ERROR CONCEALMENT IMPROVEMENTS FOR MPEG-2 USING ENHANCED ERROR DETECTION & EARLY RE-SYNCHRONIZATION

Susanna Aign

German Aerospace Research Establishment (DLR)
Institute for Communications Technology, D-82234 Oberpfaffenhofen, Germany
Tel.: +49 8153 28-2862, Fax: +49 8153 28-1442, e-mail: Susanna.Aign@dlr.de

ABSTRACT

For digital TV-transmission the video signal has to be highly protected by channel coding, since it is very sensitive to channel disturbances. However, in the case of bad reception conditions, remaining errors in the video signal may still occur. Hence, error concealment techniques might be required at the receiver. The aim of this article is to study different error concealment techniques for MPEG-2 video sequences by exploiting the remaining error-free part of the bitstream as much as possible. This is done by combining an enhanced error detection of the channel decoder with early re-synchronization. In I-pictures, where no motion vectors (MVs) exist, the gain for early re-synchronization with enhanced error detection compared to other techniques is up to 2.3 dB.

1. INTRODUCTION

For digital TV-transmission (cable, satellite, and terrestrial) an efficient compression algorithm is needed due to the bandwidth restriction of the available channels. A suitable source coding algorithm for these applications will be based on MPEG-2 [1]. However, the MPEG-2 source coded stream is very sensitive to channel disturbances. For instance, a single bit error can cause error propagation into several macroblocks due to the use of variable length coding. Those errors may propagate into several pictures due to predictive coding. If an error occurs in a header code, the receiver may risk receiving nothing.

There are several ways for handling channel errors. The first solution is to employ error correction coding. Another way for handling channel errors is the use of hierarchical source and channel coding. However, in the case of terrestrial transmission, which is considered in this article, at very long distances or at the worst reception conditions, i.e. deep fades or impulsive noise, residual errors may occur.

To enhance the picture quality even if there are residual errors in the bitstream, one may apply error concealment techniques at the receiver. These techniques will be applied at the receiver side without changing the encoder. For error concealment measures, reliable error detection is needed. One method involves the use of the error detection capability of the source decoder. However, with this technique many errors remain undetected. Therefore, another error detection technique should be considered. The channel coding for terrestrial transmission is based on a concatenated coding scheme with an outer systematic Reed-Solomon (RS) code and an inner convolutional code [2]. The outer RS(204,188)-codewords are adapted to the MPEG-2 Transport Packets of length 188 bytes. First, the outer RS-decoder can give some information about the reliability of each RS-word, but the RS-words are very long. To exploit the correct information in one erroneous packet, the reliability outputs of an inner Soft Output Viterbi Algorithm (SOVA) may be helpful [3, 4].

The aim of this article is to study different error concealment techniques in the MPEG-2 video decoder with enhanced error detection, taking into account a real transmission medium by modeling the errors of the whole terrestrial transmission scheme [4]. There are two main solutions for error concealment: The first one is to re-synchronize the bitstream after the occurance of an error at *slice-level* and to conceal the lost macroblocks with a suitable method (section 2.). This is the simplest way: After an error occurs, the information of the rest of the slice is discarded and correct re-synchronization is achieved at the next slice. The second method is to try to re-synchronize the bitstream *before* the next slice and to make use of the majority of the correct received data [5, 6]. Since some of the parameters are differentially encoded, those parameters have to be concealed also for the re-synchronized macroblocks (section 3.). Simulation results are given in section 4. and finally section 5. is devoted to conclusions.

2. ERROR CONCEALMENT TECHNIQUES

Temporal error concealment (TEC) techniques exploit the temporal redundancy in a sequence. They will be applied usually to B- and P-pictures, where MVs are available. In addition, they are much simpler than the other ones.

Different TEC techniques for inter-coded pictures (P- and B-pictures) are investigated in this article. The first one, called simple temporal error concealment (**S-TEC**), repeats the MBs of the previous anchor picture (I- or P-picture) in the current picture, where errors were detected. The drawback of S-TEC is, that shifts will be visible in the picture, if there is motion.

