SPATIAL ERROR RECOVERY USING MULTI-DIRECTIONAL INPAINTING

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ABSTRACT

During transmission over error-prone networks, the compressed video signal may suffer a large drop in video quality for the block-based motion-compensation scheme. Error recovery is widely used in video decoders to reconstruct corrupted regions. In this paper, we propose a new spatial error recovery method utilizing multi-directional inpainting. It contains eight single-directional inpaintings which perform unsymmetrical matching to search for suitable information and keep local continuity. We also present a linear combination method which merges different directional matching patches to alleviate the error propagations. Experimental results show that the proposed method provides significant gains in both subjective and objective measurements.

***Index Terms*—**Error Recovery, Error propagation, Multi-directional scanning, Inpainting, Linear combination

1. INTRODUCTION

When video stream transmits through error-prone channels, it may suffer from errors which cause mistakes in current blocks even propagate to the following blocks or the following frames. The visual quality of such a sequence should be heavily influenced. In such a situation, error recovery is proposed to reconstruct corrupted pixels utilizing all available information. Error recovery methods could be divided into two classifications: spatial error recovery (SER) and temporal error recovery (TER) [1]. The earlier one utilizes neighbor information in current frame to recover the missing data whereas the latter utilizes temporal information from successive frames. In this paper, we focus on SER.

Lots of SER algorithms such as [1]-[6] have been presented recently. Bilinear interpolation is a basic, simple and efficient method which utilizes the nearest correctly decoded pixels to reconstruct the lost areas [2]. Some improved methods are proposed such as directional interpolation [4] and order based inpainting [5] which try to find the smoothest recovery and the best neighbor matching. Further, an algorithm which divides the frame into two images representing structure and texture respectively and processes these two images separately is presented in [3]. The drawbacks of these methods are that only one or two directions are taken into consider and not been utilized sufficiently. There is a new method which considers multi-directional information. In [6], an eight directional LMS is described to execute error recovery.

In this paper, we present a new SER method based on multi-directional inpainting. It contains eight single-directional inpaintings which perform unsymmetrical matching to search for suitable information and keep local continuity. After that, we also present a linear combination method which merges different single-directional matching patches based on spatial position and reliability of neighbor information. This algorithm can greatly alleviate the error propagations. Experimental results show that the proposed method provides significant gains in both subjective and objective measurements.

The rest of this paper is organized as follows. In Section 2, details of the proposed SER based on multi-direction inpainting are described. Related experiment results are given in Section 3. Finally, we conclude the whole paper in Section 4.

2. MULTI-DIRECTIONAL INPAINTING

SER reconstructs corrupted pixels utilizing neighbor correctly decoded pixels. From a statistic point of view, it utilizes the known pixels $Y_l (1 \le l \le L)$ to recover the unknown pixels $X_k (1 \le k \le K)$. An efficient way to realize restoration is MAP which ensures $X_1, \cdots, X_K$ to gain the maximum probability $p(X_1, \cdots, X_K | Y_1, \cdots, Y_L)$.

It is very difficult to obtain the above probability distribution in practice because of the high dimensionality. Considering the correlation of $X_k (k = 1, \cdots, K)$, $p(X_k | X_1, \cdots, X_{k-1}, Y_1, \cdots, Y_L)$ could be transformed to a series of multiples of conditional probability:

This work is done while the 1st author was an intern at Philips Research Asia – Shanghai.

$$p(X_1,\cdots,X_K|Y_1,\cdots,Y_L)= \prod_{k=1}^{K} p(X_k|X_1,\cdots,X_{k-1},Y_1,\cdots,Y_L) \quad (1)$$

In order to make $p(X_1,\cdots,X_K|Y_1,\cdots,Y_L)$ maximum, it could be implemented by ensuring each $p(X_k|X_1,\cdots,X_{k-1},Y_1,\cdots,Y_L),(k=2,\cdots,K)$ maximum. When utilizing the reconstructed pixels $X_1,\cdots,X_{k-1}$ to recover X_k, the restoration result is influenced by the scanning and recovery orders because of error propagations. Choosing different recovery orders may induce different error propagation patterns. For example, if there are K continuous corrupted pixels, there are $K!$ different orders to get $K!$ recovery results. It is tremendous complex. In practice, it isn't possible or necessary to get $K!$ results and merge all of them together to get the best combinational result. A better way is utilizing several recoveries of fixed orders to approximately represent all orders to get a final recovery result. In this a way, the reconstructed quality doesn't decrease so much whereas the calculate quantity decreases significantly.

It is significantly important to choose several fixed orders to represent all of them. Then try to obtain the reconstructed result for each determined order as good as possible and combine all reovery results together. The proposed spatial error recovery could be divided into three steps:

(1)Choose eight single-directional ordinal scanning orders as fixed recovery orders;

(2)Utilize inpainting based on unsymmetrical matching to search for suitable information in each determined order;

(3)Merge eight single-directional inpainting recovery results together based on spatial position and reliability of neighbor information.

