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AN EFFICIENT MULTI-DIRECTIONAL INTERPOLATION ALGORITHM FOR SPATIAL ERROR CONCEALMENT

Jo Jong Hyon, Hwang Pyong Su and Ri Je Hyon

Institute of Information Technology, Hightech Research and Development Center, Kim Il Sung University, Pyongyang, D.P.R. Korea

Abstract

In real-time video applications, error concealment is used to conceal the corrupted parts of the video sequence without retransmission. In this paper, an efficient multi-directional interpolation algorithm is presented for spatial error concealment. First, the significant edges of missing macroblock are only estimated using a directional edge analysis on the correctly received neighboring blocks. Second, an approximation for each missing pixel is computed along each significant edge. For two boundary pixels along each significant edge direction, the sum of magnitudes of gradients, which has the same quantized direction level as the edge direction, are computed on seven neighboring pixels. Finally, a weighted average of multiple approximations is computed using the sum of gradient magnitudes as weighting factors. Compared with the previous methods using multi-directional interpolation, experimental results show that the proposed method gives better reconstruction quality in terms of objective and subjective evaluations.

Keywords:

Video Communication, Error Concealment, Multi-Directional Interpolation

1. INTRODUCTION

Compressed video is susceptible to transmission errors, and the packet losses over error-prone networks cause the corrupted region in video frame. Error concealment (EC) recovers the corrupted region in the video frame using correctly received information. EC techniques can be categorized into two classes: spatial error concealment (SEC) and temporal error concealment (TEC). SEC relies on the information within the current frame, while TEC utilizes the temporal correlations.

A number of methods have been proposed for spatial error concealment. Interpolation algorithms are widely presented because they are suitable for real-time applications due to their low computational complexity.

The simplest and fastest interpolation method is Bilinear Interpolation (BI) which has been employed in H.264/AVC reference model [1]. BI algorithm recovers each missing pixel from four pixels in the adjacent macroblocks. The previous methods [2]-[5] reconstruct the corrupted macroblocks using edge related information in the interpolation process.

A new error concealment technique based on edge-oriented interpolation is proposed [2]. First, edge direction of a lost block is estimated using one-dimensional matching techniques from two boundaries of neighboring blocks. Then, the error pixels are recovered by weighting linear interpolation along the estimated edge direction. Afterwards, the median filter is used to recover residual damaged-pixels.

Agrafiotis et al. [3] proposed a spatial error concealment method that uses edge-related information. A switching algorithm which uses the directional entropy of neighbouring edges chooses between two interpolation methods, a directional along detected edges or a bilinear using the nearest neighbouring pixels.

Ma et al. [5] proposed an edge-directed error concealment (EDEC) algorithm, to recover lost slices in video sequences. First, the strong edges in a corrupted block are estimated based on the edges in the neighboring frames and the received area of the current frame. Next, the lost regions are recovered along these estimated edges using both spatial and temporal neighboring pixels. Finally, the remaining parts of the lost regions are estimated.

A refined error concealment scheme based on directional interpolation is proposed [6]. The gradients are computed for boundary pixels in the correctly received macroblocks neighboring missing one. The strongest edge direction of missing macroblock is determined into one of sixteen different directions from 0° to 360° depending on the computed gradients. Weighted directional interpolation is applied on each missing pixel along the strongest edge direction.

Li et al. [7] proposed a spatial error concealment method which selects the appropriate spatial method using location information and Intra Mode of correctly received neighboring macroblocks.

A spatial error concealment method using multi-directional interpolation is presented [9]. First, the significant edges of missing area are estimated after performing edge analysis on the correctly received neighboring blocks. The moments of the neighboring edge magnitudes are used to obtain an adaptive threshold for rejecting non-significant directions. Then, based on the predicted significant edge directions, an approximation is obtained for each missing pixel. Finally, a weighted average is computed for each pixel.

The study proposes an efficient multi-directional interpolation algorithm which improves above mentioned multi-directional interpolation method.

The rest of the paper is organized as follows: In section 2, the proposed multi-directional interpolation algorithm is discussed. Experimental results are shown in section 3. Finally, section 4 concludes the paper.

