ERROR CONCEALMENT BASED ON DIRECTIONAL INTERPOLATION

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Abstract

Compressed bitstreams are, in general, very sensitive to channel errors. For instance, a single bit error in a coded video bitstream may cause severe degradation on picture quality. When bit errors occur during transmission and cannot be corrected by an error correction scheme, error concealment is needed to conceal the corrupted image at the receiver. Error concealment algorithms attempt to repair damaged portions of the picture by exploiting both the spatial and the temporal redundancies in the received and reconstructed video signal. In this paper, we discuss several temporal, spatial, and transform-domain error concealment techniques for MPEG coded pictures, and propose a new scheme based on directional interpolation. We also compare the performances of these techniques by computer simulation.

1. Introduction

Fast growing multimedia services have generated a great deal of interest in transmitting digital video signals. However, digitized signal increases the bandwidth for transmission. For example, if we transmit a low-resolution color image of 512 x 512 pixels with 8-bit resolution per pixel over telephone lines using a 28.8 kbit/s modem, it would take approximately 3.6 minutes for transmitting just a single frame; which is unacceptable for most applications. Therefore, video compression for reducing the bit rate to a level affordable on practical communication channels is necessary. By proper design of the coding system, it is possible to discard negligible information without affecting perceived image quality, or at most, with only small degradations.

The popular MPEG video coding standard is a hybrid algorithm of motion compensation (MC), discrete cosine transform (DCT), DPCM and variable-length coding (VLC) [1]. In the MPEG coding, the input sequence is divided into groups of pictures (GOP), as shown in Figure 1. Each GOP may include three different types of pictures: Intra-coded picture (I-picture), Predictive-coded picture (P-picture) and Bidirectionally predictive-coded picture (B-picture). I-picture is coded by itself, with no need for any previous or future information. The reconstructed I-picture is used as an anchor for forward and backward prediction of neighboring pictures. P-picture is coded using forward motion compensated prediction from the past I-picture or P-picture. B-picture is coded using bidirectional motion compensated prediction from the past and future I-picture and P-picture.

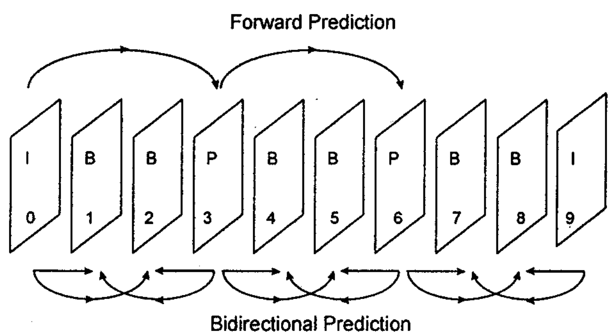

Figure 1: GOP Structure in MPEG Video Coding

This structure of the GOP implies that if an error occurs within I-picture data, it propagates through all other pictures in the same GOP. Similarly, an error in the P-picture affects the neighboring P-picture and B-picture, while errors in the B-picture can be isolated. Therefore, it is desirable to develop an error stopping mechanism to prevent error propagation within the GOP, and consequently, to improve reconstructed picture quality.

There are mainly two different approaches to solve this problem. The first approach is error correction, which makes perfect recovery from errors using structured codes such as Hamming code or Reed-Solomon code; however, it increases transmission overheads. The second approach is error concealment that provides an approximation of the original data using visual redundancy in the neighborhood of the lost block without increasing the bit rate [2].

In this paper, we describe several techniques for error concealment. Section 2 presents a modified MPEG

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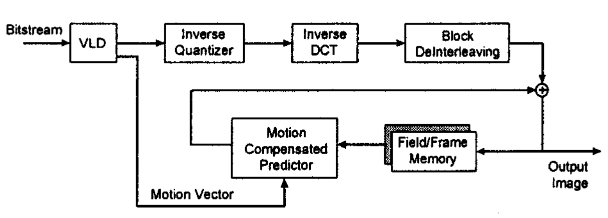
video codec as a framework for test and evaluation of error concealment algorithms. In Section 3, we discuss temporal-domain error concealment schemes based on simple temporal replacement and motion vector recovery. After we examine spatial-domain error concealment techniques based on linear interpolation in Section 4, we propose a new interpolation algorithm using directional information. In Section 5, we explain transform-domain error concealment methods. Finally, we provide simulation results and compare performances in Section 6.

