In Proc. of PW-EI-VCIP'99, San Jose, CA, USA, January 1999

Modified Overlapped Block Disparity Compensation for Stereo Image Coding

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ABSTRACT

In this paper, we propose a modified overlapped block matching (OBM) scheme for stereo image coding. The OBM scheme has been introduced in video coding, as a promising way to reduce blocking artifacts by using multiple vectors for a block, while maintaining the advantages of the fixed size block matching framework. However, OBM has its own limitations, even though it overcomes some drawbacks of block matching schemes. For example, to estimate an optimal displacement vector (DV) field, OBM requires complicated iterations. In addition, OBM does not always guarantee a consistent DV field, even through several iterations, because the estimation considers only the magnitude of the prediction error as a measure. Therefore, we propose a modified OBM scheme, which allows both consistent disparity estimation and efficient disparity compensation, without several iterations. In the proposed scheme, the computational burden resulting from iterations is reduced using "open-loop" coding, which decouples the encoding into estimation and compensation. The consistent disparity estimation is performed by using a causal MRF model and a half-pixel search, while maintaining (or reducing) the energy level of disparity compensated difference frame. The compensation efficiency is improved by interpolating the reference image in half pixel accuracy and by applying OBM in part. To prove the efficiency of the proposed OBM scheme, we provide some experimental results, which show that the proposed scheme achieves higher PSNR, about 0.5-1 dB, as well as better perceptual quality, at a fraction of the computation, as compared to a conventional OBM.

Keywords : stereo image coding, disparity estimation, overlapped block, MRF, half pixel search

1 Introduction

In general, the overall bit rate of a coded stereo pair can be reduced by using predictive coding exploiting the inherent similarity, *i.e.* the "binocular" dependency along the disparity vector (DV), in the pair. In coding of stereo images/video, as well as monocular video, fixed size block matching (FSBM), rather than pixel or feature, techniques have been widely used because FSBM is simple and effective to implement [1, 2]. On the assumption that a proper block size is selected by tradeoffs between rate and distortion [3], a main advantage of FSBM is that it eliminates the need for any overhead to specify the location of each block and thus it is only necessary to store or transmit the block-based DV field and the corresponding disparity compensated difference (DCD) frame. The central idea in the FSBM-based predictive coding is to use one image in the pair as a reference (F_1 or $F_1(Q_1)$) and to estimate the dependent image (the target, F_2) by finding best matches. Then, the resulting $DCD(Q_2)$ is encoded to improve the quality of F_2. Therefore, as shown in Figure 1, the encoding performance can be controlled by disparity estimation/compensation (DE/DC) and quantization, *i.e.* (V, Q_1, Q_2), where V and Q denote a DV field and a set of quantizers. In this paper, we assume that optimal quantizers (Q_1, Q_2) can be selected[1] and then focus only on efficient DE/DC.

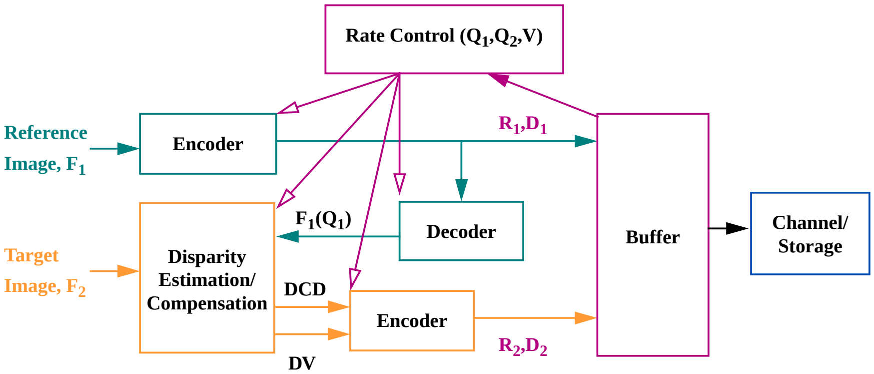

Figure 1: Block diagram of a general encoder for stereo images, where the encoder consists of disparity estimation/compensation, transform/quantization and entropy coding.

