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Title: Error Concealment for MPEG Video over ATM

Purpose: Information and discussion

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1. Summary:

Error concealment for amelioration of cell loss events is a key enabling technique for ATM video. The ATM cell loss rate (CLR) at which impairments become visible in the decoded image is central to network design principles, particularly for systems supporting VBR video. Early work on ATM systems had often been based on a reference CLR requirement of 10^{-9} for video; since then, it has become clear from work done by a number of organizations that ATM CLR in the region of 10^{-3} to 10^{-5} may be acceptable for many compressed video applications, with further improvements possible with two-tier layering. This contribution presents some recent error concealment results for MPEG-1 source coding with and without code-stream prioritization. The MPEG compression algorithm is supported by an appropriate transport/adaptation format [1] which reliably detects cell loss/error and helps identify the picture area in which the compressed information was lost.

In order to demonstrate the performance of error concealment, an MPEG-1 compressed bitstream was passed through an end-to-end simulation of an ATM-type cell-relay communications system example. Both one and two layer transmission formats corresponding to 1-priority and 2-priority scenarios were considered. One layer results are for constant bit-rate (CBR) video following MPEG-1 syntax, while two layer results utilize appropriate bit-stream prioritization enhancements for an 80:20 high-priority:standard-priority (CBR) bit-rate ratio [2]. Note that the particular example simulated is not strictly ATM/BISDN compatible, although it is representative of transport over cell-relay based transmission media. Demonstration tapes showing error concealment performance of MPEG compressed data over packet networks at relevant cell loss rates are provided.

2. Error Concealment Algorithm:

2.1 Introduction

Receiver error concealment is intended to ameliorate the impact of lost video data by exploiting available redundancy in the decoded picture. Once the image region (i.e., macroblocks, slices, etc.) to be concealed are identified, a combination of temporal and spatial replacement techniques may be applied to fill in the lost picture elements. The specific details of the concealment procedure will depend upon the compression algorithm being used, and on the level of algorithmic complexity permissible within the decoder.

In MPEG compression, video frames to be coded are formatted in groups-of-pictures (GOP) consisting of a sequence intra-coded (I), predictive-coded (P) and bidirectionally predictive-coded (B) frames. Intra-coded (I) frames are encoded spatially and used as anchor frames for motion-compensated forward prediction of P frames and forward/backward prediction of B frames. This structure of MPEG implies that if an error occurs within I frame data, it will propagate through all frames in the Group of Pictures (GOP). Similarly, an error in a P-frame will affect the related P and B frames, while B-frame errors will be isolated. Therefore, it is desirable to develop sophisticated error concealment techniques to prevent error propagation from I-frames and, consequently, to improve the quality of reconstructed pictures.

There are two approaches which have been used for I-frame error concealment: temporal replacement and spatial interpolation. Temporal replacement can provide high resolution image data as the substitute to the lost data; however, in motion areas a significant difference might exist between the current intra-coded frame and the previously decoded frame. In this case, temporal replacement will produce large distortion unless some motion-based processing can be applied at the decoder. However, this type of processing is not always available since it is a computationally demanding task. In contrast, a spatial interpolation approach synthesizes the lost data from the adjacent blocks in the same frame. In spatial interpolation the intra-frame redundancy between blocks is exploited, while a potential problem of blurring remains due to insufficient high order DCT coefficients for active areas. To address this problem, an adaptive error concealment technique has been developed and evaluated. In the proposed scheme, corrupted macroblocks are first indicated by the error tokens. Then, the decision regarding which concealment method (temporal replacement or spatial interpolation) should be used is based on easily obtained measures of image activity from the neighboring (i.e., top and bottom) macroblocks. If local motion is smaller than spatial detail, the corrupted blocks belong to class A on which temporal replacement is applied; when local motion is greater than local spatial detail, the corrupted blocks belong to class B and will be concealed by spatial interpolation. The overall concealment procedure consists of two stages. First, temporal replacement is applied to all corrupted blocks of class A through whole frame. After the temporal replacement stage, the remaining unconcealed damaged blocks of class B are more likely to be surrounded by valid image blocks. A stage of spatial interpolation is then performed on them. This will now result in less blurring, or the blurring will be limited to smaller areas. Therefore, a good compromise between distortion and blurring can be obtained. This algorithm uses some simple measures, obtainable at the decoder, to adapt between spatially and temporal concealment modes. This strategy is also useful for P and B frames. However, for P and B frames the more efficient concealment is the temporal replacement with motion compensation. When the motion vectors are lost, they are resumed from the top and bottom good neighbors.

