Let (b_x, b_y) denote a retrieved boundary pixel along the ith edge, then its reliability is determined by the following algorithm.

```
for (j = 0; j < n; j++) {
  if(j != i) {
    sign1 = y - y_{0,j} - m_j(x - x_{0,j})
    sign2 = b_y - y_{0,j} - m_j(b_x - x_{0,j})
    if(sign1 × sign2 < 0) {
      Declare the reference point is invalid.
      Return.
    }
  }
}
Declare the reference point is valid.
```

Once the reference points are obtained, the missing pixel p can be interpolated by

$$p = \frac{\sum_k \frac{p_k}{d_k}}{\sum_k \frac{1}{d_k}}, \tag{10}$$

where p_k is the kth reference point, and d_k is the distance between p_k and p. To give an example, Fig. 2(c) shows the case when two reference points are available, and we have

$$p = \frac{\frac{p_1}{d_1} + \frac{p_2}{d_2}}{\frac{1}{d_1} + \frac{1}{d_2}}$$

for this case.

If a lost pixel is enclosed by edges, then no reference point is available. In such a case, p is interpolated from the nearest edge pixels along the horizontal and vertical directions.

Fig. 3. Three MBs are lost in the left image and concealed in the right image with the proposed algorithm.

Fig. 4. Concealed results for a severe data loss case with 20 MBs lost, where the left image is obtained by the conventional spatial interpolation and the right image is obtained by the proposed method.

4. EXPERIMENTAL RESULTS

The performance of the proposed algorithm is tested on the "Foreman" QCIF (176×144) image as an example, since it contains many edges in the background. In Fig. 3, three MBs are lost as shown in the left image of Fig. 3. The lowest MB contains only one single cutting through edge. The concealed image in the right shows that the edge is successfully detected and bridged together. The uppermost MB contains three parallel edges. The concealed result shows that representative edge points are accurately determined and matched up. The middle one contains intersect edges. The concealed area looks quite natural. No blur and significant discontinuities are observed in the concealed image, which shows that our proposed algorithm does give good estimation of the locations of missing edges and the selective directional interpolation scheme works well to interpolate missing pixels in the MB.

Fig. 4 shows the "Foreman" image with 20 isolated lost MBs out of total 99 MBs. Each lost MB is surrounded by four correctly decoded MBs. Our concealed image shows visually consistent with its neighboring pixels, while spatial interpolation generates blurred reconstruction, espesially when MBs are located on linear edges. However, the lost MB that covers the "Foreman" eyes is concealed with noticeable distortion. This is due to the failure of matching edge points. It occurs for curved edges with fast changing gradient. Nevertheless, MBs located on the "Foreman" mouth and collar are still concealed well with small distortion.

For the case with the loss of consecutive MBs, a similar procedure can be applied. Note that there are more boundary pixels encircling the missing part in this case, and the edge recovery and the selective directional interpolation schemes can be slightly modified to handle this situation.

5. CONCLUSION

A new spatial-domain error concealment method was proposed in this work. The edge information in the neighborhood is detected and recognized so that broken edges in a missing MB can be properly estimated and reconstructed. Furthermore, directional interpolation of preselected boundary pixels are used to estimate other non-edge pixel values. Experimental results show our algorithm achieves an excellent concealment performance for lost MBs in either a still image or the intra frame of a video clip.

6. REFERENCES

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