The second method, in addition, uses the MVs from the surrounding MBs in the current picture (if MVs exist). This method is called motion compensated TEC (**MC-TEC**). There are several ways for the MV selection, where three different techniques are considered here. The first one uses the MVs and the respective technique from one *nearest* MB (MC-TEC-1) [7]. The second technique takes into account the MVs of all the surrounding (existing) MBs and incorporates the lost MBs with the possible MVs (also the median MVs and no MVs are considered here) (MC-TEC-2). The best matching MB is chosen following the minimum mean square error (MMSE) criterion of the border pixels for each field. The technique (frame/field, which field is used) for incorporating the MB with the median value is selected from the technique of the surrounding MBs, where the criterion for the chosen technique is again the MMSE of the border pixels. This is applied iteratively, where no MVs are only considered for the last iteration. The third technique is similar to the second one, except that the median value is not considered (MC-TEC-3).

For I-pictures only S-TEC may be applied since no MVs are available. Therefore, a *spatial error concealment* (**SEC**) technique is considered here. The pixel values of the missing MB are concealed by interpolating the surrounding border pixels. In addition, a combination of SEC and S-TEC in I-pictures (*combined error concealment* **CEC**) [8] is applied.

3. EARLY RE-SYNCHRONIZATION

By applying *early re-synchronization*, the decoder tries to exploit the remaining correct received bits before the next slice_start_code for error concealment. In [5] a method for re-synchronizing the bitstream is given. The decoder starts to decode an MB at the current position in the bitstream to check if an MB can be decoded or not. If the MB is not detected as wrong from the source/channel decoder error detection, the decoder will continue either until the next slice_start_code or until another error is detected. If the MB is declared as wrong, then the decoder will repeat decoding the MB by starting one bit after the last position.

Here, the correct received MBs will be grouped into subslices, where each subslice contains all the MBs which are correctly decoded consecutively after re-synchronization. If the subslice contains only one MB, the search is started one bit after the beginning of the MB to improve the re-synchronization process, since it is most probably, that this MB is not correctly re-synchronized. The subslice having one MB will be discarded.

Additionally, since the first few MBs of a subslice may not be re-synchronized correctly (for instance DC and AC-values), in I-pictures, the subslices are further divided before positioning, if neighbored MBs of one subslice do not fit. If the following smoothness criterion between two consecutively decoded $2N \times 2N$ MBs mb_s and mb_{s+1}

$$mse = \frac{1}{2N} \sum_{i=1}^{2N} \left((mb_s(i, 2N) - mb_{s+1}(i, 1))^2 \right) \qquad (1)$$

lies below a certain threshold, the subslice is not divided, otherwise the subslice is divided at this location. This technique avoids wrong MBs at the beginning of a subslice.

However, especially in I-pictures several informations will be lost if one decodes an MB without having decoded the previous one. Therefore, the following parameters have to be looked at carefully: i) the *quantizer_scale_factor*, ii) the *DC-value* (I-pictures), iii) the *MVs* (P/B-pictures), and iv) the *MB-address*.

The first parameter, which is coded in most of the MBs, will be concealed with the previously decoded one to prevent a *really wrong* quantizer_scale_factor. The DC-value is differentially encoded. If an MB after the occurrence of an error is re-synchronized correctly, all corresponding successive DC-values might be wrong if the *first* DC-value is wrong. A good way for obtaining an estimate of the first DC-value of a subslice is to minimize the DC coefficient difference between each lost block and its immediate vertical neighbor(s) [6]. The drawback of this method is that some errors may still occur in the picture domain if there are errors in the differential DC-values at the beginning of a subslice. This error will propagate through the whole subslice. Therefore, another technique will be applied in this article (section 3.1.).

The MVs are also differentially encoded. For MV concealment the technique described in section 3.2. is used. The MB address is coded in increments so that the correct location of the re-synchronized MB will not be known. Therefore, a positioning technique such as that described in [6] or that proposed in section 3.3. might be applied. Finally wrong re-synchronized MBs have to be discarded and the remaining lost MBs have to be further concealed (section 3.4.). This can be also applied iteratively (section 3.5.).

