CERIAS Tech Report 2001-114

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ABSTRACT

When compressed video is transmitted through a data network, such as an ATM or a wireless network, data can be lost due to channel errors and/or congestion. Techniques that post-process the received video and conceal the errors in real-time are needed. In this paper we describe an implementation of error concealment techniques on the Texas Instruments *TMS320C6201* (*'C6201*) digital signal processor.

1. INTRODUCTION

In data networks, cell or packet loss due to channel errors or congestion can cause data to be lost in the channel. When MPEG compressed video is transmitted, cell loss causes macroblocks and motion vectors to be removed from the compressed data stream. Two issues need to be addressed to alleviate this problem: finding the location of the missing data, and processing the sequence to recover the missing data. A frame from an MPEG sequence with missing macroblocks before and after error concealment is shown in Figure 1.

Recently, a great deal of work has been done in developing robust image and video coding techniques that include error concealment and resilience [1, 2, 3, 4]. The goal of error concealment is to exploit redundant information in a sequence to recover missing data. Two approaches have been used: *active concealment* and *passive concealment* [5]. In active concealment, error control coding techniques and retransmission are used to recover errors [6], while in passive concealment, the video stream is post-processed to reconstruct the missing data. Passive concealment is necessary in many applications where active concealment cannot be used due to compliance with video transmission standards or when active concealment fails.

All video decoders that will be used in consumer applications, such as set-top decoder boxes, must implement some form of passive concealment. This problem is interesting in that it absolutely requires real-time implementation. Digital signal processors (DSPs), such as the Texas Instruments *TMS320C6201* (*'C6201*), are well suited for the demands of real-time processing, typical of error concealment. The *'C6201* is a fixed-point DSP based on the VelociTI architecture. The VelociTI architecture is a high-performance, very-long-instruction-word (VLIW) architecture developed by Texas Instruments [7].

This work was supported by a grant from Texas Instruments. Address all correspondence to E. J. Delp, ace@ecn.purdue.edu, http://www.ece.purdue.edu/~ace, +1 765 494 1740. This paper is available at: ftp://skynet.ecn.purdue.edu/pub/dist/delp/pcs99.

(a) (b)

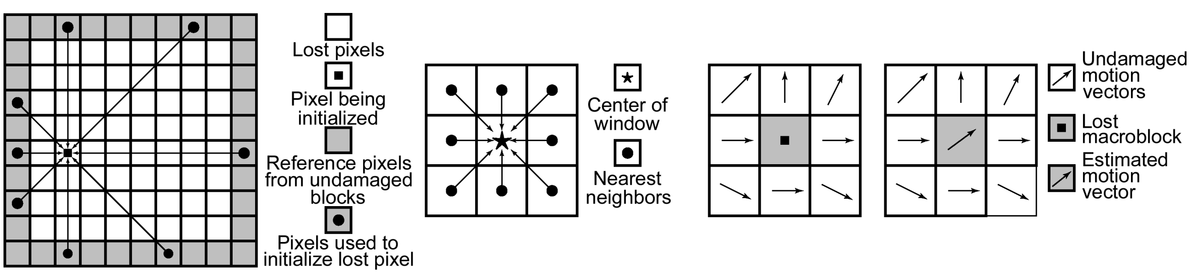
Figure 1. (a) Spatial error concealment. Left: Missing macroblocks. Right: Recovered errors.
(b) Temporal error concealment. Left: Missing macroblocks. Right: Recovered errors.

In [8, 9], several spatial and temporal techniques for the reconstruction of missing data from MPEG sequences are discussed. Each frame is modeled as a Markov Random Field, and a maximum *a posteriori* (MAP) estimate of the missing macroblock data and motion vectors is obtained [10]. A nearly optimal spatial approach that approximates the MAP estimate of each missing pixel by the median of its neighbors was presented in [11]. In our work, this nearly optimal technique is implemented for spatial concealment using a DSP.

2. ERROR CONCEALMENT ON THE *TMS320C6201* DSP

2.1 Spatial error concealment

The objective of this work is to implement the concealment technique in [11] on the *'C6201*. For our initial experiments, we simulated the data channel by randomly dropping 8x8 blocks of pixels from uncompressed grayscale frames. Our spatial technique is based on median filtering, consisting of two stages: initialization and filtering, as shown in Figure 2(a). During initialization, a 3x3 median filter is used to obtain an initial estimate for each of the lost pixels in a block. The pixels in the neighboring undamaged blocks are used as a reference to form the estimate. In the second stage, a 3x3 median filter is used to smooth the pixels in the lost block, using the 8-nearest neighbors.