In spite of its effectiveness and robustness, FSBM is suboptimal in terms of rate-distortion (RD) because of several well-known drawbacks such as (a) inconsistent estimation, (b) poor compensation and (c) blocking artifacts. Both inaccurate estimation and poor compensation are inevitable and result in extra bits for the encoding of the DV field and the DCD frame. Another annoying problem of FSBM is in the block boundaries. Especially at low rate coding, both the inconsistency and poor compensation generate annoying blocking artifacts at the reconstructed target image. Accordingly, an efficient disparity estimation/compensation (DE/DC) has been a main focus of the research on stereo image/video coding since the pioneering work by Lukacs [2, 6–10]. However, the various proposed schemes only relieve those problems in part. For example, DE with Markov random field (MRF) model can overcome the inconsistency by taking advantage of disparity information of neighboring blocks [7, 11, 12]. Subspace projection is another way to estimate a smooth DV field [10]. However, both schemes have limitations in reducing the energy level of the DCD frame. The energy level of the DCD frame can be reduced using non-integer (half or quarter) pixel-based search but it increases the rate of the DV field. Blocking artifacts also can be reduced by adopting various methods such as post processing, segmentation-based estimation/compensation, etc. However, many post-processing algorithms degrade the quality of the whole image as well as block boundaries. Also, the cost to pay for the segmentation is the increasing overhead to describe the structure of the segmentation [8, 13, 14].

Another promising way to improve encoding efficiency is overlapped block matching (OBM), which reduces blocking artifacts by linearly combining multiple blocks provided by the vectors of a block and its neighbors [15–17]. For practical implementations, non-iterative OBM schemes have been proposed. For example, windowed BM is applied for DE, without considering effects of neighboring blocks, and OBM is performed only for DC [18, 19]. Note however that these schemes do not always provide an optimal DV field for overlapped disparity compensation (OBDC), and even the DV field itself may not be optimal because the estimation only depends on the prediction error, *i.e.* mean square error (MSE) or mean absolute error (MAE) of the block. Meanwhile, an optimal DV field estimation for OBM requires complicated iterative schemes to resolve the noncausal spatial interaction among DVs of neighboring blocks. Thus, in conventional approaches, a “two-step procedure” is usually adopted to

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[1] The blockwise optimal quantization or dependent bit allocation problem for FSBM is studied in [4, 5].

resolve the non-causality problem, *i.e.* an initial DV field is estimated using FSBM and the DV field is refined to improve the encoding performance. This process repeats until the DV field converges. This iterative process makes optimal OBM difficult in real-time applications [15]. Therefore, to reduce computational complexity modified OBM schemes, such as raster scan OBM [20] or checkerboard scan OBM [21, 22], have been proposed, at the cost of slightly reduced performance. Note however that those schemes do not always guarantee a smooth displacement (disparity or motion) vector field. Due to its inconsistency, the overhead may be high in case of that the DV field is differentially encoded using variable-length codes. Another weakness of OBM stems from the fixed shape of the window. Note that spreading compensation errors tends to reduce blocking artifacts, but it might degrade compensation efficiency particularly for those blocks, which can be compensated effectively without OBM. Orchard *et al.* showed that the optimal shape of the OBDC window could be determined with the knowledge of the correlation matrix of the image [15]. However, the required computational complexity is extremely high for the adaptive window to be implemented in real-time applications.

Therefore, in this paper, we propose an effective but non-iterative OBM scheme for stereo image coding. In the proposed scheme, the computational complexity resulting from the iterative estimation has been reduced using an "open-loop" framework, which decouples encoding into two steps, *i.e.* disparity estimation and then disparity compensation. The *DE with a modified MRF model and half pixel search* results in a smooth DV field without increasing excessively the energy level of the prediction error and thus reduces bit rate for the DV field. Then, a given smooth DV field, the *overlapped block disparity compensation (OBDC) in half pixel accuracy* is selectively applied. Accordingly, the shape of OBM window is adaptively changed to prevent the oversmoothing problem and thus it lowers the energy level of the DCD frame and the OBDC complexity.

