This item is the archived peer-reviewed author-version of:

Title: Joint DC Coefficient Band Decoding and Motion Estimation in Wyner-Ziv Video Coding

Authors: Nikos Deligiannis, Marc Jacobs, Joeri Barbarien, Frederik Verbist, Jozef Škorupa, Rik Van de Walle, Athanassios Skodras, Peter Schelkens, and Adrian Munteanu

International Conference on Digital Signal Processing, 2011.

To refer to or to cite this work, please use the citation to the published version:

Deligiannis N., Jacobs M., Barbarien J., Verbist F., Skorupa J., Van De Walle R., Skodras A., Schelkens P., and Munteanu A. (2011). Joint DC coefficient band decoding and motion estimation in Wyner-Ziv video coding. *International Conference on Digital Signal Processing, Corfu, Greece*.

JOINT DC COEFFICIENT BAND DECODING AND MOTION ESTIMATION IN WYNER-ZIV VIDEO CODING

Nikos Deligiannis,[a,c] Marc Jacobs,[a,c] Joeri Barbarien,[a,c] Frederik Verbist,[a,c] Jozef Škorupa,[b,c] Rik Van de Walle,[b,c] Athanassios Skodras,[d] Peter Schelkens,[a,c] and Adrian Munteanu[a,c]

[a]Dept. of Electronics and Informatics, Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium.
[b]ELIS Department, Multimedia Lab, Ghent University, Gaston Crommenlaan 8, 9050 Ghent, Belgium.
[c]Interdisciplinary Institute for Broadband Technology, Gaston Crommenlaan 8, 9050 Ghent, Belgium.
[d]School of Computer Science, Hellenic Open University, Tsamadou 13-15, 26222 Patras, Greece.

ABSTRACT

In contrast to traditional predictive coding, Wyner-Ziv video coding enables low-cost encoding architectures, in which the computationally expensive tasks for performing motion estimation are shifted to the decoder-side. In Wyner-Ziv video coding, side-information generation is a key aspect profoundly affecting the compression capacity of the system. This paper presents a novel technique which enables side-information refinement after DC coefficient band decoding in a transform-domain Wyner-Ziv video codec. The proposed side-information refinement approach performs overlapped block motion estimation and compensation, utilizing multi-hypothesis pixel-based prediction. The experimental results show that the presented Wyner-Ziv video codec incorporating the proposed technique yields significant and systematic compression gains of up to 23.22% with respect to the state-of-the-art DISCOVER codec.

Index Terms— Distributed source coding, Wyner-Ziv video coding, side-information generation, motion estimation.

1. INTRODUCTION

In order to meet the demanding prerequisites of mobility, low encoding complexity and error resilience, Wyner-Ziv (WZ) video coding – alias distributed video coding (DVC), is a recently engineered reverse paradigm anchored in distributed source coding principles (DSC) [1]. Conversely to conventional predictive video coding systems, like the H.264/AVC standard [2], which are tailored to downlink-tuned applications, DVC schemes facilitate uplink-oriented video transmission benefitting from several key advantages. In particular, DVC architectures provide error resilience and shift the computational center of gravity towards the decoder, promoting applications involving low-complexity mobile recording equipment [1]. Moreover, in a heterogeneous user environment, DVC enables adaptable systems that effectively switch encoder-decoder complexity, thereby increasing the flexibility and efficiency of video communications [3].

Several DVC architectures have been reported in the literature. The PRISM codec [4] was among the first systems to apply DSC theory in a practical video coding architecture. However, its performance was undermined by the immense computational load imposed on the decoder, which is prohibitive for most applications. In the context of low-cost distributed video compression, Stanford University developed a feedback channel-based DVC architecture [5]. It included competitive techniques to capture motion at the decoder-side along with high performance channel codes inspired by fundamental information theoretic results in communication theory. Rate control was performed using a feedback channel, which was required to allow the decoder to substantially lower the uncertainty on the final reconstruction. These concepts were later on adopted and optimized in the DISCOVER codec [6], developed within a DVC research framework funded by the European Union and providing state-of-the-art coding performance.