2. Modified MPEG Video Codec

In MPEG, each picture is divided into slices, while each slice consists of several macroblocks. A macroblock (MB) contains 16 x 16 pixels, which is partitioned into 4 blocks. A block contains 8 x 8 pixels, over which the DCT/IDCT operation is performed.

In order to exploit the temporal redundancy in the video sequence, the motion vector for each MB is estimated from one or two anchor pictures [3]. Once the motion vector for each MB is estimated, pixel values for the target MB can be predicted from the previously reconstructed picture. All MBs in I-picture are coded in intra mode with no motion compensation. Macroblocks in P-picture and B-picture are coded in several different coding modes [1].

(a) Encoder



(b) Decoder

Figure 2: Modified MPEG Video Codec

In MPEG coded pictures, a single bit error in the bitstream could damage all the remaining MBs in the horizontal slice of the picture; therefore, information on some neighboring blocks around the lost block may not be available at the receiver. In order to reduce the effect of transmission errors, it would be better to separate the information of nearby blocks as far as possible during the encoding operation.

For efficient error concealment, we have modified the MPEG algorithm to incorporate block interleaving in the spatial domain, as shown in Figure 2. Encoding and reconstruction operations are jointly designed to achieve a good compromise among processing delay, error concealment capability, and reconstructed picture quality. To minimize the processing delay, a simple odd-even block interleaving scheme has been adopted [4].

Successive packets are first formed with the odd-indexed blocks in one slice of macroblocks, and then followed by the even-indexed blocks of the same slice. Figure 3 shows the process of packet transmission and the restored image when one packet is lost. When a packet containing the odd-indexed blocks is damaged, their adjacent even-indexed blocks are usually still available. With this block rearrangement, damaged blocks can be recovered effectively using the error concealment techniques described in the following sections.

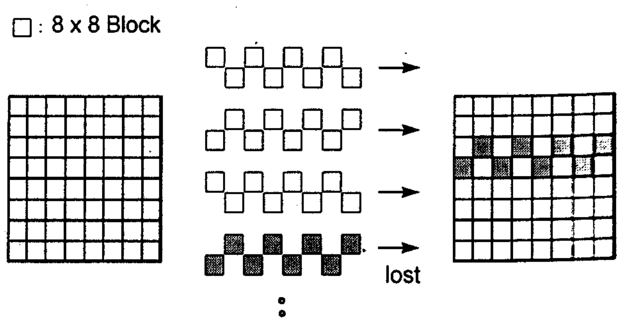


Figure 3: Block Interleaving and Packet Transmission

3. Temporal-Domain Error Concealment

Since most MBs in MPEG are coded in the motion-compensated coding mode, information on motion vectors are contained in the coded bitstream. When such motion vector information is lost during transmission, we can exploit inter-frame correlation to disguise transmission errors. In this section, we describe error concealment techniques based on simple temporal replacement and motion vector recovery in the temporal domain [5,6].

3.1 Temporal Replacement

A simple estimate for the lost motion vector is zero with an assumption that no motion has occurred between the previous and the current pictures.

For most video sequences with a still background, motion vectors have zero or small magnitudes. In such a situation, a simple temporal replacement would produce a reasonable approximation of the lost block. When a MB of the P-picture or B-picture is damaged, it can be replaced with the MB corresponding to the same location in the previous anchor picture, as shown in Figure 4 [1,5]. This scheme is not good for areas of significant movement.

