A FAST DISPLACEMENT-ESTIMATION BASED APPROACH FOR STEREOSCOPIC ERROR CONCEALMENT

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ABSTRACT

In image and video processing error concealment is an important field of research. Video applications like teleconferencing or *digital video broadcasting* (DVB) require fast and robust signal processing algorithms to fulfil real-time conditions. Therefore many fast concealment methods were developed to handle block losses in monocular sequences. In this paper we present a fast concealment strategy for block losses in stereoscopic sequences. Pixel values from the associate stereo image are used to conceal the lost block at the corresponding position. In this approach, we focus on robustness and low complexity.

1. INTRODUCTION

As mentioned in [1], stereoscopic image quality degradation caused by losses is not comparable to the degradation caused by quantization or low-pass filtering. Therefore several error concealment strategies for stereoscopic image pairs were presented in [2] and [3] yielding excellent reconstruction results at the cost of high complexity. Due to computational constraints, these algorithms are not advisable for error concealment in stereoscopic sequences. In this paper, we propose error concealment techniques with lower complexity based on displacement estimation.

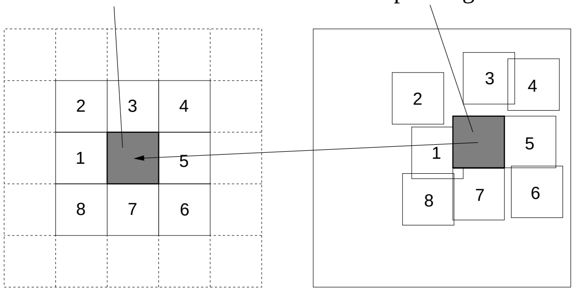


Fig. 1. Reconstruction of lost samples

In section 2 we describe concealment strategies based on displacement estimation for stereoscopic image pairs, combining actual *block matching algorithms* with an adapted block search strategy. Depending on the reference we refer to this technique as *spatial block search* (SBS) or *temporal block search* (TBS). As shown in figure 1, the estimated positions of up to eight adjacent blocks are used to find a corresponding block in the reference frame for the lost block of the corrupted frame. Using the surrounding samples (border) and the corresponding block of the reference frame the lost block can be reconstructed. For complexity reduction, we use the *directional diamond search* (DDS) as block matching algorithm.

In section 3 the simulation scenario and evaluation of the proposed strategies are presented.

2. ERROR CONCEALMENT STRATEGIES

In this section we describe error concealment strategies based on block matching and displacement compensation. Generally, the neighboring blocks of the lost block are searched in a reference frame. From the displacement vectors of the neighboring blocks the *best fitting* displacement vector is chosen for the reconstruction of the lost block. As fitting criteria we use the *side match distortion* d_{sm} [4].

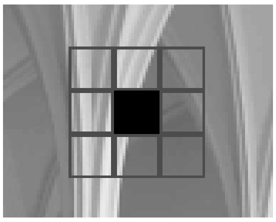
2.1. Temporal Block Search (TBS)

A common technique to conceal lost blocks of predicted frames (P-frames) is *motion compensated temporal prediction* [5]. This method estimates a lost motion vector of a block inside a P-frame using the motion vectors of the neighboring vectors. The lost block is reconstructed using the mean or median value of the neighboring motion vectors. This method yields good results especially in low-motion sequences.

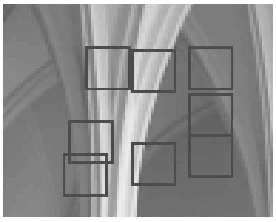
In contrast to *motion compensated temporal prediction* each neighbor motion vector is used to predict the lost block out of the previous frame. The most appropriate prediction is chosen by the *side match distortion*. In the case, that neighboring motion vectors are not available (i.e., I-frames or I-macroblocks), a motion estimation algorithm is applied for all available neighboring blocks (*temporal block search*).

2.2. Spatial Block Search (SBS)

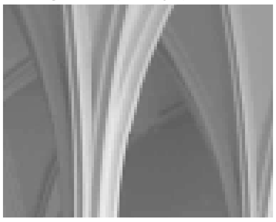
Assuming that the views of the stereoscopic sequence are coded independently, the corresponding frame can also be used for error concealment purposes. Similar to *TBS* a block search can be applied in the corresponding frame (*spatial block search*). This approach is based on the assumption that only translatory displacement occurs between the two views, which is a rather rough estimation. But as shown in sec. 3 it still yields satisfying reconstruction results.