Initial DVC architectures employed motion compensated interpolation (MCI) or extrapolation (MCE) to produce side-information at the decoder [5], [7], [8]. However, when the video content exhibits irregular motion, MCI does not succeed in predicting the correct motion field, causing a significant decrease in the overall coding efficiency. To resolve this shortcoming, improved side-information generation algorithms perform side-information refinement. In particular, initial works proposed successive side-information refinement in pixel-domain Wyner-Ziv (PDWZ) video coding architectures [9], [10], [11], [12]. In the same context, [13] presented WZ frame coding in several resolution layers, facilitating multistage resolution refinement of side-information at the decoder-side. However, state-of-the-art DVC architectures operate in the transform-domain since PDWZ video coding delivers low compression performance. In transform-domain Wyner-Ziv (TDWZ) coding, Varodayan *et al.* [14] proposed an unsupervised method to perform motion estimation in conjunction with low-density parity-check (LDPC) decoding. Similarly, [15] performed refined motion estimation in the DC domain. Alternatively, [16] introduced side-information refinement after decoding all DCT bands yielding increased final reconstruction quality. Moreover,

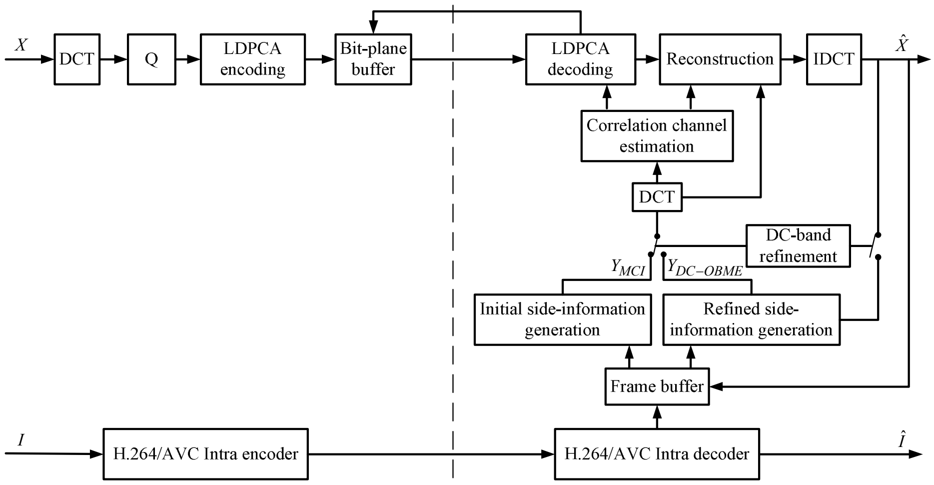

Fig. 1. The presented DVC architecture featuring the proposed DC-band-driven side-information refinement technique.

Martins *et al.* [17] proposed repeated side-information generation after reconstruction of each DCT coefficient band.

In the context of TDWZ video coding, this work presents a novel algorithm which enables side-information refinement after LDPC decoding and reconstruction of the DC coefficients of the WZ frames. In order to decode the DC coefficients of the WZ frames, the proposed codec employs an advanced MCI technique sharing key features with [6], [18], [19]. However, contrary to bidirectional motion compensation employed in [18], [19], the proposed approach performs bidirectional overlapped block motion compensation, causing the energy of the prediction error to decrease. After DC coefficient band decoding, the proposed approach refines the generated side-information using overlapped block motion estimation (OBME) and compensation. Contrary to [14], [15], the refinement is performed in the pixel-domain, alleviating the need for an overcomplete DCT transform, which would impose a significant computational load at the decoder. Moreover, the proposed technique facilitates multi-hypothesis pixel-based prediction, which contrasts [14], [15]. Conversely to [17] in which side-information refinement is carried out after decoding each DCT band, OBME enables a significant quality improvement of the side-information by exclusively decoding the DC coefficient band. The experimental results report that the proposed MCI-based TDWZ codec delivers state-of-the-art DVC performance, outperforming the DISCOVER codec [6]. In addition, when performing DC coefficient band side-information refinement, the proposed codec achieves significant Bjøntegaard rate savings of up to 23.22% over the latest executable of the DISCOVER reference codec [6].

