SECOND-GENERATION ERROR CONCEALMENT FOR VIDEO TRANSPORT OVER ERROR PRONE CHANNELS*

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ABSTRACT

Video transport over error prone channels may result in loss or erroneous decoding of the video. Error concealment is an effective mechanism to reconstruct the video content. In this paper, we review different error concealment methods and introduce a new framework, which we refer to as *second-generation error concealment*. All the error concealment methods reconstruct the lost video content by making use of some *a priori* knowledge about the video content. *First-generation error concealment* builds such *a priori* in a heuristic manner. The proposed *second-generation error concealment* builds the *a priori* by modeling the statistics of the video content. Context-based models are trained with the correctly decoded video content, and then used to replenish the lost video content. Trained models capture the statistics of the video content and thus reconstruct the lost video content better than reconstruction by heuristics.

1. INTRODUCTION

When transmitting video data over error prone channels, the video data may suffer from losses or errors. Error concealment is an effective way to recover the loss information due to the transmission errors at the decoder. Compared to other error control mechanisms such as forward error correction (FEC) [1] and automatic retransmission request (ARQ) [2], error concealment has the advantages of not consuming extra bandwidth as FEC and not introducing retransmission delay as ARQ. Error concealment can also be used together with FEC and ARQ when both FEC and ARQ fail to overcome the transmission errors [3].

Error concealment needs to be preceded with some error detection mechanism to locate the error region in the decoded video [4][5]. In this paper, we assume that the error region is located so we focus on the reconstruction of the lost video data. In general, spatial, spectral or temporal redundancies of the received video data are utilized to perform error concealment [6]. Hybrid or dynamic switching of spatial/temporal error concealment methods is also possible [7]-[9]. In this paper, we will review these error concealment methods.

All error concealment methods reconstruct the lost video content by making use of some *a priori* knowledge about the video content. Most existing error concealment methods, which we refer to as *first-generation error concealment*, build such *a prior* in a heuristic manner by assuming smoothness or continuity of the pixel values etc. The proposed *second-generation error concealment* methods train context-based models as the *a prior*. Methods of such a framework have advantages over first-generation error concealment, as the context-based model is created specifically for the video content hence can capture the statistical variations of the content more effectively.

This paper is organized as follows. In Section 2, we review *first-generation error concealment* by providing a survey of conventional error concealment methods. We introduce the new framework of *second-generation error concealment* in Section 3. We conclude in Section 4.

2. FIRST-GENERATION ERROR CONCEALMENT

First-generation error concealment methods build the *a priori* for reconstructing the lost video content in a heuristic manner. A simple example is to assume the pixel values to be smooth across the boundary of the lost and received regions. Methods of this framework assume smoothness or continuity of the video data in different domains such as spatial, spectral, temporal, or some transforms of these domains. To recover lost data with the smoothness assumption, interpolation or optimization based on certain objective functions are often used. Since first-generation error concealment methods perform error concealment with such heuristic knowledge, we also call them *heuristic-based error concealment* methods.

First-generation error concealment methods fall into two categories: spatial/spectral and temporal, as follows.

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2.1. Spatial/Spectral Error Concealment with Interpolation

Spatial error concealment assumes that images are smooth in nature. Lost image content can be reconstructed by interpolating from neighboring pixels. Work by Wang et al. [10] and Hemami and Meng [11] are earlier examples of using spatial interpolation to accomplish the task of error concealment. However, spatial interpolation approaches often suffer from blurring in the edge regions of the image. Several approaches have been proposed to resolve this problem. Suh and Ho [12] proposed to find edges first and interpolate along the edge direction. Zhu et al. [13] proposed to use a second-order derivative-based method to reduce the blur across the edge while enforcing the smoothness along the edge. Zeng and Liu [14] proposed to perform directional interpolation based on neighbor's geometric structure. Robie and Mersereau [15] proposed to use the Hough transform to determine the best orientation for either directional filtering or interpolation. Not only can interpolation be applied to the spatial domain, but also to the spectral domain such as the discrete cosine transform (DCT) domain, as proposed by Chung et al. [16]. Some other methods are based on projection-onto-convex-sets (POCS) that iteratively uses the smoothness assumption and pixel or DCT value range information for error concealment [17][18].

An extension to the assumption that natural images are smooth and the values are continuous spatially or spectrally is to adopt the Markov random fields (MRF) to model the images [19]. MRF based error concealment methods were first proposed by Salama et al. [20]-[22]. Later Shirani et al. [23] proposed to adaptively adjust the MRF model parameters but not to increase the model order and showed that the adaptive MRF outperforms MRF methods. Multiscale MRF (MMRF) by Zhang and Ma [24] is another extension of MRF. MMRF models image blocks instead of image pixels. Work by Zhang et al. [25] models the DCT coefficients as a first-order Markov process and uses Laplacian distribution to model the density function of the DCT coefficients.

2.2. Temporal Error Concealment with Motion Vector Estimation

Temporal error concealment methods use the temporal neighbor, that is, previous frame or next frame, to conceal the loss of the current frame. Temporal error concealment methods assume the video content to be smooth or continuous in time. A basic approach is to replace the lost block of the current frame with the content of the previous frame in the same block location. A better approach is to replace the lost block with the content of the previous frame at the motion-compensated location. With such a temporal error concealment scheme, motion vectors are utilized to find the corresponding block location in the previous frame. However, in the process of transmission, motion vectors can be lost as well. Without motion vectors, temporal error concealment with motion compensation cannot be achieved. Therefore, techniques to estimate the lost motion vectors were widely discussed. Boundary matching algorithm (BMA) proposed by Lam et al. [26] is a popular method to estimate lost motion vectors. Extensions to BMA can be found in [27]-[30]. Decoder motion vector estimation (DMVE) proposed by Zhang et al. [31][32] treats the loss of motion vectors as a motion estimation problem, in the decoder instead of in the encoder. Motion field interpolation (MFI) and its extensions proposed by Al-Mualla et al. [33][34] estimates the motion vectors from neighbors with single or multiple reference frames. Furthermore, Lee et al. [35] extended translational block motion to affine transform for motion-compensated error concealment.