3.1. Correction of DC-values in I-pictures

The DC-value of the whole subslice is corrected before positioning by the following algorithm: The mean DC-value of the top and the bottom neighbored MB(s) of the current subslice will be computed as follows:

$$\overline{DC}_{T/B} = \frac{1}{4n_{ss}} \sum_{s=1}^{n_{ss}} \left(DC_{b2_{T_s}} + DC_{b3_{T_s}} + DC_{b0_{B_s}} + DC_{b1_{B_s}} \right), \quad (2)$$

where $DC_{bi}, i = 0 \dots 3$ is the DC-value of the i-th luminance-block (Y) of the corresponding MB (Top or Bottom). The DC-correction for the chrominance (U and V) is computed for only one block due to the 4:2:0-format. In the case of lost MBs the DC-value of those MBs will not have some influence on equation 2. The mean DC-value of the MB(s) of the current subslice is computed as:

$$\overline{DC} = \frac{1}{4n_{ss}} \sum_{s=1}^{n_{ss}} \left(DC_{b0_s} + DC_{b1_s} + DC_{b2_s} + DC_{b3_s} \right). \quad (3)$$

The DC-values are then corrected with the difference of the mean DC-values:

$$\Delta = \overline{DC} - \overline{DC}_{T/B}, \qquad (4)$$

where this value is simply added to the $2N \times 2N$ pixel-values in the spatial-domain. With this technique wrong DC-value propagation is compensated and as many as possible re-synchronized MBs are used within the subslice. In addition the positioning technique will be more reliable with this DC-correction. Another possibility to avoid wrong DC-values is to discard the first few MBs. But with this technique some MBs will be discarded although the AC-coefficients will be correctly received. Therefore, it is better to apply the DC-value correction to make use of more correct received data.

3.2. Concealment of the MVs in P/B-Pictures

The critical parameters within P- and B-pictures are the *step-size* and the *MVs*. Since the step-size (macroblock address increment) in P- and B-pictures may have a value which is greater than one, an error in the step-size may result in too many decoded MBs. To avoid this, a step size, which is greater than one, is only allowed after two correctly decoded MBs in a subslice. With this, the re-synchronization process will be better and the results will be the same, since with step-size greater than one the MBs are skipped and the previous picture is copied at this place which yields same results as S-TEC. It may nevertheless occur, that there are more MBs decoded than there exist in a slice. If this occurs the subslices with a small length are discarded until the number of decoded MBs is less or equal to the number of missing MBs. Another criterion for finding correct decoded MBs is introduced: if the decoded MB has no MV data and no block data, this MB is seen as a wrong MB. These constraints help finding correct decoded MBs.

The MVs are encoded differentially. Therefore, the MV predictors of the first MB in a subslice have to be concealed. Since the MVs differ in the spatial domain the best way is to take the nearest MV of the neighboring MBs, since there the correlation is high. The minimization of the MV difference between each lost MB and its immediate vertical neighbors like the computation of the DC-value [6] will fail, since the motion may differ within a slice and the MV data in the first few MBs in a subslice may be wrong and this will result in wrong MV concealment. In this paper the MV of the first MB of a subslice is concealed with the mean value of the available MVs of the top and bottom neighboring MB. The mean value is computed for field and frame vectors since field and frame motion compensation is used. The MV difference of the first few MBs of a subslice may be wrong. Therefore, the MV concealment is computed for the first, the second and the third MB of a subslice, where the MBs before the concealed MBs are discarded. The best MV concealment is chosen by computing the bounding mean square error.

3.3. Subslice positioning

The technique employed here is the following: first the MBs, which are decoded before the next slice_start_code, will be located at the end of the slice. Then, the longest subslices are located before the smaller subslices. This has the advantage that the long subslices can be well located with some smoothness constraints, whereas shorter subslices (e.g. with only one MB) do not constrain the positions of the longer subslices. Indeed, the probability of a correct re-synchronization is higher for long subslices than for shorter ones. The best location for the subslices is the location with the minimum mean square error (MMSE) between the neighbored pixels. In the case of interlaced pictures, the MMSE is computed for each field.

