INTER-SEQUENCE ERROR CONCEALMENT FOR DIVERSITY RECEPTION OF DIGITAL TV SEQUENCES

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ABSTRACT

In this paper a new technique for error concealment of digital TV signals in a diversity reception scenario is proposed. Inter-sequence error concealment utilizes one or more reference sequences to reconstruct lost image blocks or slices of a video sequence. Based on the general approach of image combination for uncompressed video sequences, inter-sequence error concealment of coded TV sequences is evaluated in detail. The presented technique especially considers error propagation by motion-compensated prediction in hybrid video coding. The algorithm for error concealment is introduced on example of DVB-T signals which are transmitted in multi-frequency networks. In practice, applications like multi-standard-reception of DVB-T, DVB-H and T-DMB seem also natural.

1. INTRODUCTION

Digital Video Broadcasting - Terrestrial (DVB-T) is a standardized technique for terrestrial transmission of digital TV signals and data services. Audio and video signals are usually coded according to the MPEG-2 specification. However, MPEG-4 is employed for source coding occasionally. In a DVB-T transmission scenario, several multimedia signals can be combined in a so called multiplex. Elementary streams are hereby packetized according to the first part of the MPEG-2 standard which is called *Systems*. Resulting transport stream packets are protected against transmission errors by a two-stage channel coding scheme. Finally, a physical signal is generated by *Orthogonal Frequency Divison Multiplexing* (OFDM) which is broadcasted in a *Single Frequency Network* (SFN) or a *Multi Frequency Network* (MFN).

Despite the existence of several competing broadcasting standards, DVB-T is dominating the terrestrial transmission of *Digital TV* (DTV). According to the DVB consortium, DVB-T is deployed in over 70 countries worldwide. Until now, over 73 million receivers have been sold. About 16 million thereof have been distributed in Germany by the end of 2008. DVB-T thus is a popular and widely-used TV standard. Although it was developed for portable and stationary reception originally, DVB-T is recently adopted in mobile scenarios as well. One reason behind it is the hesitant employment of new TV standards like DVB-H or T-DMB which are especially optimized for mobile reception. Considering mobile scenarios, bad reception conditions typically exist by signal reflections, shadowing effects, and the relative movement of the receiver relating to the broadcasting station. As a result the carrier frequency shifts and the quality of the received field strength drops. Visual artifacts are therefore introduced during the video decoding process. Assuming a block-based video coder, block and slice losses typically occur.

Up to now, temporal or spatial error concealment techniques have been applied to reconstruct erroneous image parts from neighbouring image information. Well-known algorithms for temporal error concealment are the *Boundary Matching Algorithm* (BMA, [1]) and the *Decoder Motion Vector Estimation* (DMVE, [2]). Temporal approaches use image information of prior and partly even subsequent frames to conceal distorted image blocks. In detail, BMA is based on the minimization of edges which are typically inserted at the borders between reconstructed and neighbouring error-free image parts. In DMVE, reconstructed image parts are determined by maximization of similarity between neighbouring image sectors of loss and candidate blocks. Spatial error concealment techniques as the *Frequency-Selective Extrapolation* (FSE, [3]) and the *Bilinear Interpolation* ([4]) only utilize spatial image information for the reconstruction of distorted image blocks. The latter one is also referred as *H.264Intra* in literature ([5]). Whereas H.264Intra is based on the interpolation of adjacent error-free image information, FSE reconstructs the spatial frequency spectrum of surrounding image samples. Results of latest research show that spatio-temporal error concealment techniques can further enhance the image quality of reconstructed image parts. Examples are the *Content-Based Adaptive Spatio-Temporal Method* (CABLR, [6]) and the *Spatio-Bi-Temporal Fading Scheme* (SBTFS, [7]).