The main novelty of the proposed OBM scheme is in that the overall encoding performance for the target image is achieved by estimating a smooth DV field, while reducing the energy level of the DCD frame, at a fraction of the computation, over conventional OBM schemes. To verify the effectiveness, we compare the RD performance of the proposed hybrid scheme with various FSBM-based DE/DC schemes such as (i) simple FSBM, (ii) FSBM with MRF model and (iii) OBM. According to our experimental results, the proposed scheme achieves about 0.5-1 dB gain in terms of PSNR as well as better perceptual quality, when compared to conventional OBM. Note that the resulting smooth DV field also helps generate intermediate-views with lower visual artifacts in the decoder. The proposed scheme can also be applicable to video coding without loss of generality.

This paper is organized as follows. In Section 2, we describe the proposed two-step hybrid scheme, the modified OBM with MRF model and half-pixel search. In Section 3, we provide some experimental results to compare the effectiveness of the proposed scheme. Conclusions are summarized in Section 4.

2 Modified OBM for Stereo Image Coding

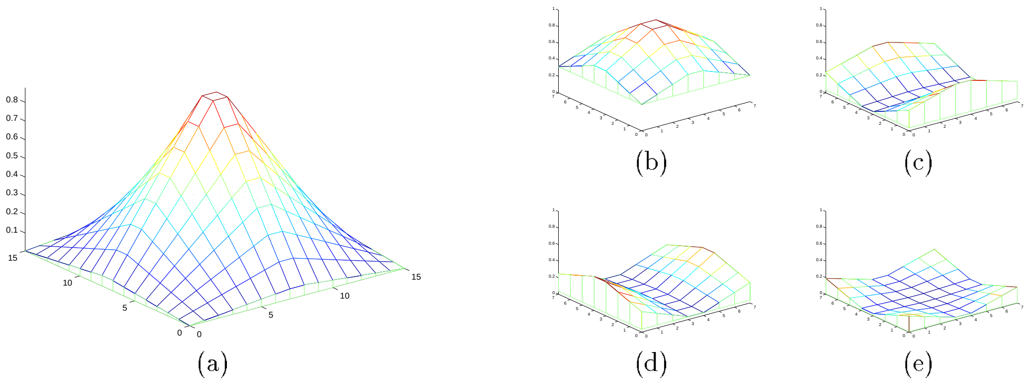
Using open-loop framework decouples the encoding into estimation and compensation, which allows non-iterative DE/DC. In general, however, non-iterative schemes may not provide an optimal DV field for OBDC. Therefore, we propose an alternative DE/DC strategy to overcome the non-optimality problem. We first estimate a smooth DV field using OBM with a modified MRF model and half-pixel search, which is an optimal in terms of the DV field. Then, a given smooth DV field, we adaptively compensate the target image with the proposed modified OBDC scheme.

2.1 Notation and Definition

Let the target image F_2 be segmented into non-overlapping square blocks, *i.e.* $F_2 = \{f_{ij}^2, (i,j) \in \Omega\}$, where f_{ij} denotes the (i,j)-th block and Ω represents a discrete and rectangular lattice, *i.e.* $\Omega = \{(i,j) | 0 \leq i < N_x, 0 \leq j <$

$N_y\}$, where N_x and N_y, respectively, are the number of blocks in vertical and horizontal directions. We define the (i,j)-th overlapping block in the target image s^2_{ij}. In conventional FSBM, $s_{ij} = f_{ij}$ and thus each target block is estimated from only one block in the reference image, *i.e.* $\hat{f}^2_{ij} = f^1_{ij\oplus v_{ij}}$ where $\oplus$ represents a block movement along the disparity vector v_{ij}. The resulting blockwise DV field can be represented as $V = \{v_{ij}, (i,j) \in \Omega\}$. Meanwhile, in OBDC, each block is estimated/compensated as a windowed-sum of a block and its neighboring blocks along the corresponding DVs.