3.4. Discarding wrong macroblocks and further error concealment

At the end of the positioning, there will be several subslices available which contain only few MBs and which are sometimes incorrect (e.g. wrong AC-coefficients) due to wrong re-synchronization, that should be deleted. The criterion for deleting them is the MSE of the border pixels of the MB if it is under a certain threshold. This is only applied to subslices with slice-length less than three. It is also possible to discard all the subslices with slice-length less than three without measuring the MSE which yields similar results, since usually the subslices with short slice-lengths are not correctly re-synchronized. As mentioned before, the subslices are divided into smaller subslices by applying the smoothness criterion (1), therefore, the first few wrong MBs of such a subslice are split into short subslice(s) and will be also discarded with this technique.

In the case of burst errors there are sometimes more than one slice consecutively disturbed, where no correct MBs can be used for positioning and DC-correction. If there are less than 10 percent of the surrounding MBs correct, the subslice will be discarded.

The deleted MBs have to be further concealed. As concealment technique one can use the previously mentioned techniques: S-TEC, MC-TEC, SEC, or CEC.

3.5. Iterative Concealment

To improve the concealment techniques in regions where more than one slice is disturbed, the algorithms can be applied iteratively. For early re-synchronization subslices, which have no neighbored MBs at the beginning, can then be positioned, if the neighbored subslices are already concealed. The MV data and the pixel-values of the concealed MBs can be used for the subslices which have no neighbored MBs in the first iteration.

4. RESULTS

Different error concealment techniques with and without early re-synchronization for different types of pictures (I, P, B) are investigated in this article. The pictures of a video-sequence (5 Mbit/s) were disturbed with the channel model [4] with 20 error patterns at different packet error rates. Simulation results for I-pictures are given in Figure 1 for the MPEG-2 coded sequence *Flower*. Three different error concealment techniques are considered for I-pictures: S-TEC, SEC, and CEC. The results with the early re-synchronization are symbolized with 're-sync'. The values for the picture without errors are given in brackets. Also results for the use of a shorter slice-length (22, 11, and 4 MBs) are given.

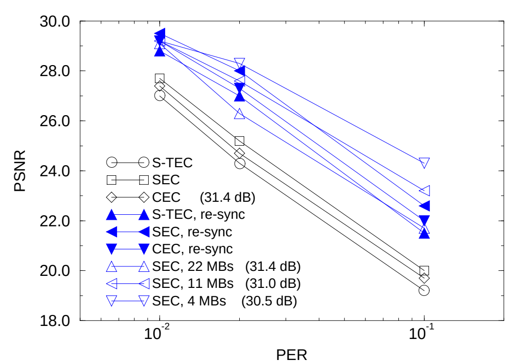

Figure 1. PSNR-comparison *Flower*, I-pictures

The simulation results show that the PSNR-values for early re-synchronization is up to 2.3 dB higher than the PSNR-values for error concealment without early re-synchronization. The use of a shorter slice length results in similar or better results, but the quality at the same bitrate will be slightly reduced. Figure 2 shows one I-picture disturbed with $PER = 10^{-1}$ without error concealment, Figure 3 shows the early re-synchronization technique without error concealment of the remaining lost MBs, and Figure 4 shows the CEC with early re-synchronization.

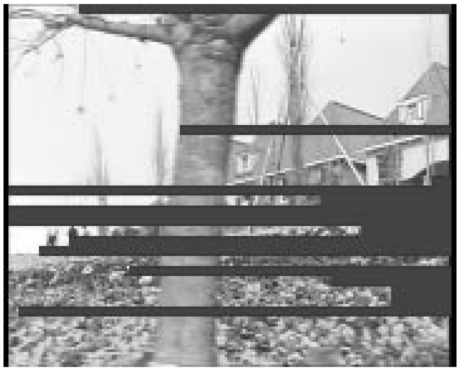

Figure 2. I-picture, no EC, $PER = 10^{-1}$

Figure 3. I-picture, no EC, re-sync

Figure 4. I-picture, CEC, re-sync

The results for P/B-pictures for different techniques are given in Figures 5 and 6. These results show that MC-TEC-1 performs better than MC-TEC-2/3. This is because the use of frame/field MVs for error concealment depends strongly on the technique with which the motion compensation was done (forward/backward, field_select). Therefore, the use of the median value will be not efficient. The results of early re-synchronization are not better than MC-TEC-1, since a wrong MV concealment results in error propagation of the whole subslice or until the MVs in a subslice are reset, where with MC-TEC-1 only one MB is effected. The use of shorter slices gives better results, but the influence of the reduced picture quality can be seen mainly for B-pictures.

