Error Concealment Techniques for MPEG Video Codec

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Abstract: Bitstreams generated by an MPEG video coder are very sensitive to channel errors. For instance, a single bit error in a coded video bitstream may cause severe degradations on picture quality. When bit errors that cannot be corrected by the employed error correction scheme occur during the transmission, 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 the spatial and temporal redundancies in the received and reconstructed video signals. In this paper, we describe several temporal and spatial-domain predictive error concealment techniques for MPEG coded pictures and propose a new scheme based on directional interpolation.

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 kb/s modem, it would take approximately 3.6 minutes for 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 needed. 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 MPEG video coding standard is a hybrid algorithm of motion compensation, discrete cosine transform (DCT), DPCM and variable-length coding (VLC) [1]. In the MPEG coding, the input sequence is first divided into groups of pictures (GOP), as shown 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 only, with no need for any previous or future information. It is used as an anchor for forward or backward prediction. P-picture is coded using one-directional 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](image)

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 is error correction, which offers perfect recovery from errors using structured codes, but it increases transmission overheads. The second is error concealment, which 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 consider temporal-domain error concealment techniques based on simple temporal replacement or motion vector recovery. For I-pictures where no motion information exists, we apply spatial-domain error concealment techniques based on linear interpolation or directional interpolation.

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 different coding modes [1].

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, the information of all the neighboring blocks of the lost block cannot be available. In order to isolate the effect of transmission errors, we should 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 reconstruction quality. To minimize the processing delay, a simple odd-even block interleaving scheme has been adopted [4].

![Diagram of Modified MPEG Codec](image)

(a) Encoder

![Diagram of Modified MPEG Codec](image)

(b) Decoder

Figure 2: Modified MPEG Codec

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 a 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 following error concealment techniques.

![Diagram of Block Interleaving and Packet Transmission](image)

Figure 3: Block Interleaving and Packet Transmission

3. Temporal-Domain Error Concealment

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

![Diagram of Temporal Replacement](image)

Figure 4: Temporal Replacement

3.2 Motion Vector Recovery

We can also exploit spatial correlation of motion vectors by noting that neighboring blocks of the picture often move together. Estimates for lost motion vectors can be found by taking the average or median values of the surrounding motion vectors. For the averaging or median operation, we may include four neighbors or six neighbors, as shown in Figure 5. Experiments revealed that utilizing four vectors was more effective [5].

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 provide good performance; however, they are not working well near motion boundaries. In general, the median method is preferred to the averaging method.
4. Spatial-Domain Error Concealment

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 values of the same picture [6]. In Figure 6, \( g(x_1, y_1), g(x_2, y_2), g(x_3, y_3) \) and \( g(x_4, y_4) \) represent pixel values of the four corners outside the lost block. Due to block interleaving, these values are assumed to be available at the receiver.

\[
g(x, y) = (1-t)(1-u)g(x_1, y_1) + (1-t)ug(x_2, y_2) + nug(x_1, y_2) + n(1-u)g(x_2, y_1)
\]

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

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:

\[
b(i, k) = \frac{1}{c_1 + c_2 + c_3 + c_4} \times (c_1b_1(k, i) + c_2b_2(k, N) + c_3b_3(1, j) + c_4b_4(N, i))
\]

where \( b(i, k) \) is the interpolated pixel value, \( b_1(i, k) \) represent values of the nearest pixels of the four neighboring blocks, and \( d_x \) is the difference between \( b(i, k) \) and \( b_x(i, k) \).

4.3 Directional Interpolation

Since edge integrity plays an important role in human visual perception [8], 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. 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.

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 spatial interpolations are carried out along the direction to recover the pixel values of the lost block.

5. Simulation Results

Computer simulations have been performed on both still images and video sequences to 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.

In Figure 9 and Figure 10, three temporal-domain error concealment methods are compared: simple temporal replacement, averaged motion vector, and median motion vector. They show PSNR values obtained with MISS AMERICA and FOOTBALL, respectively. The range for
motion vectors is limited to [-8, +8]. As shown here, the median motion vector method yields the best performance.

Figure 9: PSNR Values (MISS AMERICA)

In Figure 10 and Figure 12, three spatial-domain error concealment methods are compared: linear interpolation using corner pixels, linear interpolation with nearest pixels, and directional interpolation. They show PSNR values obtained with MISS AMERICA and FOOTBALL, respectively. When surrounding blocks of the lost block have distinctive edges, the orientation classifier works well in determining the edge direction. Therefore, we can restore more consistent image edges. It is observed that restored images by directional interpolation have the best subjective quality, having virtually no blurring effects.

Figure 10: PSNR Values (FOOTBALL)

6. Conclusions

In this paper, we described various algorithms for error concealment in video coding systems. Temporal-domain error concealment techniques provide good results in stationary areas; however, significant degradations were noticed in areas of fast movement. In contrast, spatial-domain error concealment techniques restore lost data based on the information of the adjacent image blocks, they have potential problems of blocking or blurring effects due to insufficient information available. Our directional interpolation method shows consistent and good results.

References