The overall structure is illustrated in Fig.1:

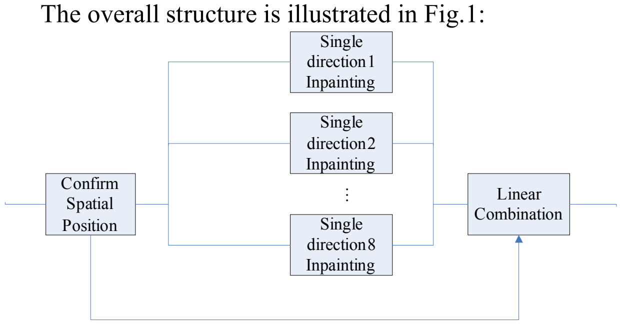

Fig.1. Overall structure of multi-direction inpainting

2.1. Multi-direction scanning

Different recovery orders may introduce different error propagation patterns. In practise, some recovery orders are not possible. For example the recovery beginning from the center of the corrupted areas has little available information. The reliability of the recovery result is so low for such an order. The utilizing of all recovery orders is complex and not necessary. It is reasonable to choose several typical orders as representation. In our proposed method, we involve eight single-directional ordinary scanning orders as shown in Fig.2.

Choosing such eight single-directional ordinary scanning orders gives lots of advantages. Firstly, for each single-directional recovery, it is more effective to focus on utilizing single directional information to search for a matching patch in such a direction than the one utilizing multi-direction data indiscriminative. Secondly, the implementation of each single-directional scanning is easier to realize collateral pipelining. It greatly reduces the time needed for such an algorithm.

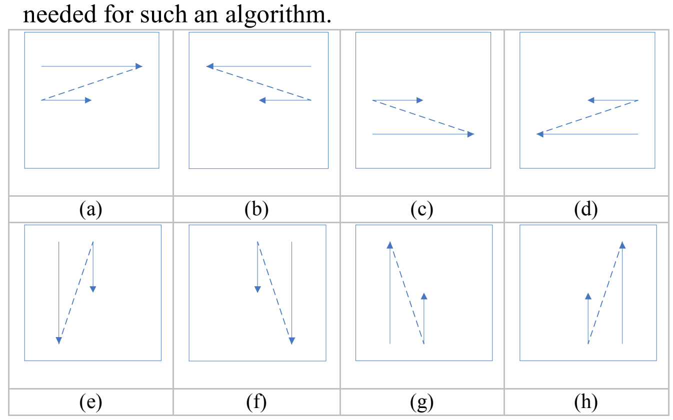

Fig.2. Eight single-directional scanning orders

2.2. Unsymmetrical inpainting

For each fixed recovery order, it is necessary to focus on utilizing single-directional information and searching for available data as much as possible.

In our proposed method, we utilize inpainting to realize recovery. Inpainting pays much attention to the primary structure and texture features. There is no need to distinguish edge and other characteristics of the image. It enjoys more flexibility and utilizes local available information in a more sufficient way.

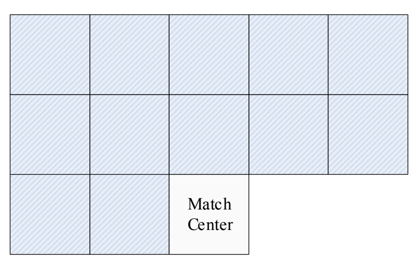

Fig. 3. Unsymmetrical inpainting patch

Single-directional inpainting focuses on single directional information. It is not a good choice to utilize a symmetrical matching patch which pays same emphasizes to all directions. As in single-directional order 1, we utilize the unsymmetrical matching patch as Fig.3 shows. Information from the scanning direction is emphasized. It is a better way to utilize the reliable pixels. To different single-directional recovery order, it is necessary to utilize different unsymmetrical matching patch focusing on related directional information.

Utilizing the unsymmetrical inpainting, the single-directional recovery is done step by step:

(1) Check current unsymmetrical patch which contains corrupted pixels in the fixed recovery order;

(2) Search the predetermined area to get the best matching patch which has the maximal similarity utilizing sum absolute difference (SAD) as measurement. SAD is defined as the differences of each corresponding couple of pixels from corrupted and matching patches.

(3) Copy the corresponding pixels from the best matching patch to current patch. which is corrupted.

2.3 Linear Combination

In our proposed method, eight single-directional scanning orders are involved. The combination of different directional reconstructed results is necessary. The weight coefficients are determined by spatial position and reliability of neighbor pixels in different directional recovery orders.