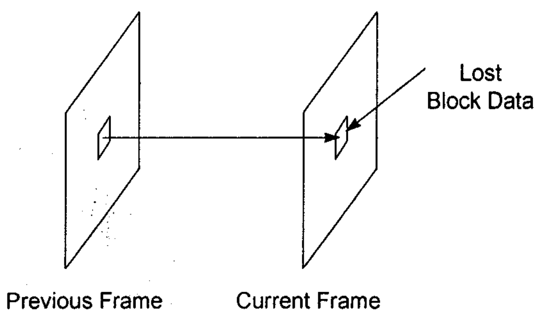
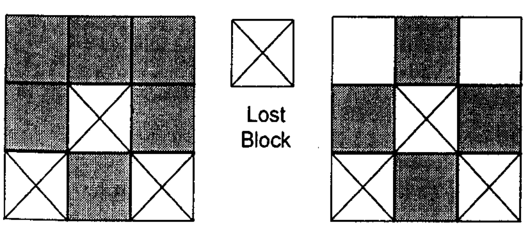


Figure 4: Temporal Replacement

3.2 Motion Vector Recovery

Since neighboring MBs in the picture often move together, we could exploit spatial correlation of motion vectors to recover the lost motion vector. Estimates for the lost motion vector can be obtained by taking the averaging or median operation on the motion vectors of surrounding MBs. In the averaging or median operation, we may include six neighbors or four neighbors, as shown in Figure 5. Experiments revealed that utilizing four vectors was more effective for obtaining a better motion vector.

Motion vectors are not homogeneous near object boundaries. Therefore, the averaging operation may lead to a false estimate. For distinct motion vectors, the median method is also vulnerable to noisy adjacent vectors and it often falls in a spurious estimate. Within objects having similar motion vectors with only small perturbations, these two methods show good performance; however, they do not work well near motion boundaries. In general, the median method is preferred to the averaging method.



(a) Six Vectors (b) Four Vectors

Figure 5: Average and Median Methods

4. Spatial-Domain Error Concealment

Since nearby pixel values are highly correlated, it is possible to recover information of the lost block by spatial-domain interpolation. The spatial-domain approach for error concealment is effective for areas of large motion, where temporal prediction is not successful. It is useful particularly for cell loss after scene changes. In this section, we discuss error concealment techniques based on linear interpolation in the spatial domain and propose a new scheme based on directional interpolation.

4.1 Linear Interpolation using Corner Pixels Only

This method is based on linear interpolation that replaces the lost data with linearly interpolated values, calculated from the neighboring corner pixel values of the same picture [6]. In Figure 6, $g_a(x_1, y_1)$, $g_b(x_1, y_2)$, $g_c(x_2, y_2)$ and $g_d(x_2, y_1)$ represent pixel values of the four corners outside the lost block. Due to block interleaving, those pixel values are assumed to be available at the receiver.

Interpolated pixel values within the lost block are calculated by the following formula :

$$g(x,y) = (1-t)(1-u)g_a(x_1,y_1) + (1-t)ug_b(x_1,y_2) + tug_c(x_2,y_2) + t(1-u)g_d(x_2,y_1) \quad (1)$$

where $t = (x - x_1)/(x_2 - x_1)$ and $u = (y - y_1)/(y_2 - y_1)$.

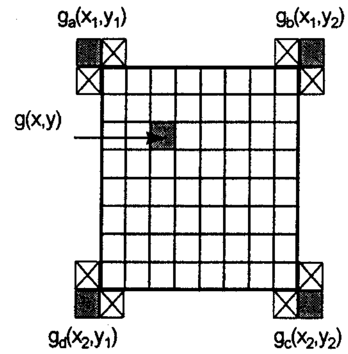


Figure 6: Simple Linear Interpolation

4.2 Linear Interpolation using Nearest Pixels

In this method, each pixel of the lost block is interpolated using the nearest pixels from the four neighboring blocks along the block boundaries [7]. In Figure 7, pixel values of the lost block are interpolated by the following formula:

$$b(i,k) = \frac{1}{d_L + d_R + d_T + d_B} \times (d_R b_L(k,1) + d_L b_R(k,N) + d_B b_T(1,i) + d_T b_B(N,i)) \quad (2)$$

where $b(i,k)$ is the interpolated pixel value, $b_x(i,k)$

represent values of the nearest pixels of the four neighboring blocks, and d_x is the distance between $b(i,k)$ and $b_x(i,k)$.