5. CONCLUSION

Different error concealment techniques have been investigated in this article. The results show that early re-synchronization in combination with the use of reliability

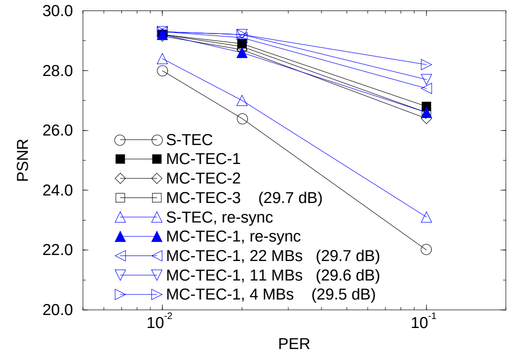

Figure 5. PSNR-comparison *Calendar*, P-pictures

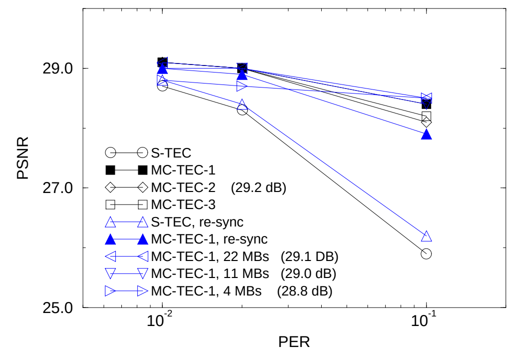

Figure 6. PSNR-comparison *Calendar*, B-pictures

outputs of the channel decoder is a very good technique to make use of correct data as much as possible. The knowledge of the exact location of the errors is helpful for re-synchronization. Therefore, it is worthwhile to use early re-synchronization with enhanced error detection.

Acknowledgement: I would like to thank C. Le Buhan from EPFL for useful advice.

REFERENCES

[1] "MPEG-2 video, audio and systems international standard." ISO-IEC/JTC1/SC29/WG11 MPEG 94, Nov. 1994.

[2] K. Fazel, S. Kaiser, P. Robertson, and M. Ruf, "A Concept of Digital Terrestrial TV-Broadcasting," *Wireless Personal Communications Journal*, vol. 2, no. 1 & 2, pp. 9–27, 1995.

[3] J. Hagenauer and P. Hoeher, "A Viterbi algorithm with soft-decision outputs and its application," in *Proc. IEEE Globecom'89*, vol. 3, pp. 47.1.1–47.1.7, Nov. 1989.

[4] S. Aign, "Error concealment enhancement by using the reliability outputs of a sova in MPEG-2 video decoder," in *Proc. ISSSE'95*, pp. 59–62, Oct. 1995.

[5] S. Lee, J. S. Youn, S. H. Jang, and S. H. Jang, "Transmission error detection, resynchronization, and error concealment for MPEG video decoder," in *Proc. SPIE'93*, vol. 2094, pp. 195–204, 1993.

[6] C. Le Buhan, "Software embedded data retrieval and error concealment scheme for MPEG-2 video sequences," in *Proc. SPIE'96*, vol. 2668, Feb. 1996.

[7] S. Aign and K. Fazel, "Error detection & concealment measures in MPEG-2 video decoder," in *Proc. Int. Workshop on HDTV'94*, Oct. 1994.

[8] S. Aign, "Adaptive temporal & spatial error concealment measures in MPEG-2 video decoder with enhanced error detection," in *7th Tirrhenian Workshop on Digital Communications, Signal Processing in Telecommunications*, Springer, Sept. 1995.