2. PROPOSED METHOD

2.1 ESTIMATING THE SIGNIFICANT EDGES

The magnitude $G(x,y)$ and direction $\theta_g(x,y)$ of the gradients for boundary pixels are calculated applying Sobel operators on luminance value of three layers of pixels surrounding the missing area [8].

Since some of these gradients are caused by noise or insignificant differences in intensity, the weak gradients should be eliminated. For this purpose, first, weak gradients are eliminated by applying a fixed minimum threshold T_m. As a result, the set of valid edges, E_c, is defined as follows [9]:

$$E_c = \{[G(x,y)\theta_g(x,y)] | G(x,y) \geq T_m\} \quad (1)$$

Second, edges are quantized into discrete levels and normalized array of edge magnitudes is formed.

Eight different direction levels between 0 and 180 degree are defined as shown in Fig.1. One counter is set for each direction, and the initial value of eight counters are set to zero.

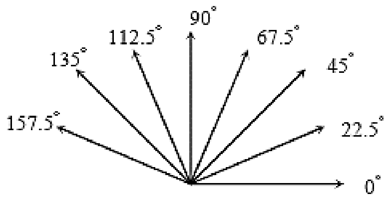

Fig.1. Eight quantized direction levels

The gradient direction of each member within E_c are quantized into one of eight direction levels as shown in Fig.1. The counter corresponding to the gradient direction is increased with the corresponding magnitude.

Then, the array of magnitudes for eight level counters are normalized to form E_q as follows.

$$E_q = \{\rho_i | \rho_i = G_i \Big/ \sum_{j=1}^{n} G_j, i = 1, 2, ..., n\} \quad (2)$$

where n is the number of quantization levels, G_i is the magnitude of counter for the i^{th} quantized direction level.

Third, an adaptive threshold τ_a based on the edge-oriented information of neighboring areas is introduced to retain the significant edges as following [9].

$$\tau_a = \mu + c \times \sigma \quad (3)$$

where μ and σ are the mean value and standard deviation of the edge magnitudes in the correctly received areas neighboring the missing macroblock, respectively. The coefficient c is computed as follows [9].

$$c = 1 - \frac{1}{\log_2(n)} \sum_{\rho_i \in E_q} \left(\rho_i \log_2\left(\frac{1}{\rho_i}\right) \right) \quad (4)$$

It means that the small value of edge entropy corresponds to a small number of significant edges [9]. Namely, a smaller value of c preserves more significant edges, and a higher value of c preserves less significant edges.

In this paper, value of n is 8, therefore Eq.(4) is expressed as follows.

$$c = 1 - \frac{1}{\log_2(8)} \sum_{\rho_i \in E_q} \left(\rho_i \log_2\left(\frac{1}{\rho_i}\right) \right) = 1 - \frac{1}{3} \sum_{\rho_i \in E_q} \left(\rho_i \log_2\left(\frac{1}{\rho_i}\right) \right)$$

Finally, the set of all significant edges, E_t, for the missing macroblock can be defined as following [9]:

$$E_t = \{[G(x,y)\theta_g(x,y)] \in E_c \,|\, G(x,y) \geq \tau_a\} \quad (5)$$

2.2 PROPOSED MULTI-DIRECTIONAL INTERPOLATION ALGORITHM

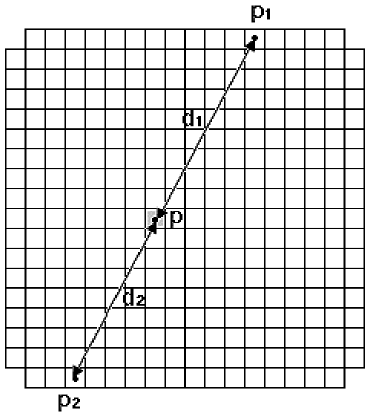

Fig.2. Directional interpolation

As shown in Fig.2, the approximation for missing pixel p along the k^{th} significant edge, p_k*, is calculated as following Eq.(6) as in [9]:

$$p_k^* = \frac{d_2 \times p_1 + d_1 \times p_2}{d_1 + d_2} \quad (6)$$

where p_1 and p_2 are the boundary pixels from which the missing pixel is interpolated. They can be determined as intersection of macroblock boundaries with a line which passes p having direction of the k^{th} significant edge. d_1 denotes the distance from p_1 to p, and d_2 denotes the distance from p_2 to p.