2.2. Error concealment

The decoder applies an error concealment algorithm which is supported by the transport-level error detection and video re-entry features of the proposed structure. The error concealment approach implemented by the decoder is summarized below:

(a) Detect cell (packet) errors using the cyclic redundancy check code (CRC), and identify the spatio-temporal position of MPEG slices which are in error.

(b) Discard received video data corresponding to macroblocks and/or slices received in error.

(c) For two-layer MPEG transmission, low priority errors which result in the loss of DCT coefficients are handled by forcing EOB's in affected macroblocks. Sometimes, low priority errors (mostly in P or B frames) may result in high level data loss, such as macroblock type, motion vectors ..., the lost macroblocks are replaced by a pseudo code (no-code, no-quant, etc.) with motion resumed from top or bottom MBs;

(d) For high-priority errors (or for one-layer transmission), each errored macroblock is replaced with an estimate from the surrounding spatial region and/or the previous frame by the adaptive error concealment algorithm;

(e) Estimates for lost macroblocks are obtained using an appropriate adaptive algorithm which exploits an appropriate combination of spatial data and/or temporal data with motion information.

It is remarked here that error concealment is a decoder design option, and possible approaches span a range of complexity and performance.

3. Simulation Results

Simulation results obtained from a detailed end-to-end model that incorporates MPEG compression/decompression and a custom cell-relay (ATM type) transport format are reported briefly. The experimental results (both objective and subjective) show that a reasonable quality of reconstructed pictures can be obtained on one-tier transmission media with packet/cell loss rates as high as 0.1%. The numerical results are shown in Fig.1 to Fig4 and the subjective results are summarized in the table 1.

A demonstration tape showing the end-to-end performance of the described system with error concealment is also provided. The results shown in the tape are:

(a) System performance at cell loss rate (CLR) = 10^{-3}, with:
- no transport priorities (one-layer transmission)
- no error concealment.

(b) System performance at cell loss rate (CLR) = 10^{-3}, with:
- no transport priorities (one-layer transmission)
- adaptive error concealment algorithm.

(c) System performance at cell loss rate (CLR) = 10^{-4}, with:
- no transport priorities (one-layer transmission)
- adaptive error concealment algorithm.

(d) Two-layer system performance at low priority cell loss rate (LP-CLR) = 1.33×10^{-3}, with:
- two transport priorities (HP/LP) with 25% data HP
- adaptive error concealment algorithm.

(e) Two-layer system performance at low priority cell loss rate (LP-CLR) = 1.33×10^{-4}, with:
- two transport priorities (HP/LP) with 25% data HP
- adaptive error concealment algorithm.

[1] CCITT/MPEG document AVC-139 "Transport and Error Concealment for MPEG-2" dated Nov. 1991.

[2] FCC WP1 Certification Document, “Advanced Digital Television: Prototype Description”, Feb. 1992.