2. PROPOSED ARCHITECTURE

The block diagram of the proposed codec is depicted in Fig. 1. The proposed DVC system is based on the TDWZ video coding architecture developed at Stanford University [5], incorporating key improvements adopted from prior art [20], [21]. The core contribution of this paper lies in the development of a novel DC-band-driven side-information refinement algorithm, as detailed next.

At the proposed DVC encoder, the video frame sequence is partitioned into key and WZ frames. The key frames, I, are intra coded using the H.264/AVC Main profile intra frame codec. The WZ frames, X, are divided into non-overlapping spatial blocks of size 4×4, and each block undergoes a 4×4 integer discrete cosine transform (DCT). The derived DCT coefficients are grouped into 16 coefficient bands. Thereafter, employing a set of predefined quantization matrices (QMs), each coefficient band, b, is independently quantized with 2^{L_b} levels. In this work, the QMs of the DISCOVER codec [6] have been applied, in order to ensure a meaningful comparison with the latter. The derived quantization indices are split into bit-planes, resulting into L_b bit-planes per coefficient band. Each bit-plane is then passed to a rate-adaptive LDPC Accumulate (LDPCA) [22] encoder and the produced syndrome bits are stored in a bit-plane buffer. Using a feedback channel, the derived syndrome bits are transmitted in portions upon the decoder's request.

At the decoder, the encoded key frames are H.264/AVC intra decoded and stored in a frame buffer. Next, an MCI technique, detailed in Section 3, generates the initial side-information, Y_{MCI}, providing state-of-the-art MCI-based DVC performance. The created side-information is DCT transformed and converted to soft information in order to LDPCA decode the bit-planes of the WZ DC coefficient band. After LDPCA decoding, the derived bit-planes are grouped into quantization indices and minimum mean square error (MMSE) reconstruction [1] is carried out to obtain the decoded DC band coefficients. Then, the DCT transformed side-information is updated with the decoded DC band coefficients and inverse DCT is performed. The proposed side-information refinement module performs bidirectional overlapped block motion estimation and compensation using the updated WZ frame and reference frames from the buffer. This operation yields an improved side-information, denoted by $Y_{DC-OBME}$, which is used to LDPCA decode and MMSE reconstruct the remaining DCT coefficient bands of the WZ frame. Finally, after decoding all the DCT coefficient bands, the inverse DCT is performed and the decoded WZ frame is displayed and stored in the reference frame buffer.

3. INITIAL SIDE-INFORMATION GENERATION

In order to create efficient side-information Y_{MCI} for decoding the DC band of the WZ frame, the proposed architecture employs an MCI technique. The schematic representation of the employed MCI is depicted in Fig. 2. The proposed method constitutes an alteration of the algorithm presented in [18], [19], with a number of modifications and extensions.

In the first stage, for each WZ frame X forward block-based motion estimation with integer-pixel accuracy is performed between the previous and the next reference frame, denoted by X^p and X^n, respectively. In a hierarchical predictive structure, the reference frames are the already decoded previous and next key and/or WZ frames – see Fig. 3. Similar to [19], the error metric (EM) employed for block matching is a modified version of the sum of absolute differences (SAD) metric, which favors smaller motion vectors [19]:

$$EM\left(x, y, \mathbf{v} = \left(v_x, v_y\right)\right) = \left(1 + k \cdot \|\mathbf{v}\|\right) \cdot \sum_{j=0}^{N-1} \sum_{i=0}^{N-1} \left| \begin{array}{l} X^n\left(N \cdot x + i, N \cdot y + j\right) \\ \quad - X^p\left(N \cdot x + i + v_x, N \cdot y + j + v_y\right) \end{array} \right| \quad (1)$$

where, x and y respectively denote the column and row coordinates of the block for which motion estimation is performed, N denotes the block size, $\mathbf{v} = \left(v_x, v_y\right)$ represents the candidate motion vector and k is a constant set to $k = 0.05$ [19]. In compliance with prior art [18], [19], a block size of $N = 16$ and a search range of $r = 32$ pixels is employed in the forward motion estimation algorithm.