3. SECOND-GENERATION ERROR CONCEALMENT

Second-generation error concealment builds the *a priori* by training a context-based model for an *object* or *region of interest* (*ROI*) and uses the model to recover the lost data. With object-based video coding standards such as MPEG-4 [36], the video bitstream already contains ROI information, which makes second-generation error concealment possible. In case the ROI information is not available in the video bitstream, object trackers can be used to extract the ROI information. Since the context-based model is created specifically for the object, it can capture the statistical variations of the object effectively, and yield good concealment result. Since second-generation error concealment methods train and apply context-based models for error concealment, we also call them *model-based error concealment* methods.

Principal component analysis (PCA) has been widely used to model objects or ROI. The most well known example is eigenface [37], where the face images can be modeled well with PCA. Figure 1 shows an example of using PCA to model face images with a mean and two eigenvectors. The mean captures the average face appearance and the eigenvectors characterize variations such as pose or expression variations.

(a) (b) (c)

Figure 1. PCA for face images: (a) mean; (b) 1st eigenvector; (c) 2nd eigenvector

With PCA as the model of the object statistics, we can train the PCA model, i.e., the mean and eigenvectors, from correctly decoded data in the ROI. Then, we project any corrupted ROI to the PCA model to recover the lost portion of the ROI. Using face images as an example of ROI, we illustrate such error concealment in Figure 2. The PCA model in ② is trained in advance. The corrupted ROI in ① is projected to the PCA model to get the recovered ROI ③.

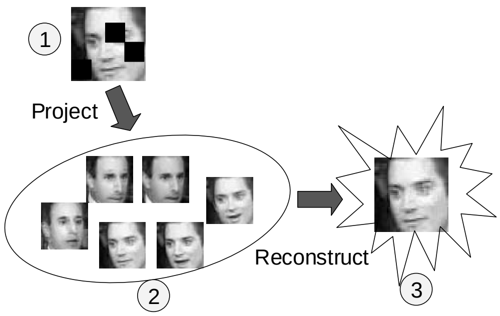

Figure 2. Error concealment with PCA

POCS can also be adopted with the PCA modeling of the object. Error concealment based on POCS formulates each constraint about the unknowns as a convex set. The optimal solution is obtained by iteratively projecting a previous solution onto each convex set. The projections refer to (1) projecting the data with some losses to the PCA model that is built on error-free data, and (2) replacing the reconstructed data from the first projection with the correctly received data in the corresponding region. Illustration of POCS based error concealment with PCA is shown in Figure 3. The PCA model in ② is pre-trained with correctly decoded ROI. Any corrupted ROI in ① is projected to the PCA model to obtain the recovered ROI ③. After the reconstructed ROI ③ is obtained, the region in ③ where the data was originally correctly decoded is replaced with the correctly decoded data. The result is projected again to the PCA model and so on until the reconstruction result is satisfactory.

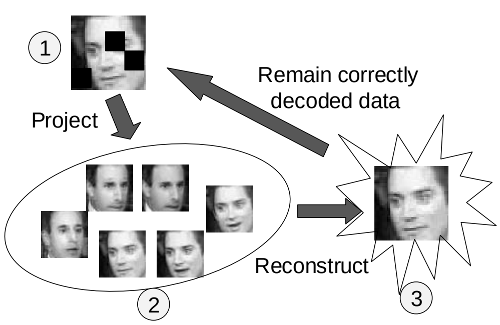

Figure 3. POCS based error concealment with PCA

Interested readers can refer to the work in [38][39] for model-based error concealment with mixture of principal components (MPC) and updating mixture of principal components (UMPC) respectively. MPC and UMPC are extensions of PCA modeling of the ROI content. In addition to the capability of PCA to capture the statistical variations of the ROI content, MPC can model the multi-modal characteristic of the data. UMPC can further adapt with the non-stationary nature of the ROI content.

In addition to PCA, MRF model can also be used for model-based error concealment. Shirani et al. [40] proposed to use an appropriate form of MRF to model the shape information of MPEG-4 video. The MRF parameters are obtained from the edge directions of the neighbors. A Maximum A Posteriori (MAP) estimation gives the most likely reconstruction result given such an MRF model. Furthermore, model-based error concealment can use models that were originally proposed for model-based video coding. These include 3-D model based approaches where a 3-D model of the object appearance is built before coding and 2-D model based approaches that use deformable segmentation of the image and affine motion models. A fine overview may be obtained by Aizawa and Huang [41] and Pearson [42].

Temporal model-based error concealment is also possible. The object or ROI information is provided by either the video bitstream or some object tracker. Models can be built for motion vectors. For example, eigenflow proposed in [43] can be used to model motion vectors and reconstruct any lost motion vectors. The recovered motion vectors can then be used for temporal error concealment.

5. CONCLUSION

In this paper, we proposed a new second-generation error concealment framework. Second-generation error concealment methods train and reconstruct the lost video content by context-based modeling and thus provide better error concealment results than heuristic-based error concealment methods.

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