(a) (b)

Figure 2. (a) Spatial error concealment. Left: Initialization stage. Right: Filtering stage.
(b) Temporal error concealment. Left: Neighboring motion vectors. Right: Estimated motion vector.

A block diagram of the system used in our initial experiments is shown in Figure 3. A *'C6201*-based hardware system from Spectrum Signal, the Detroit processor, was used as the computational engine. This system uses a PC as host, communicating through the PCI bus. Video is digitized using a Matrox Corona system and transferred to the Detroit processor, where the frames are processed. At this time, the overall system is running at 10 – 15 frames/second on 640x480 size video sequences.

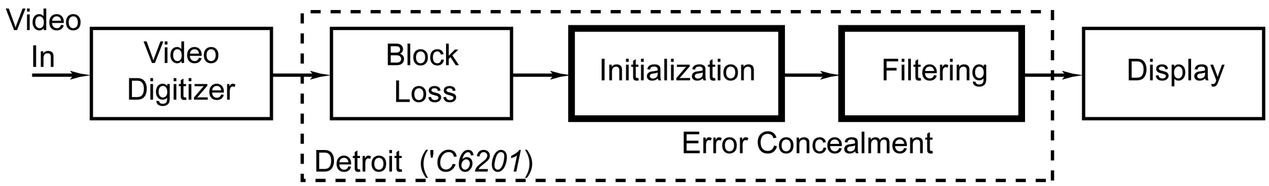


Figure 3. Block diagram of the spatial error concealment system.

2.2 Temporal error concealment

Temporal error concealment techniques that use information from previous frames to recover errors in a current frame can also be implemented on the *'C6201*. The lost information can include motion vectors and macroblocks. A simple approach is to copy the macroblock at the same spatial location of the missing macroblock in the previous frame [12]. This is useful in sequences with low degree of motion. To reduce distortion in sequences with high motion, more elaborate techniques need to be used. In these approaches, the lost data is recovered by estimating the missing motion vector and/or macroblock. In [11], an estimate of the missing motion vector is obtained by searching for the vector that maximizes the *a posteriori* distribution of the boundary pixels of the lost macroblock given its neighbors. Another approach is to estimate the missing motion vector by obtaining the median [9] or average [13] of the motion vectors of neighboring undamaged motion vectors.

In [9], it is shown that using the median of the neighboring undamaged motion vectors compares favorably to averaging. This is the technique chosen for our proposed implementation on the *'C6201*. The reference frame and neighboring undamaged motion vectors are required for this implementation. Each dimension of the motion vectors from neighboring macroblocks is considered separately. The resulting motion vector is used to replace the motion vector in the damaged macroblock, as shown in Figure 2(b).

3. IMPLEMENTATION ISSUES

We envision an implementation scenario where error concealment is a module of an MPEG decoder. Our spatial technique will be used on I frames with isolated damaged macroblocks, using information from the current frame only. When adjacent macroblocks are damaged, a modified temporal technique, such as the one described in [9], can be used. In P frames and B frames, only our temporal technique will be used. Reference frames are necessary for the temporal technique, therefore the error concealment module must have access to the frame buffer used by the motion compensation module of the decoder.

In implementing the error concealment on the *'C6201,* several issues need to be addressed. To obtain the highest performance with the spatial technique, the neighboring pixels need to be transferred into internal data memory. Both initialization and filtering stages are data intensive, thus the high penalty of accessing external memory locations must be avoided. The data and computational requirements for the temporal technique are lower than those in the spatial technique, because only the neighboring undamaged motion vectors are needed. Another issue is the limited amount of on-chip memory available on the *'C6201* (64 Kbytes). A frame must be partitioned into sections, and each section transferred into internal data memory as needed. Direct memory access is used for all block data transfers to increase efficiency. Data transfers must occur while computation is being performed to maximize overlapping.

In our initial experiments, we have determined that a single 200MHz *'C6201* is needed for the implementation of the spatial technique. To reconstruct a missing block, each pixel is median filtered twice. Our implementation of the median filter executes in 130 cycles, thus being capable of processing up to 89 frames/second. Because the computational requirements of our temporal technique are lower, a single *‘C6201* would be required in our implementation scenario. The operations are based on integer values. This is also the case for other tasks within an MPEG decoder, such as motion compensation [14]. Therefore, there is an advantage in using a fixed-point DSP because of the low latency of the instructions. All arithmetic and logic operations we use in the *‘C6201* are single-cycle. Thus, the combination of a fast clock cycle and lower cost makes the use of the *‘C6201* very attractive for this class of applications.

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