In general, the overlapped window W is designed to decay toward the boundaries on the assumption that blockwise estimation error increases as a pixel moves away from the block center and the increase is symmetric with respect to the block center [23]. Another property of the window is that the windowed-sum over the image is identical to the original image, *i.e.* $I = \sum_\eta W_\eta$, where W_η denotes window components affecting compensation for a block. Typical selections for the overlapped window are the sinusoidal and the bilinear windows [2]. Optimal shape of the overlapped window also can be considered but the improvement is not a significant for the computational complexity [15]. In our experiments, therefore, we adopt the bilinear window as shown in Figure 2 (a). Window components corresponding to each region of a block are shown in Figure 2 (b)-(e).



(b) (c)

(a) (d) (e)

Figure 2: Bilinear window function for the overlapped block matching and its combined weighting matrices. (a) Bilinear OBM window (16 × 16) (b) Main ($\hat{f}^2_{ij\oplus v_{ij}}$) (c) Horizontal ($\hat{f}^2_{ij(N)\oplus v_{i-1j}}, \hat{f}^2_{ij(S)\oplus v_{i+1j}}$) (d) Vertical ($\hat{f}^2_{ij(W)\oplus v_{ij-1}}, \hat{f}^2_{ij(E)\oplus v_{ij+1}}$) (e) Corner ($\hat{f}^2_{ij(NW)\oplus v_{i-1j-1}}, \hat{f}^2_{ij(NE)\oplus v_{i-1j+1}}, \hat{f}^2_{ij(SW)\oplus v_{i+1j-1}}, \hat{f}^2_{ij(SE)\oplus v_{i+1j+1}}$). The capital letters (N,W,S,E) denote locations of quadrants of a block, *i.e.* north, west, south, and east, respectively.

The bilinear window is separable and thus the selected $2B \times 2B$ window W is defined as follows,

$$\begin{aligned} W(m,n) &= W_m \times W_n \\ W_m = W_n &= \begin{cases} \frac{m+0.5}{B}, & 0 \leq m < B \\ W_{2B-m-1}, & B \leq m < 2B \end{cases} \end{aligned} \tag{1}$$

where W_m and W_n denote the separable vertical and horizontal windows, respectively.

2.2 Disparity Estimation Using Overlapped Windowed

Figure 3 shows the DE using overlapped window and smoothness constraint. In general, the DV field by the overlapped window is not likely to be consistent because the MSE/MAE-based prediction is sensitive to various noise effects such as intensity variation. Note that the two images in a pair may have slightly different intensity

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[2] Note that FSBM can be considered as a OBM with a rectangular function.

levels due to the camera noise and lighting condition. In addition, lack of texture and/or repetitive texture may disturb consistent estimation.

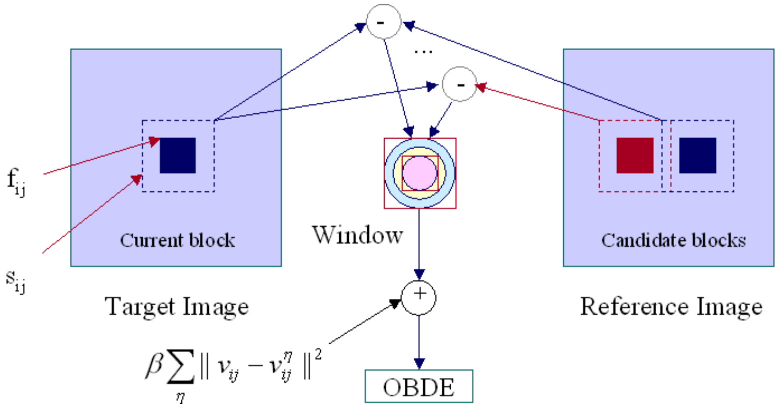

Figure 3: Disparity estimation based on block matching with an enlarged window. In the target image, colored and dashed areas correspond to a block, f_{ij}, and an enlarged block, s_{ij}, respectively.