The influence of spatial position takes account of distances from the nearest correctly received pixels of four directions. As Fig.4 shows, pixel A has more similarity with the top and left correctly received neighbors while pixel B has more consistency with the bottom and right ones.

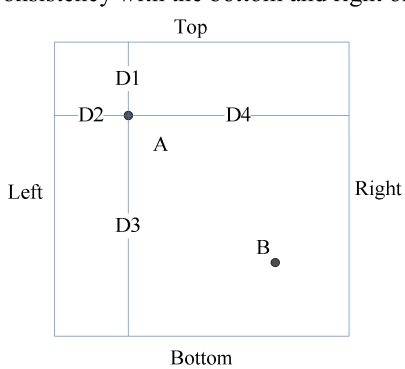

Fig.4. Definition of D_k

D_k (k=1, 2, 3, 4) represents directional distances. The combination weight coefficients are given as:

$$\omega_i^k = \frac{\sum_{k=1}^{K} w_k \cdot D_k}{\sum_{k=1}^{4} D_k} \quad (k = 1, \cdots, 4; i = 1, \cdots, 8) \qquad (2)$$

w_k influences the weights for combination. It is determined by the reliability which is determined by the recovery order. As in single-directional order 1, recovery begins from top and left. It pays more weight on top and left neighbor pixels. The correlative measurement also proves such a conclusion. Utilizing correlation to determine the weight coefficients is a reasonable way whereas it brings much complexity. We have tested lots of images and present a simple method to get the weight coefficients illustrated as follow:

$$\omega_i^k = \frac{5 \cdot D_a + 2 \cdot D_b + D_c}{16 \cdot \sum_{k=1}^{4} D_k} (k = 1, \cdots, 4; i = 1, \cdots, 8) \qquad (3)$$

D_a, D_b, D_c represent directional distances. Each of them is one of D_k (k=1, 2, 3, 4). In different single-directional scanning orders, they have different choices:

TABLE Ⅰ
PAIR OF IN DIFFERENT SCANNING ORDER

i	1	2	3	4	5	6	7	8
a	1	1	3	3	2	2	4	4
b	2	4	2	4	1	3	1	3
c	3	3	1	1	4	4	2	2

3. EXPERIMENT RESULTS

In order to compare our error recovery method with other existing techniques, results of our algorithm and algorithms in [2],[4],[5],[6] have been measured for image Lena, Ape, Pepper, Renata and Mobile in Block and Slice corrupted situations. We utilize the improved PSNR which just measuring the corrupted areas as objective measurement. Table II and Table III give the PSNR comparisons between previous methods and our proposed one. The PSNR in our algorithm increases for all test images. Meanwhile Fig.5 and Fig.6 show the subjective results relating to block and slice losses respectively for image Lena. It can be seen that our proposed algorithm provides the best subjective quality.

TABLE Ⅱ
PERFORMANCE COMPARISON FOR BLOCK LOSS (dB)

Image	[2]'BI	[5]'DAI	[6]'OI	[7]'8LMS	Ours
Lena	24.03	25.72	23.74	25.97	26.63
Renata	22.03	22.01	20.73	21.87	23.88
Ape	20.25	20.35	18.46	20.16	20.72
Pepper	24.85	27.36	24.34	26.67	26.78
Mobile	17.34	16.99	15.37	17.58	17.73

TABLE Ⅲ
PERFORMANCE COMPARISON FOR SLICE LOSS (dB)

Image	[2]'BI	[6]'OI	[7]'8LMS	Ours
Lena	22.21	21.32	22.07	23.58
Renata	19.01	18.75	17.44	20.45
Ape	19.15	17.94	19.08	19.95
Pepper	25.22	23.26	24.00	25.56
Mobile	16.28	13.80	16.27	16.53

(a)Corrupted (b)BI
(c)Ordered Inpainting (d)Direct Inpainting
(e)8 directional LMS (f) Proposed method

Fig.5.Recovery of block loss (a) Corrupted Image (b) Bilinear Interpolation [2] (c) Order-based Inpainting [5] (d) Directional Interpolation [4] (e) 8 Directional LMS [6] (f) Our Proposed method

(a)Origin (b)Corrupted
(c)BI (d)Ordered Inpainting
(e)8 directional LMS (f)Proposed method

Fig.6.Recovery of slice loss (a) Corrupted Image (b) Bilinear Interpolation [2] (c) Order-based Inpainting [5] (d) Directional Interpolation [4] (e) 8 Directional LMS [6] (f) Our Proposed method

4. CONCLUSION

In this paper, we present a new SER method based on multi-directional inpainting. The single-directional inpainting information is gained through unsymmetrical inpainting which tries to utilize available neighbor information and keep local continuity. We also investigate the problem of combining different directional matching patches and give a way to acquire weight coefficient based on spatial position and reliability of neighbor information. Experimental results show that the proposed method is satisfying in both subjective and objective measurements.

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