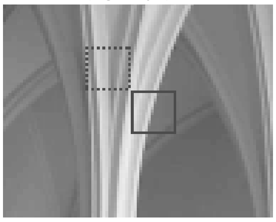
(a) Erroneous block with neighbors (left-eye)



(b) Matched neighbor blocks (right-eye)



(c) concealed image (left-eye)



(d) reference block, corresponding neighbor (dotted) (right-eye)

Fig. 2. SBS example: left-eye (corrupted) and right-eye (reference) image (“Hall”)

Figure 2 illustrates the concealment of one lost 16×16 macroblock. Figure 2(a) shows the eight neighbors of the lost block, which are searched in the associated image of the stereo pair. The matches are shown in figure 2(b). The reconstruction, shown in figure 2(c), is done with the solid enframed block in figure 2(d), which has the minimal *side match distortion*. This block belongs to the match of the left upper neighbor (dotted enframed block) of the lost one. To reduce discontinuities the borders of the reconstruction block are low pass filtered .

2.3. Temporal and Spatial Block Search (TSBS)

The disadvantage of TBS and SBS is, that they were developed on the assumption, that the reference frame (either the previous frame or the corresponding stereoscopic image) is undamaged. During the transmission of H.264 video data over an unreliable network it is very probable, that groups of macroblocks (slices) of both images are lost. Therefore we combined the temporal and spatial error concealment strategies to *temporal and spatial block search* (TSBS), where the adjacent blocks of the lost block are searched as well in the previous temporal reference frame as in the spatial reference frame of the actual stereoscopic image pair. Based on the the minimal *side match distortion* d_{sm}, the reconstruction block is chosen.

3. SIMULATION AND RESULTS

To classify the performance of the proposed block matching error concealment strategies compared to high complex methods like 3D-BS, we first applied SBS to a stereoscopic image pair. In a next step, we applied TBS, SBS and TSBS to a stereoscopic sequence. The quality of the reconstructed sequence is evaluated, using the *double stimulus continuous quality scale method*. The complexity of each strategy is estimated and compared.

For sequences we assume an error prone, packet oriented network. To simulate packet losses, the *Gilbert-Elliot-Model* is commonly used. Due to the variable length coding we assume, that a single RTP packet loss leads to a lost *network abstraction layer unit* (NALU) containing a group of macroblocks.

3.1. Error concealment for stereoscopic images

We compared the efficiency of SBS with the more sophisticated 3D-BS strategy. Figure 3 shows the highly degraded right image of the stereoscopic image pair “Castle” with six burst errors (103 of 713 lost 16×16 blocks). For comparison we also concealed these error bursts with a monoscopic method [6]. The concealment results of SBS are subjectively and objectively better than the monoscopic concealment, that only recovers low pass content.

In table 1 the average PSNR values of differently reconstructed burst errors of 10 blocks in two stereoscopic image pairs (“Hall” and “Castle”) are listed. Besides the already mentioned monoscopic error concealment method a stereoscopic approach based on feature matching and perspective transformation (3D-BS [1]) was applied. For *SBS* the directional diamond search was chosen as block matching algorithm.

Reflecting the subjective impression, SBS yields higher PSNR values compared to the monoscopic technique. Comparing SBS and 3D-BS, the higher PSNR of SBS does not reflect the subjective impression. Depending on the block matching, the reconstruction quality of SBS ranges from excellent to weak. In case of block mismatches, the reconstruction by SBS is of a lower visual quality than a (monoscopic) interpolation technique. 3D-BS is a more robust error concealment strategy yielding a more reliable, but due to the low pass filtering (smoothing) generally lower reconstruction PSNR.

Table 1. Average block-PSNR for arbitrary block losses

PSNR in dB	Hall		Castle	
	8×8	16×16	8×8	16×16
Monoscopic	23,16	19,71	17,94	17,26
3D-BS	30,18	28,43	20,92	20,78
SBS (DDS)	34,77	31,85	22,29	22,17

3.2. Error concealment for stereoscopic sequences

To evaluate the effectiveness of the proposed error concealment strategies for sequences a Multiple Description H.264 video transmission scenario over an unreliable network was simulated. To this end left and right image sequences (720×480) were coded independently using IPPP mode at $3.2\mathrm{Mbps}$. Every 12^{th} frame was an I frame. The quality was quantified by an objective measure (PSNR) and subjective tests. Figure 4 shows a damaged and a concealed (TSBS) stereoscopic frame pair.

Figure 3.2 shows the PSNR trend of different error concealment methods. The Mean-PSNR of *spatial block search* is $33{,}55\mathrm{dB}$ (SBS), the Mean-PSNR of *temporal block search* is $35{,}52\mathrm{dB}$ (TBS) and *temporal and spatial block search* yields $36{,}2688\mathrm{dB}$ (TSBS).