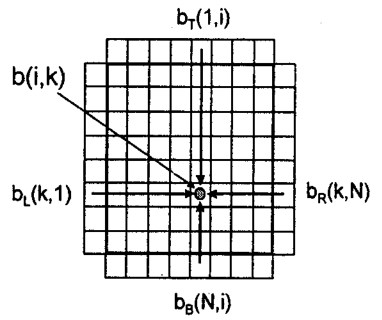


Figure 7: Linear Interpolation

4.3 Directional Interpolation

Since edge integrity plays an important role in human visual perception, we can utilize spatially correlated information more thoroughly by performing directional interpolation based on an edge orientation in the local neighborhood of the lost block [8,9]. We can restore image edges that are continuous with those present in the neighborhood by applying directional interpolation in the spatial domain, as explained in Figure 8.

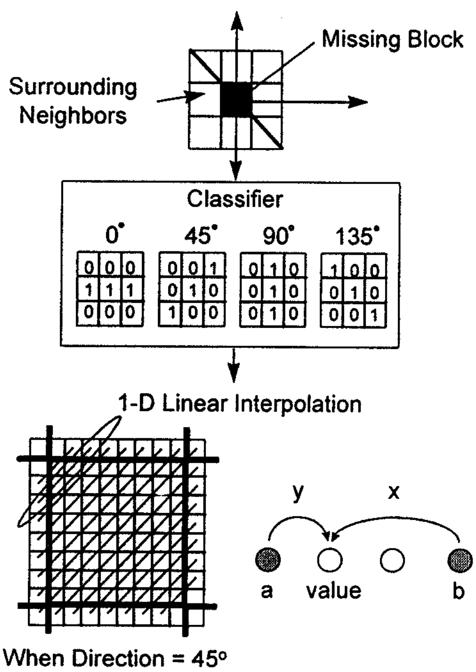


Figure 8: Directional Interpolation

The edge orientation of the lost block is estimated by convolving pixel values of the image blocks around the lost block with a set of predetermined directional masks and choosing the index of the mask that yields the maximum value. For the selected direction, a series of one-dimensional linear interpolations are carried out along the direction to obtain the pixel values of the lost block. Interpolated pixel values within the lost block are calculated by the following simple formula :

$$value = \frac{ax + by}{x + y} \quad (3)$$

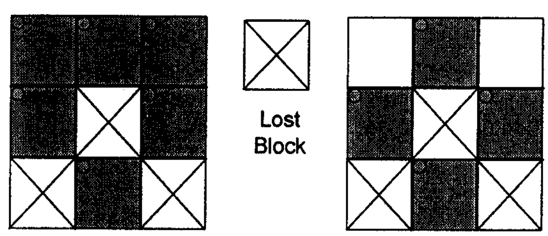
5. Transform-Domain Error Concealment

In MPEG, the original pixel blocks or motion-compensated residual error blocks are transformed into the DCT domain before quantization and coding. Since neighboring pixel blocks have similar characteristics in the spatial domain, their DCT coefficients have similar values. Due to this inter-block correlation, the DC and some AC coefficients of a lost block can be estimated from the DC values of its neighboring blocks. In this section, we discuss error concealment techniques in the transform domain by exploiting the inter-block correlation.

5.1 Estimation of DC Coefficient

Since the DC coefficient of a block represents the average pixel value of the block, a loss of the DC coefficient will affect the brightness or color of the corresponding block. There are several ways to recover the DC coefficient, if it is lost or damaged [5].

One estimate for the DC coefficient of a corrupted block is the simple average or median value of DC coefficients of the neighboring blocks. As in the case of motion vector recovery, we can include six neighbors or four neighbors in the averaging or median operation, which is illustrated in Figure 9. Taking four neighboring blocks for the DC estimate turns out to be more effective.



(a) Six Vectors (b) Four Vectors

Figure 9: Estimation of DC Coefficient

An alternative method for estimating the lost DC coefficient is to use the spatial-domain correlation of pixels along the block boundaries of the lost block. Rows of pixels directly adjacent to the corrupted block are more spatially correlated with that block than rows further away.