Subsequently, the resulting unidirectional motion field, MF_F, is used to derive the bidirectional motion field, MF_B, between the interpolated and the reference frames. In particular, similar to [18], the points where the motion vectors of MF_F intercept the interpolated frame are determined first. For each block in the interpolated frame, the motion vector for which the intercept point is closest to the top-left corner of the block is selected. This motion vector $\mathbf{v}_i$ is subsequently scaled with the ratio between the distance of the interpolated frame to the previous reference frame and the distance between both reference frames, yielding the new forward motion vector for the block. This ratio is always ½ since hierarchical prediction is used – see Fig. 3. Similarly, the backward motion vector of the interpolated block is determined by scaling the inverted motion vector $-\mathbf{v}_i$ by ½. This operation generates the initial

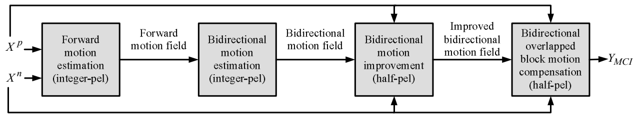

Fig. 2. Proposed motion compensated interpolation.

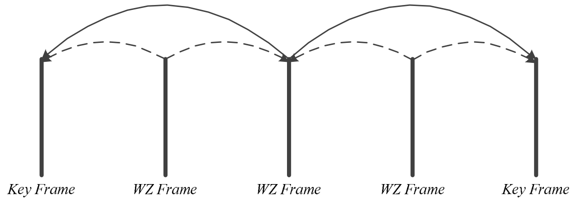

Fig. 3. Motion compensated interpolation structure for GOP size 4.

bidirectional motion field between the interpolated frame and both reference frames.

Subsequently, the obtained bidirectional motion field is further improved. Similar to [18], the algorithm searches for symmetric motion vector pairs, corresponding to linear motion trajectories, around the initially determined motion vector pair. This procedure employs the SAD between the referred blocks in the previous and next reference frames as an error metric and supports half-pel motion estimation accuracy [23]. The required interpolation for half-pel motion estimation is performed using the 6-tap interpolation filter of H.264/AVC [2]. Contrary to [18], no subsequent motion field smoothing is performed.

In the last step of our MCI algorithm, bidirectional overlapped block motion compensation (OBMC) is performed using the previously derived bidirectional motion field, yielding the interpolated frame.

4. SIDE-INFORMATION ENHANCEMENT

This section details the proposed algorithm which improves the quality of the side-information after decoding the WZ DC coefficient band. The critical concept at the basis of the proposed algorithm is the fact that after decoding the DC coefficient band, the WZ decoder has an improved approximation of the WZ frame at its disposal, which can be used to significantly improve the quality of the already obtained side-information. The proposed algorithm is executed in the pixel-domain in order to avoid a complex overcomplete DCT representation. Therefore, prior to side-information refinement, the initial DCT transformed side-information is updated with the decoded DC band coefficients and an inverse DCT is performed, yielding the partially decoded WZ frame. The proposed side-information refinement technique uses the available partially decoded WZ frame to perform motion estimation employing the previous, X^p, and the next, X^n, reference frame. In contrast to the MCI method described in Section 3, in which motion estimation was performed blindly, the proposed refinement technique enables asymmetric bidirectional motion search. Moreover, in the proposed technique, the motion estimated blocks are considered overlapping so as to decrease the energy of the prediction error.

In particular, let $\tilde{X}$ be the partially decoded WZ frame after DC coefficient band decoding and reconstruction. Similar to our work in [24], the WZ frame is divided into overlapping spatial blocks, of 16×16 pixels with an overlapping step of 4 pixels. For each overlapping block in $\tilde{X}$, the best matching block within a search range of 20 pixels, is found in the previous reference frame X^p. The employed EM for block matching is the SAD metric. That is, the derived forward motion vector $\mathbf{v}^F$ is

$$\mathbf{v}^F = \arg\min_{\mathbf{v}^F} \sum_{i=0}^{15}\sum_{j=0}^{15} \left| \tilde{X}_{\mathbf{m}}(i,j) - X^p_{\mathbf{m}-\mathbf{v}^F}(i,j) \right|, \quad (2)$$

where, $\tilde{X}_{\mathbf{m}}(i,j)$ denotes the sample values at position (i,j), $0 \le i,j \le 15$, in the block of size 16×16 samples with top-left coordinates $\mathbf{m} = (m_x, m_y)$ in $\tilde{X}$. Also, $X^p_{\mathbf{m}-\mathbf{v}}(i,j)$ represents the sample values of a motion displaced block in X^p. In an analog manner, the backward motion vector $\mathbf{v}^B$ per overlapping block in the partially decoded WZ frame is

$$\mathbf{v}^B = \arg\min_{\mathbf{v}^B} \sum_{i=0}^{15}\sum_{j=0}^{15} \left| \tilde{X}_{\mathbf{m}}(i,j) - X^n_{\mathbf{m}-\mathbf{v}^B}(i,j) \right|. \quad (3)$$