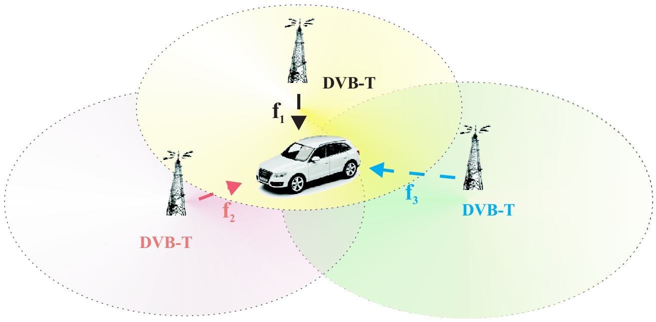

Figure 1: Diversity reception of DVB-T signals in a multi frequency network on example of in-car TV

Currently, *In-Car TV* based on DVB-T is an emerging market. Vehicles equipped with TV receivers usually have several tuners and even more antennas. Those diversity receivers can improve the image quality in SFNs. SFNs are characterized by synchronous transmission of identical physical signals at the same frequency by several transmitters. At a car-mounted receiver, for example, several signals superimpose and contribute to better reception conditions. Using a diversity receiver, the image quality of received TV sequences can be enhanced by choosing the best signal being received at different antennas.

In the future, a rise of image quality for erroneously-received DVB-T sequences is conceivable also in MFN scenarios. In MFNs, TV sequences are simultaneously broadcasted by several transmitters at different frequencies. Identical physical signals are therefore not mandatory as superposition is frequency-selective at the receiver. Even identical bitstreams can not be assumed because of varying parameters for video coding and error protection. Considering a diversity receiver with more than one decoding unit, multiple versions of a particular TV sequence can be received in a MFN. Fig. 1 shows such a diversity reception of DVB-T sequences on example of mobile in-car reception. In case of transmission errors, digital TV sequences contain block and slice losses after decoding.

Due to different transmission channel characteristics in MFNs, deviating spatial and temporal distributions of lost image parts can be assumed for corresponding representations of a TV sequence.

Inter-Sequence Error Concealment (ISEC) uses one ore more reference sequences to reconstruct lost image parts of a video sequence. In [8], the concept of ISEC was first introduced for a distorted high-resolution sequence with high image quality like a DVB-T signal. A corresponding *error-free* low-resolution sequence with low image quality like a DVB-H or T-DMB signal is utilized as a reference sequence for ISEC. The reference is assumed to be error-free as mobile TV standards usually specify enhanced error protection mechanisms. The focus of [8] therefore is on the alignment of image resolutions. In [9], we apply the concept of ISEC to delayed TV sequences. Thus, emphasis is especially put on synchronization of multi-broadcasted TV sequences.

In this paper, we extend the concept of inter-sequence error concealment to several *distorted* representations of a TV sequence having identical image resolutions. The algorithm is introduced on example of DVB-T signals being multiple-received in MFNs. As diversity reception in MFNs shows only weak correlation for block and slice losses of multiple-received TV signals, error concealment by combining several distorted representations of a particular TV sequence is promising. However, the combination step has to be carried out during the video decoding process as corresponding bitstreams of a multiple-received TV sequence can differ in MFNs. In this paper, the focus therefore is on the image combination of coded video signals especially considering error propagation by motion-compensated prediction in hybrid video coding.

2. ERROR CONCEALMENT OF MULTIPLE-RECEIVED TV SIGNALS

Considering multiple-received DVB-T signals, two or more representations of a particular TV sequence are available. In this paper, we will focus on inter-sequence error concealment utilizing two corresponding TV sequences which have identical image resolutions, identical frame rates, and comparable visual quality. As indicated before, both representations typically contain lost image parts. The concealment problem is symmetric if both sequences have comparable visual quality. However, for simplified description of the proposed algorithm, we choose the sequence containing less errors and denote it as *Selected TV Sequence* (STVS) in the following. The second sequence is used as a reference and is therefore abbreviated as *Reference TV Sequence* (RTVS). To guarantee powerful inter-sequence error concealment of the STVS based on image combination utilizing the RTVS, the properties of multiple-received TV signals have to be examined in general. Images of DVB-T signals are usually characterized by a high spatial resolution and a pleasant visual quality. However, TV signals can be delayed against each other in diversity reception scenarios due to sender-side processing times or varying propagation delay. Another reason is given by transmitters which are not synchronized.

Fig. 2 shows the general approach of the proposed error concealment technique as a flow diagram. It can be divided into three main steps: preprocessing, image combination and postprocessing. Corresponding images of both sequences STVS and RTVS are denoted as $A(m,n,t)$ and $B(m,n,t)$ where $m \in \{1,...,M\}$ and $n \in \{1,...,N\}$. In case of delayed signals STVS and RTVS each frame has to be temporally registered. In [9], a technique for the synchronization of video signals is proposed which shows high detection rates and low synchronization error for high image quality. The algorithm is robust against deviant image resolutions, image cropping and block or slice losses. This is mainly based on the utilization of a numerical optimization technique. As we assume identical image resolutions in our scenario, the synchronization technique can be used in a simplified version in case of delayed TV sequences. For example, the mean squared error (MSE) of error-free image parts can be minimized over time for a given search range. After synchronization, corresponding images can be combined. In detail, we replace distorted image parts of frame $A(m,n,t)$ of the selected TV sequence with corresponding error-free image information of frame $B(m,n,t)$ of the reference TV sequence.