Therefore, we introduce an MRF model to estimate a smooth DV field by considering the DV field and the estimation error together. In general, conventional MRF-based schemes have high computational complexity because they require several (stochastic) iterations to estimate an optimal (pixelwise) dense DV field [24]. Thus, we propose a simplified blockwise DE scheme for stereo image coding, which estimates a smooth DV field without complicated iterations by considering only blocks in a 1^{st} order causal neighborhood as shown in Figure 4. Meanwhile, the same neighborhood is used for encoding the DV field, *i.e.* the difference between v_{ij} and the median of its causal neighborhood is encoded using DPCM. As a result, estimating a smooth DV field contributes to reducing side information, which is essential especially at low rate coding.

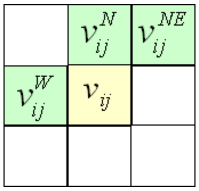

Figure 4: A first order causal neighborhood. The same neighborhood is used in the encoding of the DV field, *i.e.* $DPCM(v_{ij}) = v_{ij} - median(v_{ij}^{W}, v_{ij}^{N}, v_{ij}^{NE})$.

Based on MRF model and the *maximum a posteriori probability* (MAP) estimation, for a given a pair of stereo images (F_1, F_2), the optimal DV filed V is estimated by minimizing the cost function $U(V|F_1, F_2)$ defined as follows [7,8],

$$\begin{aligned} U(V|F_1,F_2) &= U(F_2|F_1,V) + U(V) \\ &\propto \sum_{(i,j)\in\Omega} \{ ||W \times (s_{ij}^{2} - s_{ij\oplus v_{ij}}^{1})||^2 + \beta \sum_{\eta} ||v_{ij} - v_{ij}^{\eta}||^2 \} \end{aligned} \tag{2}$$

where η denotes a neighborhood and $\beta (> 0)$ is a weighting constant controlling the degree of smoothness. Each term of the right side in (2) represents the constraints of the similarity between stereo image for a given disparity and an *a priori* assumption on the smoothness of the DV field. In this framework, if we set $\beta = 0$ and $s_{ij} = f_{ij}$, (2) corresponds to conventional FSBM, which only assumes that the image intensities in the stereo pair are similar along the DV.

Note that, in the proposed scheme, the choice of model parameters is relatively robust. For example, a small fixed weight (*e.g.* $\beta = 0.1$) is enough for the smoothness term regardless of images because the smoothness constraint is exploited only to avoid various local minima in DE[3]. However, conventional MRF schemes, mainly developed in computer vision, require selecting an "optimal" set of weighting parameters more carefully.

To further reduce prediction error, the DE/DC is performed in half pixel accuracy. The projected images in a stereo pair are sub-sampled versions of real scene and thus the resulting correspondence between two images may not be aligned with integer pixel location. Therefore, to estimate/compensate the target image on the interpolated reference image along the disparity helps estimate more accurate DV field and thus reduces the energy of the DCD frame. The performance can be increased by adopting more elegant interpolation methods such as ideal filter (*e.g.* sinc function) or Wiener filter [25, 26]. Clearly the higher the subpixel accuracy (*i.e.* the larger displacement space), the greater the probability of finding a good match. Note however that we cannot choose arbitrary small value because, as the subpixel accuracy increases, at the same time, both the rate for the resulting DV field and the number of being compared candidate blocks in the search area are increased. In our experiments, as a compromise, we use bilinear interpolation, as used in most video coding standards, to obtain the half-pixel precision intensity value.

In general, OBDC is efficient only when high frequency components exist in the block. Thus, during the DE, a block with higher prediction error than a threshold is selected as an OBDC candidate. The DCD is calculated by taking the difference between the predicted block and the original block in the target image, *i.e.* $DCD = f_{ij}^2 - \hat{f}_{ij}^2$. Thus, $\phi_{ij}^0 = 1$, if $|DCD| > T_\phi$. Then, after the DE with overlapping window, the DVs for those blocks with $\phi_{ij}^0 = 1$ are refined by considering the effects of neighboring blocks, *i.e.* OBDC. For each block with $\phi_{ij}^0 = 0$, if the energy level of the DCD using OBDC is lower as compared to block DC (BDC), then a new DV is assigned to the block. Meanwhile, the block having the same DV with its neighbors is also selected $\phi_{ij} = 1$, because OBDC is not efficient due to its computational complexity, when the disparity vectors of the neighboring blocks are the same or a block can be compensated effectively without OBDC.