Next, per overlapping block, the proposed technique selects the best prediction direction. Namely, for every overlapping block, the algorithm retains only the motion vector (forward or backward) which provides the minimum SAD value.

Since the motion estimated blocks in the partially decoded WZ frame $\tilde{X}$ are overlapping, each pixel $\tilde{X}(i,j)$ in the partially decoded WZ frame belongs to several overlapping blocks $\tilde{X}_{\mathbf{m}_n}$. For each overlapping block, OBME has identified the best temporal predictor in the previous or in the next reference frame, denoted by $X^T_{\mathbf{m}_n-\mathbf{v}^T_n}$. Therefore, each pixel $\tilde{X}(i,j)$ in the partially decoded WZ frame has a number of pixel predictors from the two reference frames. This information is taken into account during compensation. In particular, the estimated value of a pixel in the refined side-information frame, denoted by $Y_{DC-OBME}(i,j)$, is determined as the mean value of the predictor pixel values determined by OBME, that is

$$Y_{DC-OBME}(i,j) = \frac{1}{N_{\mathbf{m}_n-\mathbf{v}^T_n}} \sum_{n=1}^{N} X^T_{\mathbf{m}_n-\mathbf{v}^T_n}(i_n, j_n) \quad (4)$$

where, $N_{\mathbf{m}_n-\mathbf{v}^T_n}$ is the number of predictors for the refined side-information pixel $Y_{DC-OBME}(i,j)$.

We notice that the presented algorithm performs bidirectional multi-hypothesis pixel-based prediction, thereby reducing blocking artifacts while simultaneously improving side-information generation. In the following, this algorithm is referred to as the DC-OBME side-information refinement method.

5. EXPERIMENTAL RESULTS

This section evaluates the performance of the presented TDWZ codec equipped with the proposed techniques to generate side-information at the decoder. The experimental results are presented in two stages. At first, we evaluate the performance of the proposed system using our motion compensated interpolation method. Next, we show the compression gains brought by the proposed DC-OBME side-information refinement method. To appraise the coding efficiency of the proposed DVC codecs, various state-of-the-art low-cost encoding codecs have been selected as benchmarks, namely DISCOVER [6], H.264/AVC Intra and H.264/AVC No Motion [2]. The considered test conditions include all frames of Foreman, Carphone, Football, and Soccer sequences, at QCIF resolution, a frame rate of 15Hz, and a GOP size of 4. As in [6], in order to maintain a constant quality of the decoded sequence, the QPs of the H.264/AVC intra coded frames and the QMs of the Wyner-Ziv frames are carefully selected.