Since the DC coefficient is simply the average value of the 8 x 8 pixel block, each partial DC value is obtained by taking average of a shaded portion of each neighboring block, as shown in Figure 10.

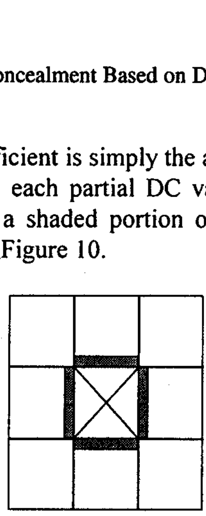


Figure 10: Partial DC Values

Partial DC values can be formed by averaging one, two, or four rows of pixels in adjacent blocks, whereas the true DC value of each adjacent block is the average of all eight rows of pixels within the block. Our experiment taking the partial DC value with just one row provides the best approximation of the true DC value of the lost block.

5.2 Estimation of AC Coefficients

Each DCT coefficient value of a block represents the signal magnitude of the associated basis vector present in the image block. The basis vectors associated with each frequency component for the 8-point DCT are shown in Figure 11 [10].

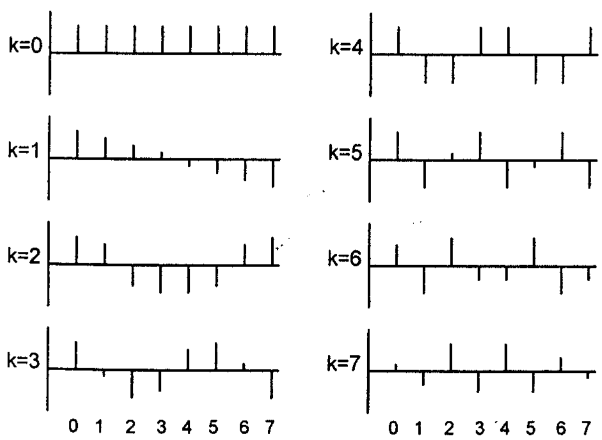


Figure 11: Basic Vectors of 8-point DCT Transform

An error in any DCT coefficient corresponds to adding too much or too little of the associated basis image to the image block during the reconstruction operation. Frequently, when an error occurs in some DCT coefficient, the basis image corresponding to the corrupted frequency component appears erratically in the reconstructed image block. If we replace the damaged coefficient with a reasonable estimate, the picture quality can be improved.

5.2.1 Low-Frequency AC Coefficients

Block-based image coding schemes, such as DCT coding, generally yield blocking effects at low bit rates partly due to insufficient bit allocation and partly due to independent processing of each block. Among various ideas, AC correction was proposed to compensate for the blocking artifacts [11,12,13]. In AC correction, the precision of AC coefficients is extended by estimating one or more additional bits of significance using the DC coefficients of nearby blocks, prior to inverse quantization and inverse transformation.

For error concealment applications, we adopt the idea of AC correction to obtain reasonable estimates for low-frequency AC coefficients. As illustrated in Figure 12, AC coefficients of the center block that is assumed to be lost are predicted as weighted sums of DC values of surrounding blocks.

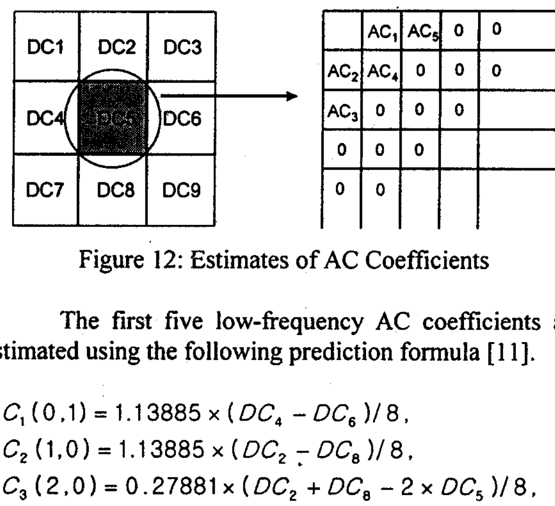


Figure 12: Estimates of AC Coefficients

The first five low-frequency AC coefficients are estimated using the following prediction formula [11].