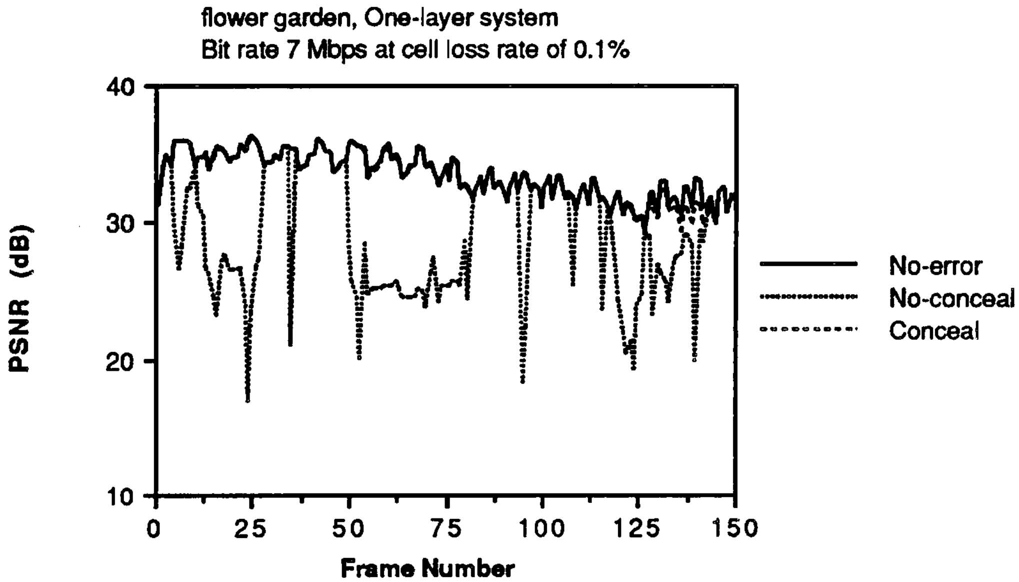
flower garden, One-layer system
Bit rate 7 Mbps at cell loss rate of 0.1%
PSNR (dB)
40
30
20
10
0
25
50
75
100
125
150
Frame Number
No-error
No-conceal
Conceal

Fig.1

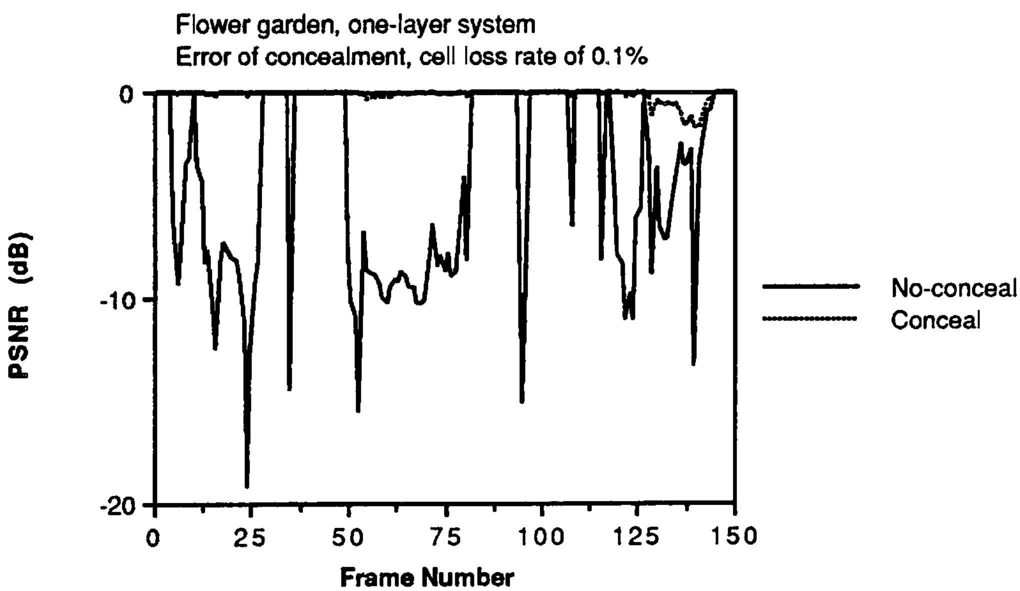
Flower garden, one-layer system
Error of concealment, cell loss rate of 0.1%
PSNR (dB)
0
-10
-20
0
25
50
75
100
125
150
Frame Number
No-conceal
Conceal