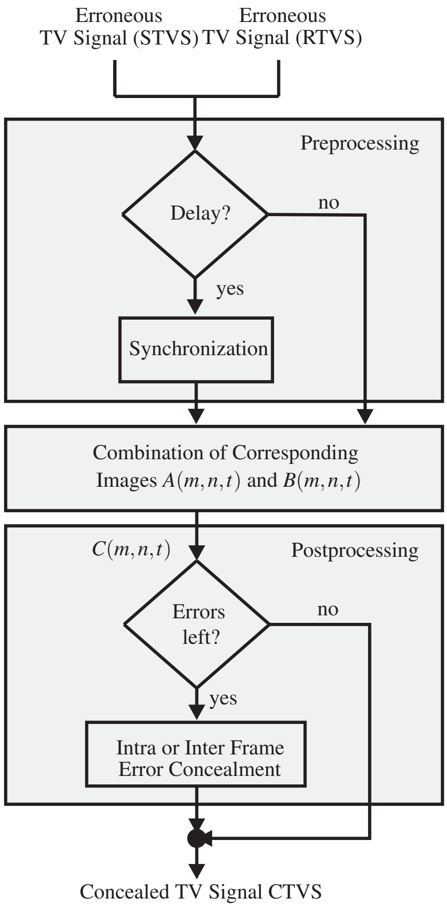

Figure 2: Flow Diagram of the proposed approach for error concealment of TV signals in a diversity reception scenario

In case of multiple-distorted pixels, i. e. corresponding pixels which are distorted in both sequences, well-known intra and inter frame concealment techniques have to be applied for resulting image $C(m,n,t)$ of the *Concealed TV Sequence* (CTVS) in a postprocessing step. BMA and DMVE are used for temporal error concealment. H.264Intra and FSE are applied for spatial concealment.

Based on the general approach for inter-sequence error concealment of TV sequences in a diversity reception scenario, we will focus on coded sequences in particular. We consider a hybrid video coding scheme with motion-compensated prediction and quantization of the prediction residual. Hereby, error propagation of concealed image parts plays an important role. Therefore, inter-sequence error concealment of intra-coded and predictively-coded frames are examined separately in Sec. 2.1 and 2.2.

2.1 Error Concealment of Intra-Coded Frames

Let us now consider inter-sequence error concealment of intra-coded frames on example of I-frame $A(m,n,t)$ of the STVS. We utilize the corresponding synchronized image $B(m,n,t)$ of RTVS as a reference. Three image areas of frame $A(m,n,t)$ can be distinguished for ISEC. First, we determine error-free image samples $W_A(m,n,t)$. In case of comparable visual quality of selected TV sequence and reference TV sequence, they remain unchanged.

$$W_A(m,n,t) = \begin{cases} 1 & \text{if } A(m,n,t) \text{ is error-free} \\ 0 & \text{else} \end{cases} \quad (1)$$

Second, image parts $Z_A(m,n,t)$ are erroneous in image $A(m,n,t)$ and error-free in reference image $B(m,n,t)$. Distorted image parts

$Z_A(m,n,t)$ are replaced by corresponding error-free reference samples. We call this step *Inter-Sequence Error Concealment, Type 1* ($ISEC_1$). Sample positions $Z_A(m,n,t)$ are determined by taking the *Hadamard-Product* with subsequent modulo-2-operation.

$$Z_A(m,n,t) = \left(\left(W_A(m,n,t)+1\right) \odot W_B(m,n,t)\right) \bmod 2 \quad (2)$$

$W_B(m,n,t)$ derives from Eq. (1). The Hadamard-Product is used here for exact mathematical formulation as it specifies the point-wise multiplication of two matrices. In the following, symbol $\odot$ always denotes a Hadamard-Product. The image combination step results in a combined image $C(m,n,t)$ of the CTVS.