$$AC_1(0,1) = 1.13885 \times (DC_4 - DC_6)/8,$$
$$AC_2(1,0) = 1.13885 \times (DC_2 - DC_8)/8,$$
$$AC_3(2,0) = 0.27881 \times (DC_2 + DC_8 - 2 \times DC_5)/8,$$
$$AC_4(1,1) = 0.16213 \times (DC_1 + DC_9 - DC_3 - DC_7)/8,$$
$$AC_5(0,2) = 0.27881 \times (DC_4 + DC_6 - 2 \times DC_5)/8$$

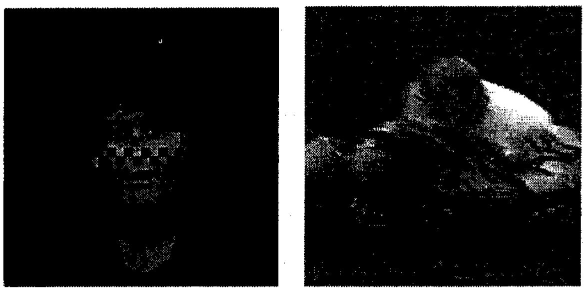
where DC_5 is obtained as the average of the DC values of surrounding blocks. In our experiment, we estimate AC(0,1), AC(1,0), AC(2,0) and AC(0,2) using only four DC values of the four neighboring blocks. Due to block interleaving, the other blocks are assumed unavailable.

5.2.2 High-Frequency AC Coefficients

High-frequency AC coefficients represent details of the image block. High-frequency coefficients of typical images have small magnitudes and their spatial correlation generally decreases rapidly with increasing frequencies. Therefore, without sacrificing too much in picture quality, we can assume erroneous high-frequency AC coefficients to be zero. Simply setting erroneous coefficients to zero above some frequency level is, sometimes, more effective than applying any other special concealment techniques.

6. Simulation Results

Computer simulations have been performed on both MISS AMERICA and FOOTBALL video sequences to test and evaluate performances of the error concealment algorithms explained in the previous sections. Numerical results are here compared in terms of PSNR values of restored images from the same lost data. Figure 13 shows damaged sample images, MISS AMERICA and FOOTBALL, by some lost packets.

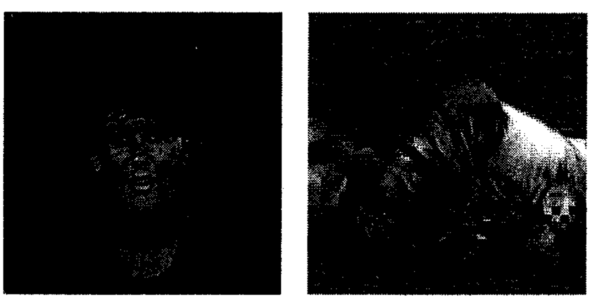


(a) MISS AMERICA (b) FOOTBALL

Figure 13: Damaged Images with Lost Packet

6.1 Temporal-domain Restoration

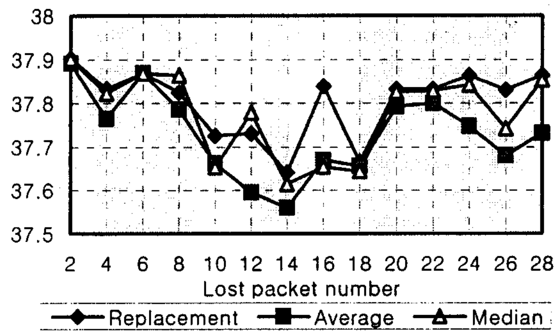
On the above two sample images, we have applied three temporal-domain error concealment methods: simple temporal replacement, averaged motion vector, and median motion vector. Figure 14 shows the restored images by estimating the motion vector as the median of motion vector of four adjacent blocks.