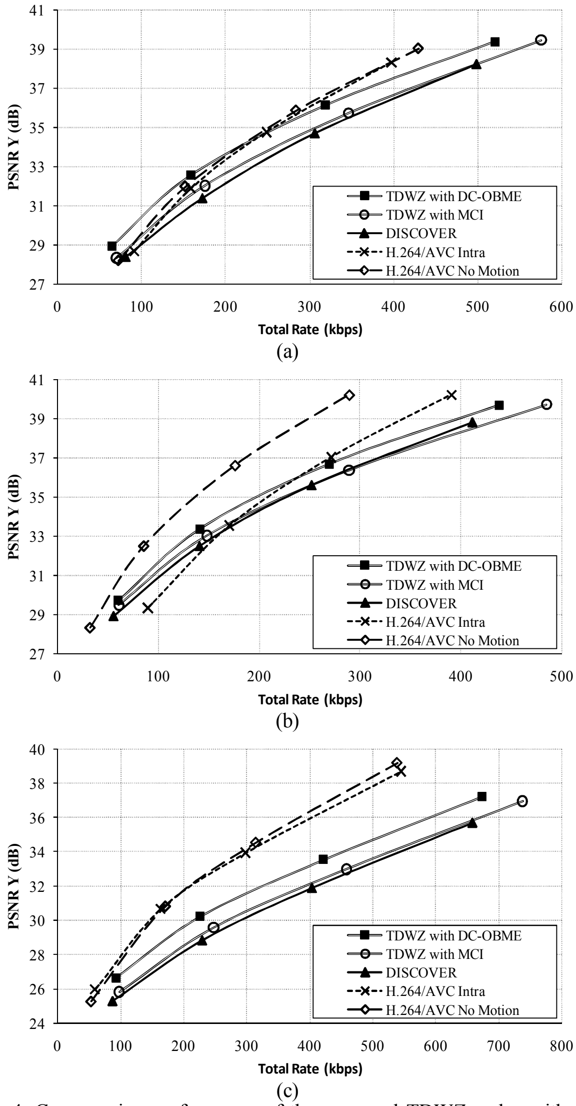

Fig. 4. Compression performance of the proposed TDWZ codec with and without DC-OBME refinement in (a) Foreman, (b) Carphone, and (c) Football, QCIF at 15Hz; a GOP of 4 is considered.

In the beginning, we evaluate the performance of the proposed TDWZ codec without the DC-OBME side-

TABLE I
BJØNTEGAARD GAINS OF THE PROPOSED MCI-BASED TDWZ CODEC WITHOUT DC COEFFICIENT BAND REFINEMENT AGAINST DISCOVER [6].

Sequence	ΔR (%)	ΔPSNR (dB)
Foreman (QCIF)	-7.29	0.42
Carphone (QCIF)	-2.90	0.17
Football (QCIF)	-6.14	0.35
Average	-5.44	0.31

TABLE II
BJØNTEGAARD GAINS OF THE PROPOSED DVC CODEC WITH DC COEFFICIENT BAND REFINEMENT AGAINST OUR MCI-BASED TDWZ CODEC AND DISCOVER [6].

Sequence	vs. MCI-based TDWZ		vs. DISCOVER	
	ΔR (%)	ΔPSNR (dB)	ΔR (%)	ΔPSNR (dB)
Foreman (QCIF)	-16.25	0.93	-22.90	1.35
Carphone (QCIF)	-10.99	0.57	-13.57	0.73
Football (QCIF)	-17.55	1.05	-23.22	1.40
Average	-14.93	0.85	-19.90	1.16

information enhancement method. The experimental results, depicted in Fig. 4, show that the proposed MCI-based TDWZ codec delivers higher compression performance than the state-of-the-art DISCOVER codec. The corresponding Bjøntegaard (BD) [25] gains, which are summarized in Table I, show that the presented TDWZ codec yields average BD rate and PSNR improvements of 5.44% and 0.31dB, respectively. Since both codecs employ the same H.264/AVC Intra frame codec and the same QPs, one concludes that the presented TDWZ codec performs more efficient Wyner-Ziv coding compared to DISCOVER. This performance gain is mainly attributed to the employed MCI method, which in contrast to [18], [19], comprises bi-directional overlapped block motion compensation, as explained in Section 3.

In the following, we assess the compression gains brought by the proposed DC-OBME side-information refinement method presented in Section 4. The experimental results – see Fig. 4, show that our TDWZ codec equipped with the proposed side-information refinement technique consistently yields the best rate-distortion (RD) performance among the evaluated DVC codecs. Table II summarizes the BD improvements brought by the proposed technique compared to our MCI-based TDWZ codec and DISCOVER. One observes that the proposed side-information refinement with DC-OBME brings average BD savings of 14.93% with respect to our MCI-based TDWZ codec. When compared to the state-of-the-art DISCOVER codec, the presented TDWZ with side-information refinement yields notable average BD rate and PSNR improvements of 19.9% and 1.16dB, respectively. We note that the obtained compression gains increase with the amount of irregular motion in the coded sequence. For instance, we observe that our TDWZ codec with DC-OBME refinement brings significant BD gains of 22.9% and 23.22% over DISCOVER in Foreman and Football, respectively. We also notice that, due to the employment of DC-OBME in the proposed side-information refinement method, the obtained compression gains are systematic across all rates – see Fig. 4. This contrasts with other works in the literature, e.g. [17], in which compression gains are mainly obtained in medium and high rates.