$$C(m,n,t) = W_A(m,n,t) \odot A(m,n,t) + Z_A(m,n,t) \odot B(m,n,t) \quad (3)$$

Finally, sample positions $E_{AB}(m,n,t)$ of image $C(m,n,t)$ are distorted in both images $A(m,n,t)$ and $B(m,n,t)$. Binary matrix $E_{AB}(m,n,t)$ is one in case of multiple loss of image information and zero otherwise.

$$E_{AB}(m,n,t) = \left(W_A(m,n,t)-1\right) \odot \left(W_B(m,n,t)-1\right) \quad (4)$$

According to Fig. 2, positions $E_{AB}(m,n,t)$ have to be concealed with well-known error concealment techniques in the postprocessing step. Hereby, the complete image information of combined image $C(m,n,t)$ can be exploited. In principle, every conventional technique can be used to conceal multiple-distorted image parts. As pointed out before, we focus on BMA, DMVE, FSE and H.264Intra.

2.2 Error Concealment of Predictively-Coded Frames

In hybrid video coding, frames can be compressed differentially based on intra-coded images. The energy of such difference images can be reduced dramatically by motion-compensated prediction. Motion-compensated prediction based on differential coding therefore significantly contributes to a high compression efficience. However, in case of distorted transmission of coded video sequences, errors in reference images can propagate into predictively-coded frames. Considering a block based video coder, transmission errors typically result in block or slice losses. In detail, distorted image samples of I-frames and P-frames can affect related P-frames and B-frames. However, not every macroblock of a reference image has to be chosen as a reference for motion-compensated prediction. Therefore, error propagation in hybrid video coding highly depends on the image content of a particular video sequence.

Fig. 3 shows error propagation by motion compensation for predictively-coded image $A(m,n,t)$ of the STVS. Intra-coded frame $A(m,n,t-1)$ is used as reference for prediction during decoding. We now describe the concept of inter-sequence error concealment for predictively-coded frames on example of $A(m,n,t)$. Taking two reference images into consideration during decoding, this description also holds for bidirectionally predicted B-frames.

Image parts $Z_A(m,n,t)$ are marked red and diagonally cross-hatched in Fig. 3. As they are only distorted in the P-frame of STVS, samples $Z_A(m,n,t)$ can be replaced according to Eq. (3). For error concealment of multiple-distorted samples $E_{AB}(m,n,t)$ well-known spatial or temporal techniques are applied (see also Sec. 2.1). Vertically-hatched and blue marked area $P_A(m,n,t)$ indicates the positions of samples in P-frame $A(m,n,t)$ which are predicted by motion-compensation from replaced samples $Z_A(m,n,t-1)$ of I-frame $A(m,n,t-1)$ and finally reconstructed by adding the quantized prediction residual. Considering comparable visual quality of STVS and RTVS, samples which are indicated by $P_A(m,n,t)$ can be recovered near-losslessly. They are not replaced here as just in case of deviant visual quality drift occurs. Drift is the temporal accumulation of a mismatch between inserted image information from the RTVS and original error-free pixels of the STVS, here.

A comparable effect arises for image parts $P_{AB}(m,n,t)$ of P-frame $A(m,n,t)$ indicated by green right-diagonal hatching in Fig. 3. Multiple-distorted samples $E_{AB}(m,n,t-1)$ of I-frame $A(m,n,t-1)$ usually can not be reconstructed perfectly by well-known spatial or temporal concealment techniques. The error between concealed and original image information propagates into $P_{AB}(m,n,t)$ of P-frame $A(m,n,t)$ as reconstructed image samples and quantized prediction residual do not fit together. As a consequence, drift occurs. In case of fully identical coding parameters like quantization and coding scheme of sequences STVS and RTVS, identical motion vector fields arise. As a consequence, samples $P_{AB}(m,n,t)$ can not be concealed by image combination as they are distorted in both corresponding images $A(m,n,t)$ and $B(m,n,t)$ of the multiple-received TV sequences. Successful ISEC is only possible for deviating motion vectors fields respectively varying error propagation for STVS and RTVS. Deviating motion vector fields can be achieved by different coding schemes, GOPs of various length, varying quantization or temporally shifted key frames in the coding process of STVS and RTVS. Considering one or more of the mentioned characteristics, the image quality of distorted image parts $P_{AB}(m,n,t)$ can also be enhanced by replacing those erroneous image samples in $A(m,n,t)$ by corresponding error-free image information of $B(m,n,t)$. Summing up, ISEC for predictively-coded frames of the STVS can be formulated as follows:

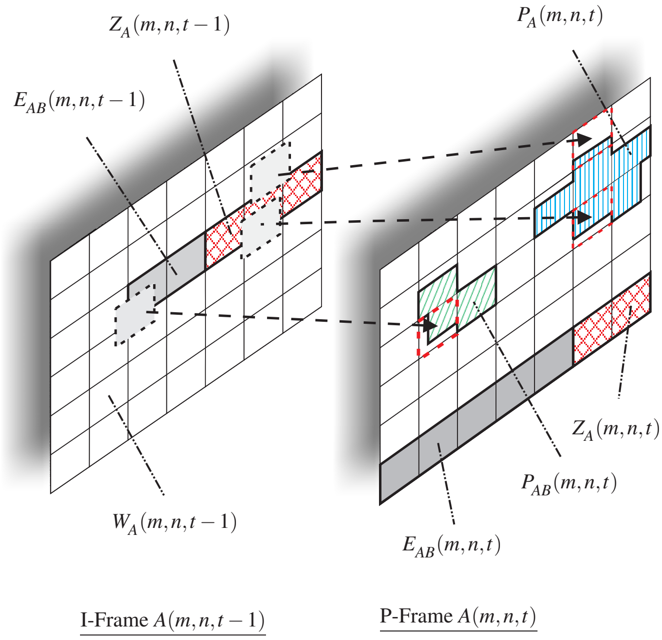

Figure 3: Error propagation by motion compensation for predictively-coded frame $A(m,n,t)$ of the STVS

$$C(m,n,t) = \left(W_A(m,n,t)+P_A(m,n,t)\right) \odot A(m,n,t) + \\ + \left(Z_A(m,n,t)+P_{AB}(m,n,t)\right) \odot B(m,n,t) \quad (5)$$

We call this procedure *Inter-Sequence Error Concealment, Type 2* ($ISEC_2$). Resulting image $C(m,n,t)$ of the CTVS contains image information of P-frame $A(m,n,t)$ in areas $W_A(m,n,t)$ and $P_A(m,n,t)$. Pixels indicated by $Z_A(m,n,t)$ and $P_{AB}(m,n,t)$, however, originate from reference image $B(m,n,t)$. Sample positions $E_{AB}(m,n,t)$ of image $C(m,n,t)$ are distorted in both images $A(m,n,t)$ and $B(m,n,t)$ and have to be concealed utilizing well-known spatial, temporal or spatio-temporal techniques.

3. SIMULATION RESULTS

Simulation results for inter-sequence error concealment of digital TV signals in a diversity reception scenario are given in this section on example of DVB-T signals. The proposed technique is evaluated by the objective and subjective quality of concealed image parts.

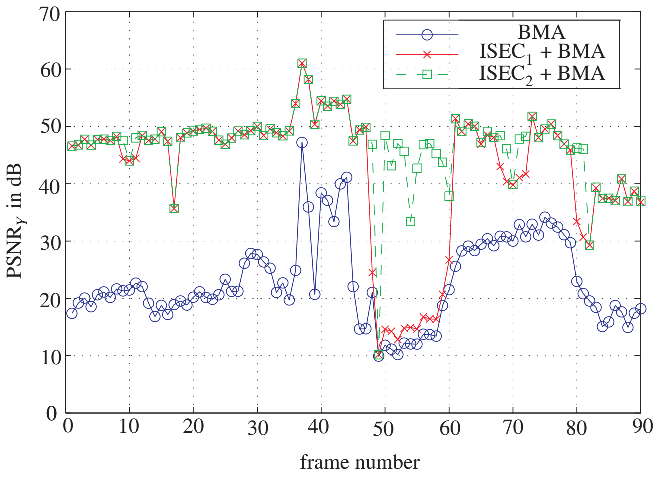

Figure 4: Objective quality of concealed image parts against frame number for 90 frames of TV sequence *Ad*

With *Ad*, *Series* and *Talkshow* we use typical TV sequences. The image resolution is 720x576 at a frame rate of 25 fps. The TV sequences are compressed due to the MPEG-2 specification with coding scheme IBBP.