As shown in Fig.3, we determine seven pixels neighboring p_1 and p_2, respectively. The line connecting p_1 with p_2 should pass a center pixel of the seven neighboring pixels. Then, g_{k1} and g_{k2}, the sum of magnitudes of gradients which are quantized into the same direction level as the k^{th} significant edge direction, are calculated for these seven pixels.

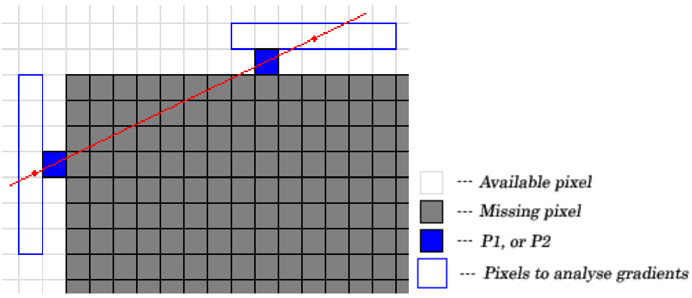

Fig.3. Pixels to analyse the gradients for boundary pixel

The approximation for each pixel in the missing macroblock, p*, is calculated using following multi-directional interpolation algorithm.

$$p^* = \sum_{k=1}^{|E_t|} w_{gk} \times p_k^* \quad (7)$$

$$w_{gk} = (G_k + g_k) \Big/ \sum_{j=1}^{|E_t|} (G_j + g_j) \quad (8)$$

$$g_k = \begin{cases} 4 \times (g_{k1} + g_{k2}), & g_{k1} > 0 \text{ and } g_{k2} > 0 \\ 2 \times (g_{k1} + g_{k2}), & g_{k1} = 0 \text{ or } g_{k2} = 0 \end{cases} \quad (9)$$

where $|E_t|$ is the cardinality of E_t, namely the number of significant edges in E_t. G_k is the magnitude of the k^{th} significant edge in E_t.

Above equation implies that an approximation along one significant edge direction should have more weight if seven pixels neighboring two boundary pixels have the same direction as the significant edge in the weighted multi-directional interpolation.

The Fig.4 shows the block diagram of the proposed multi-directional interpolation algorithm. As stated above, the significant edges of missing macroblock are only estimated, then an approximation for each missing pixel is computed along each significant edge. For two boundary pixels along each significant edge, the proposed method computes the sum of magnitudes of gradients, which has the same quantized direction level as the significant edge, on seven neighboring pixels. Finally, a weighted average of multiple approximations is calculated using the sum of gradient magnitudes as weighting factors.

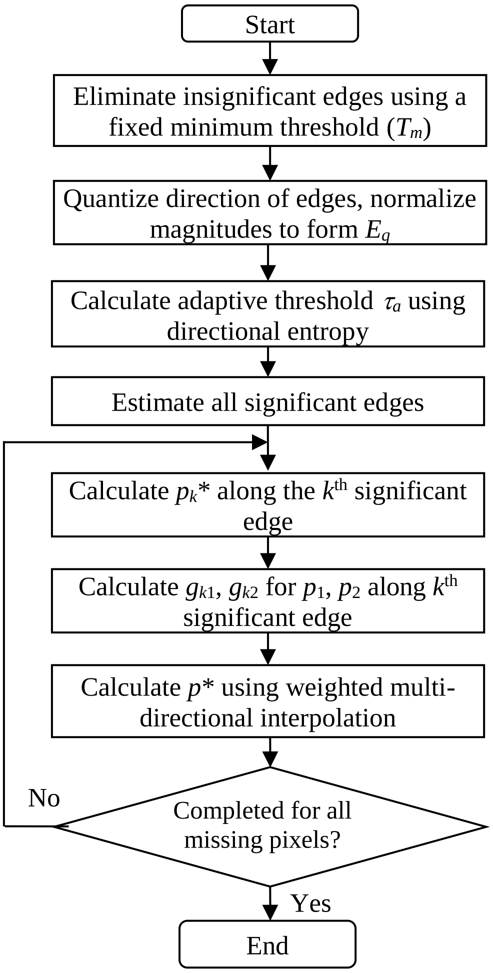

Fig.4. Block diagram of the proposed multi-directional interpolation

3. EXPERIMENTAL RESULTS

We have conducted various experiments to evaluate the performance of our proposed method. We have compared our proposed method, the so called Efficient Multi-Directional Interpolation (EMDI), with the previous Multi-Directional Interpolation (MDI) method [9]. The performance comparison is carried out on four test images shown in Fig.5, including Lena (512×512), Peppers (512×512), F16 (512×512), and office (512×512).