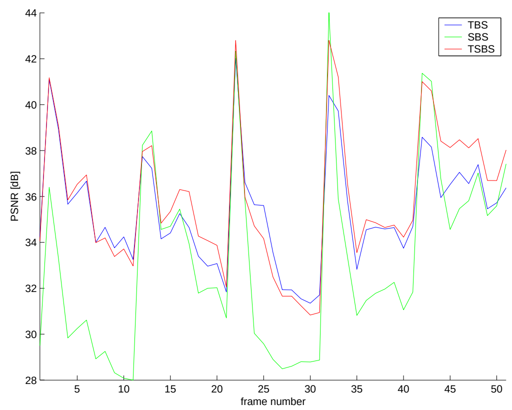


Fig. 5. PSNR trend of 50 frames of a stereoscopic sequence (Balloons, 720×480)

A subjective evaluation with 15 subjects was carried out using the *double stimulus continuous quality scale method* (DSCQS). The result of this psycho visual evaluation is a *differential mean opinion score* (DMOS) between a reference sequence and a corresponding test sequence. A smaller DMOS can be interpreted as a smaller quality gap between the test and the reference sequence.

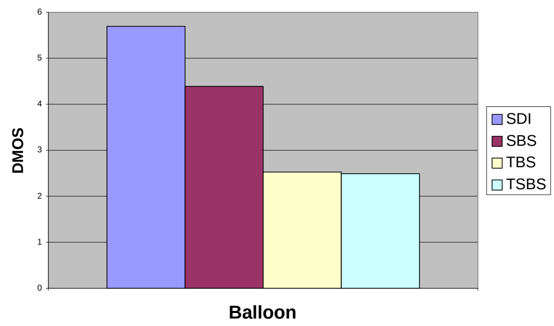


Fig. 6. Psycho visual test results (DMOS) for stereoscopic error concealment (Balloons, 720×480)

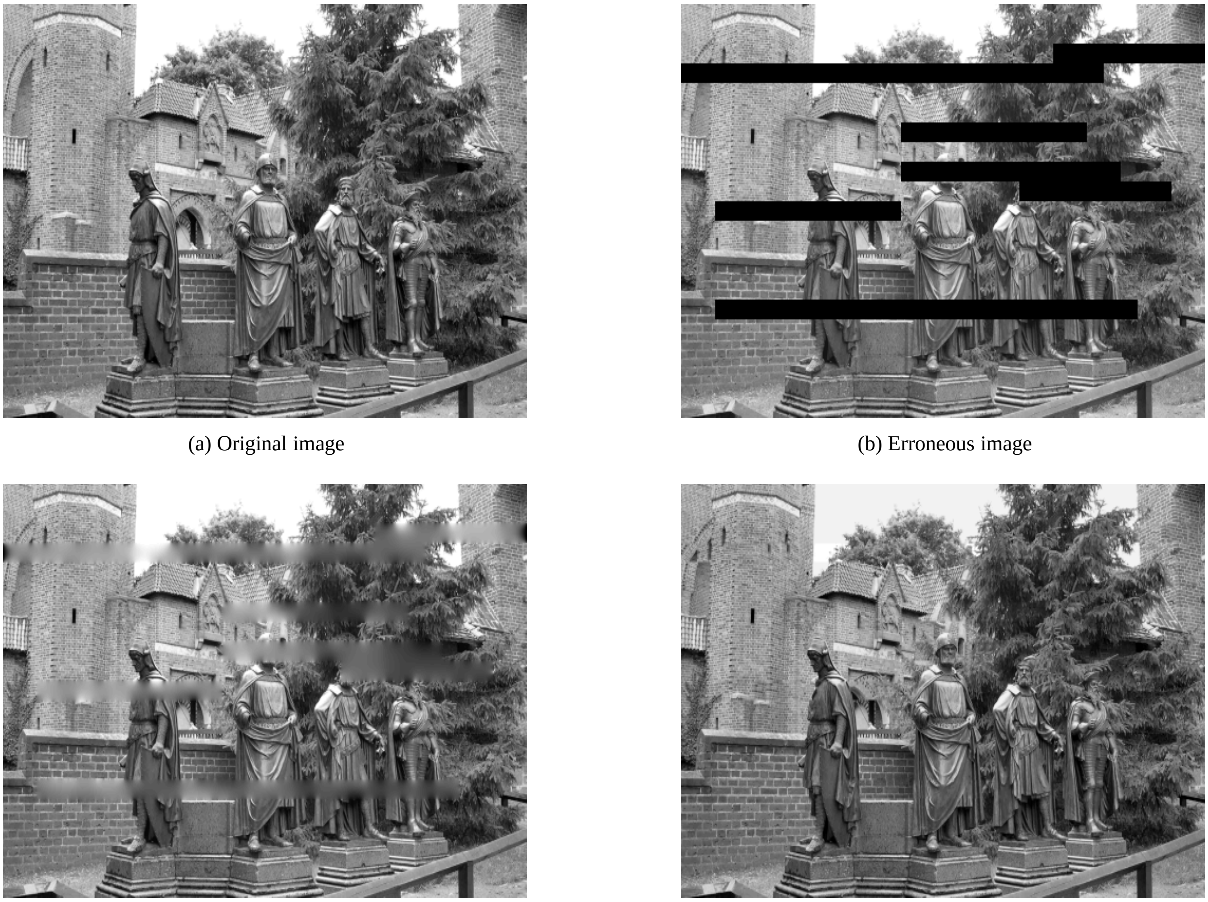
Table 2. DMOS, standard derivations and confidence intervals for stereoscopic error concealment