Diversity reception in MFNs is simulated by decoding two representations of a TV sequence simultaneously. Both video signals (STVS and RTVS) have slice losses of 3% respectively 5%. Slice losses are uniformly distributed and introduced independently of each other. By error propagation, 9%-11% of STVS and 14%-17% of RTVS are lost. As a reasonable image quality is typical for DVB-T, the bitrate of the STVS is about 2.4 Mbps on average. The RTVS has an objective image quality of about 40 dB $PSNR_Y$ relating to the STVS. An interface between both decoders allows the exchange of image information on block basis. By implementing the proposed technique for error concealment in a hybrid video coder, error propagation by motion-compensated prediction can be evaluated.

We use BMA, DMVE, FSE and H.264Intra as well-known techniques for error concealment. The search range for both temporal techniques is 30. DMVE finds the best match by considering 8 lines of decoded pixels that surround the lost macroblock. FSE is performed under consideration of orthogonal deficiency compensation ([10]). The compensation factor is chosen to 0.8. For selection of basis functions we use an isotropic model with correlation coefficient $\rho = 0.7$. The algorithm terminates after 100 iterations.

Fig. 4 shows the objective image quality of concealed image parts against the frame number for 90 frames of test sequence *Ad*. The blue curve indicates the objective image quality for CTVS using (pure) BMA for error concealment. Reference sequence RTVS is not utilized. As can be seen for frames 50 to 60, temporal concealment techniques fail in case of large movement. Inter-sequence error concealment (Type1) plus subsequent BMA using the RTVS is depicted in red. For most frames a significant gain in terms of $PSNR_Y$ is shown. Considering frames 50-60, however, $ISEC_1$ improves the image quality only negligibly. This is because only few samples are distorted in the STVS and error-free in corresponding reference images of the RTVS. In case of large motion, the mismatch of concealed and original samples is large for P- and B-frames. $ISEC_2$ plus subsequent BMA (green curve) can therefore increase the objective quality of concealed image information by up to 30 dB for particular frames.

In Tab. 1 the mean objective image quality of concealed pixels is depicted for TV sequences *Ad*, *Series* and *Talkshow* in terms of $PSNR_Y$. Results are given for the well-known reference techniques (pure) BMA, DMVE, FSE and H.264Intra without utilizing the reference TV sequence. They are compared with those of $ISEC_1$ and $ISEC_2$ in terms of $PSNR_Y$. The absolute gain $\Delta PSNR_Y$ of $ISEC_1$ and $ISEC_1$ is given in bold numbers. $ISEC_1$ relates to (pure) BMA, DMVE, FSE and H.264Intra. The additional gain of $ISEC_2$ is based on $ISEC_1$. Several conclusions can be drawn from results in Tab. 1:

- Inter-sequence error concealment provides a substantial gain for well-known temporal and spatial concealment techniques. Considering sequence *Series*, a gain of 9.1 dB and 10.1 dB respectively is achieved by $ISEC_1$ for both temporal techniques BMA and DMVE in terms of $PSNR_Y$. $ISEC_2$ shows an additional gain of 2.0 dB and 2.1 dB respectively. The objective quality of concealed image parts can be enhanced comparably for spatial approaches. For the FSE, a gain of 6.9 dB $PSNR_Y$ can be obtained by $ISEC_1$. In case of variant motion vector fields for STVS and RTVS, $ISEC_2$ can further rise the gain by 3.4 dB. Considering H.264Intra, the objective image quality is enhanced by 5.3 dB $PSNR_Y$ for $ISEC_1$ and in addition by 1.4 dB for $ISEC_2$.
- On average, the rise of objective image quality achieved by $ISEC_1$ (here: 8.4 dB) is higher than the additional gain of $ISEC_2$ (here: 3.3 dB) for test sequences *Ad*, *Series* and *Talkshow*.
- Different allocations of the gain obtained by $ISEC_1$ and $ISEC_2$ are possible for sequences with high motion. Considering sequence *Ad*, $ISEC_1$ shows a moderate gain of about 5.7 db and 4.6 dB $PSNR_Y$ respectively for BMA and DMVE whereas the additional gain by $ISEC_2$ reaches 9.6 dB in each case. In case of large motion, correct image information can not be found for lost blocks by (pure) BMA and DMVE because of occlusions and uncovered background. By replacing image parts $Z_A(m,n,t)$, $ISEC_1$ can increase the image quality. However, a high mismatch between concealed pixels and original image information being available after coding still occurs for samples $P_{AB}(m,n,t)$. Here, drift can be suppressed successfully by $ISEC_2$ showing therefore a high gain.
- Tab. 1 shows an extraordinary high gain of 17.7 dB and 14.4 dB respectively in terms of $PSNR_Y$ for sequence *Ad* which is achieved by $ISEC_1$ based on FSE and H.264Intra. $ISEC_2$ only reaches a negligible additional gain. This is because spatial techniques work well in case of many error-free pixels which are neighboured to lost blocks. Considering slice losses, however, only few neighbouring samples can be utilized for spatial error concealment. Here, $ISEC_1$ can significantly rise the amount of those neighbouring pixels. Then, $ISEC_1$ can increase the objective quality of concealed samples by replacing distorted samples $Z_A(m,n,t)$ as well as improving the concealment of multiple-distorted image parts $E_{AB}(m,n,t)$. Drift which is suppressed by $ISEC_2$ in predictively-coded frames therefore drops.