In comparison to conventional low complexity codecs, the proposed DVC codec manages to partially outperform H.264/AVC Intra in Foreman and Carphone, and H.264/AVC No Motion in Foreman. In Football, a sequence with very irregular motion characteristics, the proposed codec diminishes the performance gap of DVC with respect to H.264/AVC Intra and No Motion. The obtained coding results underline the benefit of the proposed side-information generation techniques, since Foreman and Football are sequences exhibiting very complex motion.

Finally, we endeavor a comparison against alternative side-information refinement techniques available in the literature. In particular, the proposed technique outperforms the method of [16] by 15% and 17.14% in DB rate reduction in Foreman and Soccer, QCIF, 15Hz, GOP4, respectively. Furthermore, compared to the method presented in [17], the proposed technique brings average BD rate gains of 10.42% and 13.68% in Foreman and Soccer, QCIF, 15Hz, GOP4, respectively.

6. CONCLUSIONS

This work addresses the problem of efficient side-information generation in transform-domain Wyner-Ziv video coding. A novel technique, which comprises side-information refinement, is presented. In order to produce an intermediate version of the side-information, the proposed codec employs an advanced MCI technique featuring bidirectional OBMC. After DC coefficient band decoding, the proposed approach performs side-information refinement based on OBME. Contrary to other works in the literature, the proposed technique alleviates the need for an overcomplete DCT transform, thereby reducing the computational load at the decoder. The experimental results show that the presented TDWZ codec, incorporating the proposed side-information generation framework, achieves significant and consistent compression gains over the state-of-the-art DISCOVER codec.

7. ACKNOWLEDGEMENTS

This work was supported by the Fund for Scientific Research (FWO) Flanders (post-doctoral fellowship of P. Schelkens), the projects G.0391.07 and G.0146.10 and by the Flemish Institute for the Promotion of Innovation by Science and Technology (PhD bursary Frederik Verbist).

8. REFERENCES

[1] Z. Xiong, A. Liveris, and S. Cheng, "Distributed source coding for sensor networks," *IEEE Signal Processing Magazine,* vol. 21, pp. 80-94, September 2004.

[2] T. Wiegand, G. J. Sullivan, G. Bjøntegaard, and A. Luthra, "Overview of the H.264/AVC video coding standard," *IEEE Transactions on Circuits and Systems for Video Technology,* vol. 13, pp. 560-576, July 2003.

[3] B. Macchiavello, D. Mukherjee, and R. L. de Queiroz, "Iterative side-information generation in a mixed resolution Wyner-Ziv framework," *IEEE Transactions on Circuits and Systems for Video Technology,* vol. 19, pp. 1409-1423, October 2009.

[4] R. Puri, A. Majumdar, and K. Ramchandran, "PRISM: A video coding paradigm with motion estimation at the decoder," *IEEE Transactions on Image Processing,* vol. 16, pp. 2436-2448, October 2007.

[5] B. Girod, A. Aaron, S. Rane, and D. Rebollo-Monedero, "Distributed video coding," *Proceedings of the IEEE,* vol. 93, pp. 71-83, January 2005.

[6] X. Artigas, J. Ascenso, M. Dalai, S. Klomp, D. Kubasov, and M. Quaret, "The DISCOVER codec: Architecture, techniques and evaluation," in *Picture Coding Symposium, PCS 2007*, Lisboa, Portugal, 2007.

[7] G. Petrazzuoli, M. Cagnazzo, and B. Pesquet-Popescu, "High order motion interpolation for side information improvement in DVC," in *IEEE International Conference on Acoustics, Speech and Signal Processing*, Dallas, TX, 2010.

[8] M. Cagnazzo, W. Miled, T. Maugey, and B. Pesquet-Popescu, "Image interpolation with edge-preserving differential motion refinement," in *IEEE International Conference on Image Processing*, Cairo, Egypt, 2009, pp. 361-364.