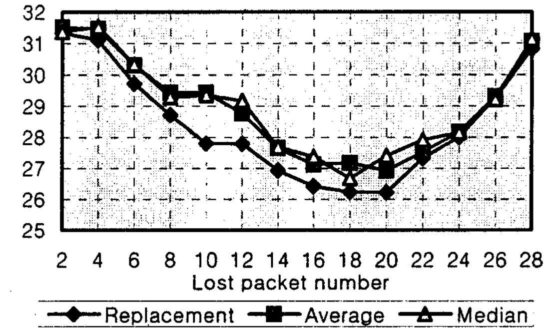
(a) MISS AMERICA (b) FOOTBALL

Figure 14: Restored Image in the Temporal Domain

Figure 15 shows PSNR values of restored images obtained by applying the three temporal-domain methods on MISS AMERICA and FOOTBALL that are damaged in different packet numbers, respectively. The range of the restored motion vectors is limited to [-8, +8]. As shown in this figure, the method using the motion vector estimated by the median operation yields the best performance.



(a) PSNR Values with MISS AMERICA

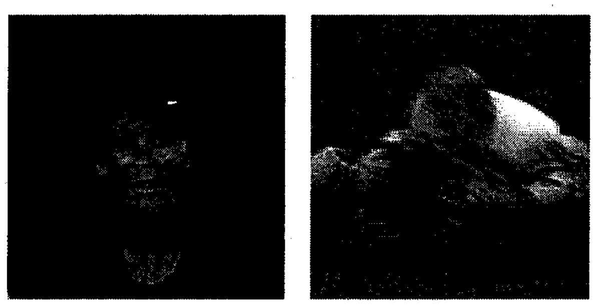


(b) PSNR Values with FOOTBALL

Figure 15: Comparison of Temporal-Domain Methods

6.2 Spatial-domain Restoration

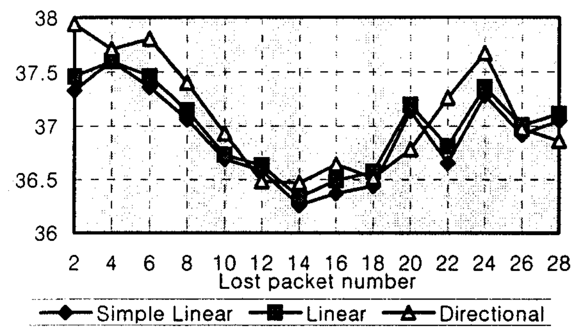
We have also applied the spatial-domain error concealment methods, explained in Section 4, on the same damaged sample images. Figure 16 shows the restored images using directional interpolation in the spatial domain. When surrounding blocks of the lost block have distinctive edges, the orientation classifier works well in determining the edge direction. Therefore, more consistent image edges are restored.



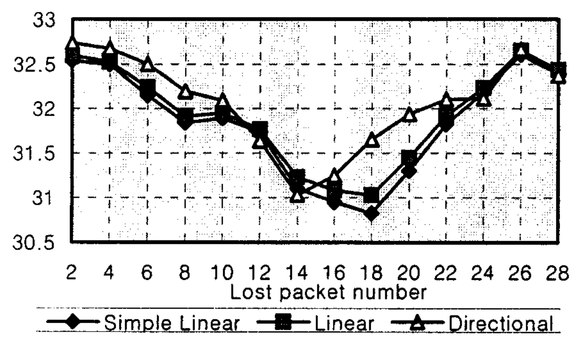
(a) MISS AMERICA (b) FOOTBALL

Figure 16: Restored Image in the Spatial Domain

In Figure 17, we compare performances of the three spatial-domain error concealment methods: linear interpolation using corner pixels, linear interpolation with nearest pixels, and directional interpolation. It is observed that restored images by directional interpolation have the best subjective quality, having virtually no blurring effects.