The experiments are performed on the test images involving regular isolated error patterns as shown in Fig.6(a), and the size of corrupted blocks is 16×16 pixels. In our experiments, we have set T_m to 1.0.

The objective Peak signal-to-noise ratio (PSNR) comparison results of the competing methods for the reconstructed images are presented in Table 1.

Fig.5. Four test images

Table.1. Performance comparison in PSNR for 16×16 regular isolated error patterns.

Image	Previous MDI [9]	Proposed
Lena	32.61	32.79
Peppers	31.93	32.09
F16	29.83	29.91
Office	31.07	31.42
Average	31.36	31.55

The Table.1 shows that the proposed method gives the better performance than the previous MDI method [9]. In particular, when compared with MDI method [9], our algorithm shows an average PSNR improvement of 0.19 dB, achieves a maximum PSNR gain of 0.35 dB. Subjective performance comparisons for the test images are shown in Fig.6.

Subjective comparison also shows that the proposed method achieves better reconstruction quality when compared with the previous MDI method [9].

Second, the performance comparison of the competing methods is carried out on four test CIF (352×288) video sequences, including akiyo, bowing, coastguard and foreman. The test video sequences are previously encoded with JM19.0. The experiments are conducted on the first ten I-frames per a video sequence, which involves 16×16 regular isolated error patterns.

PSNR performance comparison for reconstructed I-frames is shown in Table 2.

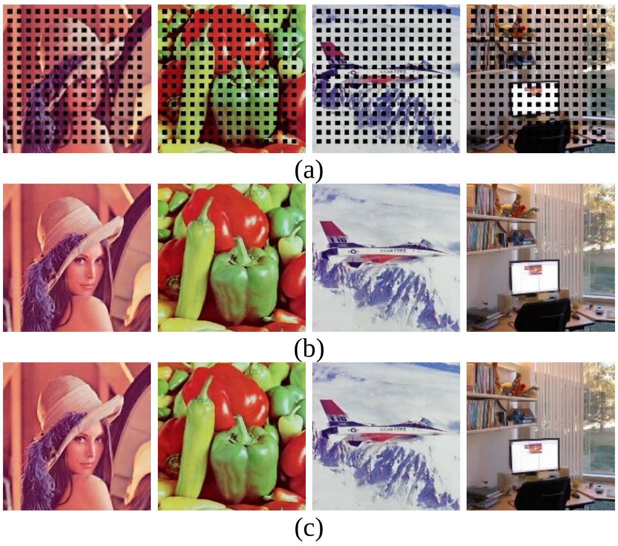

Fig.6. Subjective Comparison for 16×16 regular isolated error patterns (a) Error image (b) EC using MDI [9] (c) Proposed

Table 2. PSNR Performance comparison for video sequences

Video Sequence	MDI [9]	Proposed
Akiyo	34.21	34.62
Bowing	33.33	33.81
Coastguard	29.99	30.11
Foreman	35.53	35.77
Average	33.26	33.58

When compared with the previous MDI method, the proposed method consistently gives better performance on test video sequences, and achieves an average PSNR improvement of 0.32dB.

4. CONCLUSION

A spatial error concealment algorithm which uses efficient multi-directional interpolation is presented in this paper. The significant edges of the missing macroblock are only estimated using a directional edge analysis on the correctly received neighboring blocks. An approximation for each missing pixel is obtained along each significant edge. Continuously, for two boundary pixels along each significant edge direction, the sum of magnitudes of gradients, which has the same quantized direction level as the edge direction, are computed on seven neighboring pixels. Finally, a weighted average of multiple approximations is computed using the sum of gradient magnitudes as weighting factors. We compare the proposed method with MDI method [9]. Experimental results show that the proposed method can effectively enhance the performance of spatial error concealment and reconstruction quality in terms of objective and subjective measures.

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