[9] X. Artigas and L. Torres, "Iterative generation of motion-compensated side-information for distributed video coding," in *IEEE International Conference on Image Processing*, Genoa, Italy, 2005, pp. 833-836.

[10] J. Ascenso, C. Brites, and F. Pereira, "Motion compensated refinement for low complexity pixel based distributed video coding," in *IEEE Conference on Advanced Video Signal Based Surveillance*, Como, Italy, 2005, pp. 593-598.

[11] A. B. B. Adikari, W. A. C. Fernando, W. A. R. J. Weerakkody, and H. K. Arachchi, "Sequential motion estimation using luminance and chrominance information for distributed video coding of Wyner-Ziv frames," *IEE Electronic Letters,* vol. 42, pp. 398-399, March 2006.

[12] W. A. R. J. Weerakkody, W. A. C. Fernando, J. L. Martinez, P. Cuenca, and F. Quiles, "An iterative refinement technique for side-information generation in DVC," in *IEEE Internation Conference on Multimedia and Expo*, Beijing, China, 2007, pp. 164-167.

[13] X. Fan, O. Au, N. M. Cheung, Y. Chen, and J. Zhou, "Successive refinement based Wyner-Ziv video compression," *Signal Processing: Image Communication,* vol. 25, pp. 47-63, 2010.

[14] D. Varodayan, D. Chen, M. Flieri, and B. Girod, "Wyner-Ziv coding of video with unsupervised motion vector learning," *Signal Processing: Image Communication,* vol. 23, pp. 369-378, June 2008.

[15] M. B. Badem, M. Mrak, and W. A. C. Fernando, "Side information refinement using motion estimation in DC domain for transform-based distributed video coding," *IEE Electronics Letters,* vol. 44, Jul. 2008.

[16] S. Ye, M. Ouaret, F. Dufaux, and T. Ebrahimi., "Improved side information generation for distributed video coding by exploiting spatial and temporal correlations," *EURASIP Journal on Image and Video Processing,* vol. 2009, pp. 1-15, 2009.

[17] R. Martins, C. Brites, J. Ascenso, and F. Pereira, "Refining side information for improved transform domain Wyner-Ziv video coding," *IEEE Transactions on Circuits and Systems for Video Technology,* vol. 19, pp. 1327-1341, Sep. 2009.

[18] J. Ascenso, C. Brites, and F. Pereira, "Improving frame interpolation with spatial motion smoothing for pixel domain distributed video coding," in *5th EURASIP Conference on Speech and Image Processing, Multimedia Communications and Services*, Smolenice, Slovac Republic, 2005.

[19] J. Ascenso, C. Brites, and F. Pereira, "Content adaptive Wyner-Ziv video coding driven by motion activity," in *IEEE International Conference on Image Processing*, Atlanta, GA, 2006.

[20] C. Brites, J. Ascenso, J. Q. Pedro, and F. Pereira, "Evaluating a feedback channel based transform domain Wyner-Ziv video codec," *Signal Processing: Image Communication,* vol. 23, pp. 269-297, April 2008.

[21] C. Brites and F. Pereira, "Correlation noise modeling for efficient pixel and transform domain Wyner-Ziv video coding," *IEEE Transactions on Circuits and Systems for Video Technology,* vol. 18, pp. 1177-1190, September 2008.

[22] D. Varodayan, A. Aaron, and B. Girod, "Rate-adaptive codes for distributed source coding," *Signal Processing, Elsevier,* vol. 86, pp. 3123–3130, 2006.

[23] S. Klomp, Y. Vatis, and J. Ostermann, "Side information interpolation with sub-pel motion compensation for Wyner-Ziv decoder," in *International Conference on Signal Processing and Multimedia Applications*, Setúbal, Portugal, 2006.

[24] N. Deligiannis, A. Munteanu, T. Clerckx, J. Cornelis, and P. Schelkens, "Overlapped block motion estimation and probabilistic compensation with application in distributed video coding," *IEEE Signal Processing Letters,* vol. 16, pp. 743-746, September 2009.

[25] G. Bjøntegaard, "Calculation of average PSNR differences between RD-curves," ITU-T Video Coding Experts Group (VCEG),, Austin, TX, Document VCEG-M33, April 2001.