2.3 Encoding of Stereo Images Using Hybrid OBDC

As shown in Figure 5, in conventional OBDC, a target block is compensated from the nine overlapped blocks in the reference image along the corresponding disparity vectors. Thus, the whole compensation is obtained by summing up the window-operated nine blocks.

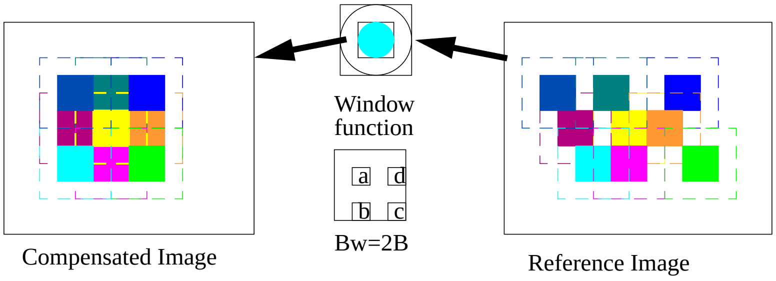

Figure 5: Disparity compensation based on the overlapped block matching. Colored and dashed areas correspond to a block, f_{ij}, and an enlarged block, s_{ij}, respectively.

In the proposed scheme, the bilinear window is selectively applied to those blocks yielding higher prediction errors, *i.e.* $\phi_{ij} = 1$, and BDC to the others. This reduces computational complexity of OBDC, while preventing oversmoothing effects. Figure 6 shows an example of resulting window shapes, when $\phi_{ij} = 0$ and others are one.

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[3] An optimal value of β can be selected by Lagrangian optimization.

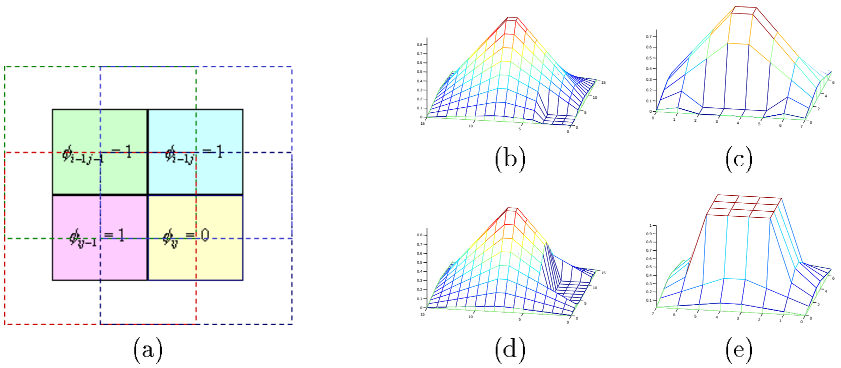


Figure 6: Adaptive windowing for selective overlapped block disparity compensation. (a) Given $\phi_{ij} = 0$ and $\phi_{i-1j-1} = \phi_{i-1j} = \phi_{ij-1} = 1$, OBM windows are changed adaptively according to the ϕ's. OBM windows for (b) s_{i-1j-1} (c) s_{i-1j} (d) s_{ij-1} (e) s_{ij}.