Fig.2

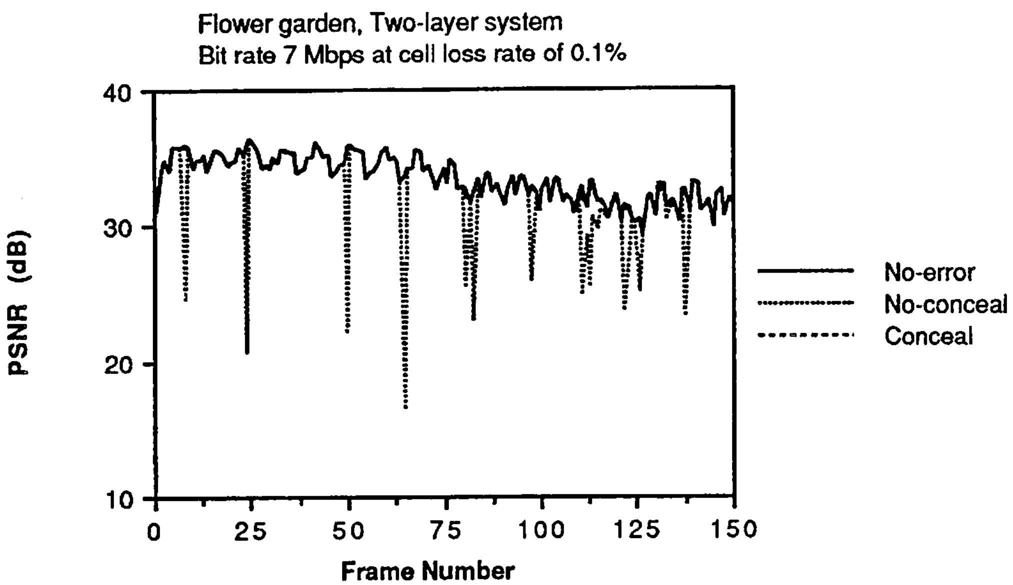
Flower garden, Two-layer system
Bit rate 7 Mbps at cell loss rate of 0.1%
PSNR (dB)
40
30
20
10
0
25
50
75
100
125
150
Frame Number
No-error
No-conceal
Conceal

Fig.3

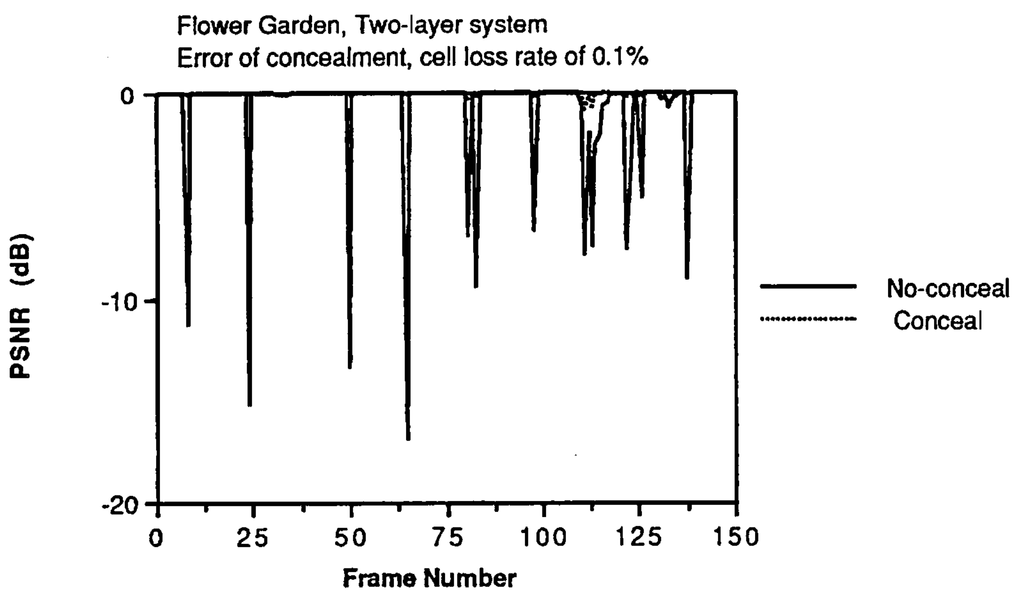
Flower Garden, Two-layer system
Error of concealment, cell loss rate of 0.1%
PSNR (dB)
0
-10
-20
0
25
50
75
100
125
150
Frame Number
No-conceal
Conceal

Fig.4