(a) PSNR Values with MISS AMERICA

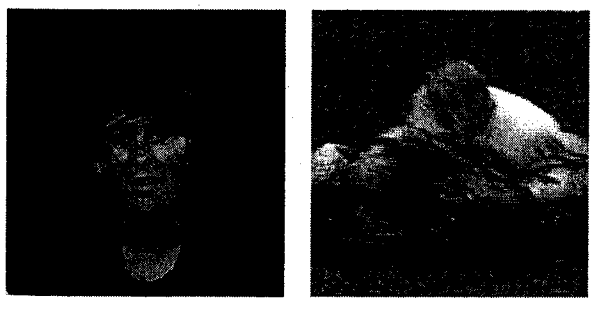


(b) PSNR Values with FOOTBALL

Figure 17: Comparison of Spatial-Domain Methods

6.3 Transform-domain Restoration

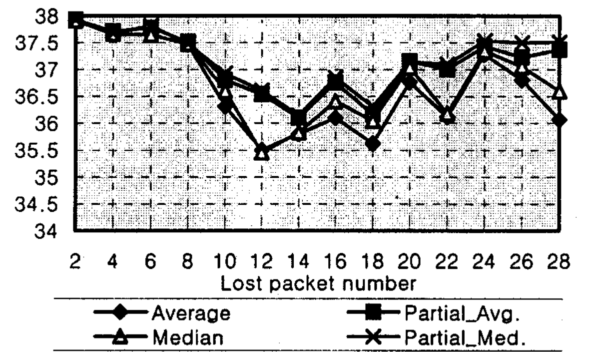
Figure 22 shows restored images with the estimated DC and four AC coefficients, as described in Section 5.



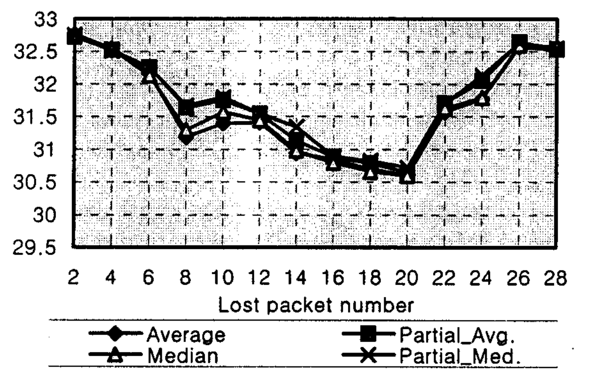
(a) MISS AMERICA (b) FOOTBALL

Figure 18: Restored Image in the Transform Domain

In this approach, restoration of the lost DC value is very important because it affects the restoration of four low-frequency AC coefficients. In Figure 19, we have compared performances of the four transform-domain error concealment methods: average or median of DCs of four neighboring blocks, average or median of partial DCs of four adjacent blocks. Due to inaccurate estimate of the DC value and insufficient number of AC coefficients, restored images in the transform domain lose some details. The method using the median value of the partial DCs of four neighboring blocks shows the best performance.



(a) PSNR Values with MISS AMERICA



(b) PSNR Values with FOOTBALL

Figure 19: Comparison of Transform-Domain Methods

7. Conclusions

In this paper, we have described various error concealment algorithms for MPEG video coding systems. Temporal-domain methods can provide good restored images by replacing the lost block with a data block in the previous picture frame. However, active areas of large motion can be restored more effectively by spatial-domain interpolation methods, which synthesize the lost data from the adjacent blocks in the same picture frame. In addition, transform-domain error concealment can be employed to restore the DC value and low-frequency AC coefficients of the damaged block.

In this work, we have also proposed a new method based on direction interpolation in the spatial domain and implemented several error concealment algorithms to evaluate their performances. Our experiment demonstrates that the spatial-domain concealment method based on directional interpolation provides consistently good results. This method can be combined with temporal-domain error concealment techniques to develop more effective error concealment techniques for compressed video signals.

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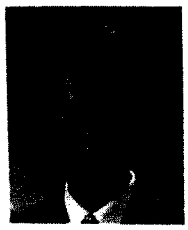
Biographies



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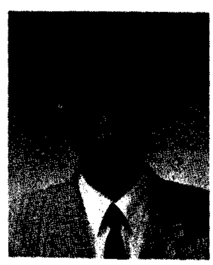

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