Balloons	DMOS	S.D.	confidential interval
SDI	5,69	1,19	±0,65
TBS	2,52	2,64	±1,45
SBS	4,39	1,12	±0,62
TSBS	2,49	1,37	±0,75

In figure 6 and table 2 the DMOS, the standard deviation (S.D.) and the confidence interval are presented. As reference, the DMOS value of an interpolation of bordering pixel values (spatial domain interpolation, SDI) is listed. TBS yields good DMOS values, but high S.D respectively a greater confidence interval. The combination of TBS with SBS (TSBS) yields slightly better DMOS values but a lower S.D and smaller confidence interval. Which can be seen as a high quality and robust reconstruction method for lost blocks.

3.2.1. *Complexity Comparison*

The main constraint for error concealment in stereoscopic sequences is computational complexity. A comparison of the computational complexity in terms of additions (ADD) and multiplications (MULT) can be found in table 3. The listed values for 3D-BS are approximations for CIF sequences. The effort needed for the estimation of the fundamental matrix is not take into account, because it strongly depends on the chosen method. The fundamental matrix increases the robustness of the feature matching in 3D-BS, but it is not necessarily needed. For TBS we assume that no motion information is available (I frame).



(a) Original image

(b) Erroneous image

(c) Mono concealment (PSNR $= 17,3$dB)

(d) Stereo concealment, SBS (PSNR $= 21,7$dB)

Fig. 3. Example of error concealment with the right image of a stereoscopic image pair ("Castle")

Table 3. Complexity (ADD and MULT)

	ADD	MULT
3D-BS	$\approx 2 \cdot 10^6$	$\approx 2 \cdot 10^5$
SBS/TBS	$\approx 5 \cdot 10^4$	
TSBS	$\approx 1 \cdot 10^5$	

Besides the lower number of additions, no multiplication is needed for SBS/TBS or TSBS As previously mentioned the proposed methods were developed with low complexity in mind, using the *side match distortion* and *sum of absolute difference*.

4. SUMMARY

In this paper we presented low complexity approaches for stereo error concealment of independently coded stereoscopic sequences based on block matching. Using the *side match distortion* and *sum of absolute difference* no multiplication is needed.

Extending the monoscopic *temporal block search*, we utilized the additional information of the second stereoscopic channel (SBS). The combination of *spatial* and *temporal block search* (TSBS) yields excellent reconstruction results, which was proven by a psycho visual evaluation. The reconstruction quality of TBS and TSBS is nearly comparable. The additional effort of spatial block search reduces the probability of block mismatches.

5. REFERENCES

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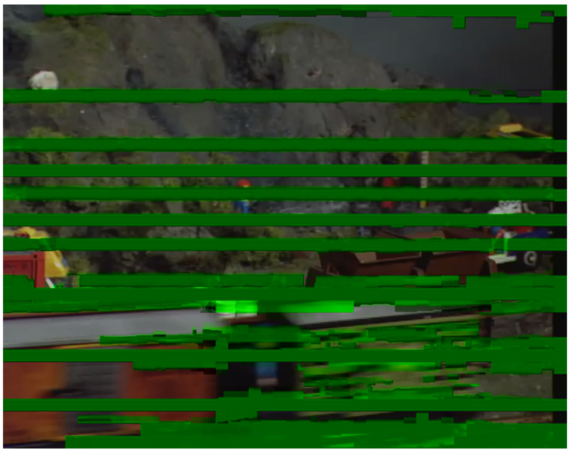

(a) left-eye

(b) right-eye

(c) left-eye

(d) right-eye

Fig. 4. Damaged SBS and TSBS concealed stereoscopic sequence frame (Train, 720×576)

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