Note that, as shown in Figure 5, in the case of where the window width and height are double of those of block, *i.e.* $B_w = 2 \times B$, one quarter of a block only depends on three neighboring blocks and itself. For example, each pixel in the upper left part (NW) of the target block $f^2_{ij(NW)}$ is compensated by the weighted-sum of only four blocks as follows

$$\hat{f}^2_{ij(NW)} = a \cdot \hat{f}^2_{ij(NW)\oplus v_{ij}} + b \cdot \hat{f}^2_{ij(NW)\oplus v_{i-1j}} + c \cdot \hat{f}^2_{ij(NW)\oplus v_{i-1j-1}} + d \cdot \hat{f}^2_{ij(NW)\oplus v_{ij-1}} \tag{3}$$

where (a, b, c, d) are the parts of the window W as shown in Figure 5. If $\phi_{ij} = 0$, the neighboring blocks are regarded as having the same disparity vectors and thus effects of neighboring blocks are ignored. The resulting OBM window for the block is in Figure 6 (e). Note however that the block with $\phi_{ij} = 1$ affects neighboring blocks.

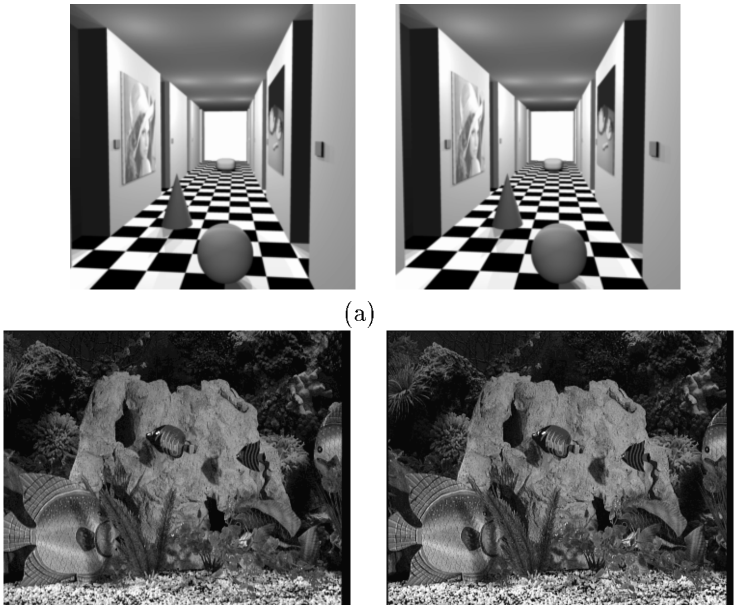
The encoding procedure based on the proposed hybrid OBDC is as follows

- **Step 0** The reference image is independently encoded using JPEG.
- **Step 1** The disparity is estimated using an enlarged bilinear window, *i.e.* $B_w = 2B$. The window function W is operated on the disparity-predicted difference, without considering DE errors of neighboring blocks. For the enlarged block s_{ij}, the resulting difference is obtained as $e_{obm;ij} = \|W \times \{s^2_{ij} - s^1_{ij\oplus v_{ij}}\}\|$. The corresponding DE cost is defined by adding a smoothness constraint as shown in (2). The estimation is performed in half-pixel accuracy.
- **Step 2** Given a DV, a block is determined as an OBDC candidate, if the energy level of the difference, $DCD = f^2_{ij} - \hat{f}^2_{ij}$, is larger than the threshold, *i.e.* $\phi^0_{ij} = 1$, if $|DCD| > T_\phi$.
- **Step3** After DE with windowed BM, for each block with $\phi^0_{ij} = 1$, the DV is refined by considering OBDC. The DV is replaced and the block is selected OBDC block, $\phi_{ij} = 1$, if the resulting DCD has less energy than that of previous one.
- **Step 4** OBDC is selectively performed for those blocks with $\phi_{ij} = 1$ by summing up all windowed compensation blocks based on (3).
- **Step 5** The resulting DV field and DCD frame are encoded using DPCM and JPEG, respectively. For DPCM of the DV field, its median is selected from the pre-defined causal neighborhood.

At the decoder, the reference image is decoded first and then the target image is reconstructed according to ϕ_{ij}, *e.g.* by performing OBDC, if $\phi_{ij} = 0$ and BDC, otherwise. The final target image is reconstructed by summing up the DCD frame, if any.