Summing up, gains obtained by $ISEC_1$ and $ISEC_2$ depend on the distribution of slice losses, the image content and motion of a TV sequence and the use of temporal or spatial approaches for well-known error concealment.

Table 1: Mean objective quality of concealed image parts for 100 frames of TV sequences *Ad*, *Series* and *Talkshow*

Sequence	*Ad*		*Series*		*Talkshow*	
	$PSNR_Y$	Δ	$PSNR_Y$	Δ	$PSNR_Y$	Δ
BMA [1]	18.64		25.90		20.76	
$ISEC_1$ + BMA	24.34	**5.7**	35.02	**9.1**	28.85	**8.1**
$ISEC_2$ + BMA	33.95	**9.6**	37.04	**2.0**	31.99	**3.1**
DMVE [2]	19.68		25.92		24.28	
$ISEC_1$ + DMVE	24.23	**4.6**	34.40	**10.1**	33.15	**8.9**
$ISEC_2$ + DMVE	33.84	**9.6**	36.48	**2.1**	36.47	**3.3**
FSE [3]	20.30		27.38		26.87	
$ISEC_1$ + FSE	38.04	**17.7**	33.74	**6.9**	33.82	**7.0**
$ISEC_2$ + FSE	39.07	**1.0**	37.14	**3.4**	36.03	**2.2**
H.264Intra [5]	21.86		28.70		27.99	
$ISEC_1$+H.264Int.	36.27	**14.4**	33.26	**5.3**	31.95	**4.0**
$ISEC_2$+H.264Int.	36.92	**0.7**	34.63	**1.4**	33.29	**1.3**

Fig. 5(a) shows a predictively-coded image of TV sequence *Series*. Slice losses in a macroblock raster are noticeable as they also occur in intra-coded frames. Additionally, arbitrarily shaped error patterns occur by motion-compensated prediction. The subjective image quality of error concealment by frequency-selective extrapolation without utilization of a reference sequence can be evaluated in Fig. 5(b). Three areas are eye-catching: The TV logo, the right sleeve and the right eye of the person facing the camera. The luminance of the logo and the eye do not fit because concealed pixels and original image information after video coding mismatch in the subsequent reference frame. Furthermore, the edge between the sleeve and the white background can not reconstructed satisfactorily by FSE. Fig. 5(c) shows $ISEC_1$ with successive FSE. The subjective quality of concealed image information is clearly enhanced and now barely discriminable from error-free image parts.

4. CONCLUSIONS

In this paper a new approach for error concealment of digital TV signals in a diversity reception scenario is proposed. Inter-sequence error concealment utilizes one or more distorted reference sequence to reconstruct lost blocks or slices of an erroneous TV sequence. In terms of objective and subjective image quality, ISEC can improve well-known spatial or temporal techniques. Depending on the distribution and the percentage of slice losses, gains of up to 18 dB can be achieved on average in terms of $PSNR_Y$. Current research focuses on inter-sequence error concealment using more than one reference sequence. One scenario might be the multi-standard reception of DVB-T, DVB-H and T-DMB.

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a)

b)

c)

Figure 5: Predictively-coded image from sequence *Series* a) with lost image information b) error concealment by frequency selective extrapolation ($PSNR_Y$ = 25.05 dB) c) error concealment by ISEC (Type1) and successive FSE ($PSNR_Y$ = 38.37 dB)