3 Experimental Results

In this experiment, the right image is selected as reference image and then a constant quantization factor ($Q_1 = 80$) is assigned for the reference image. Exhaustive search is performed within a search range of $[0, \pm 15]$ pixel in half-pixel accuracy. For the images which do not satisfy the parallax constraints, we search ±2 pixels in vertical direction. In order to test the effectiveness of the proposed algorithm, we have simulated for two pairs of stereo images; *a synthesized image*, *Room*, and *an natural scene*, *Aqua*. The image size of pairs are 256×256 and 288×360, respectively. The used stereo pairs are as shown in Figures 7. The decoded images and the used source codes (based on JPEG coder), will be available at `http://escalus.usc.edu/~wwoo/Stereo/`.


(a)

(b)

Figure 7: Stereo pairs. (a) Room (256 × 256) (b) Aqua (288 × 360)

First, we investigate how the size of block affects the RD performance. Figure 8 compares the resulting DV fields of the *Room* image, which are obtained from FSBM for six different block sizes, from 32 × 32 to 1 × 1. Note that as the block size is reduced the resulting disparity field appears to be noisy, even though those DV fields reduce the estimation errors. It results in the increases of the rates for the DV fields and thus may result in worse RD performance than independent encoding such as JPEG.

Figure 9 shows corresponding RD curves with different block sizes. The performance is measured in terms of the bit rates of the encoded image and peak signal to noise ratio (PSNR). As expected, DE/DC-based coding with block provides better coding performance than two independent coding (JPEG) of each image, because DE/DC-based coding takes advantage of the binocular redundancy in a stereo pair. Note however that, as we reduce the block size($\leq 2 \times 2$), obviously the bit rate of the DV field is increased at the cost of reducing the DE error. As a compromise between overhead and the energy of the estimation error, we choose a block size of 8×8

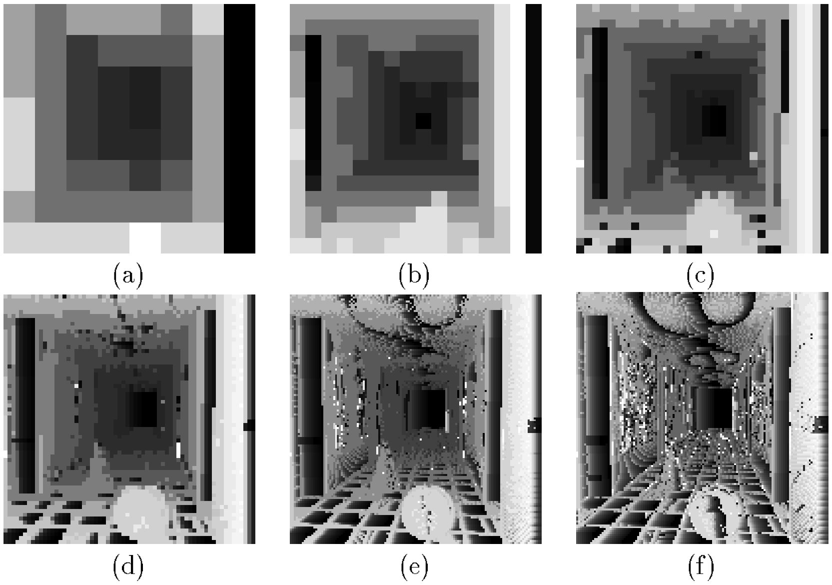


Figure 8: Disparity vector field using FSBM with different size of block (*Room*). (a) 32 × 32 (0.003 bps) (b) 16 × 16 (0.012 bps) (c) 8 × 8 (0.046 bps) (d) 4 × 4 (0.169 bps) (e) 2 × 2 (0.725 bps) (f) 1 × 1 (3.151 bps)

for DE in the following experiments.

Figure 10 (a) and (b) compare corresponding RD plots for the two stereo pairs, *Room* and *Aqua*, respectively. The proposed hybrid OBM scheme is compared with FSBM, MRF and OBM in terms of PSNR and bit rate of the target image. The results of JPEG without disparity compensation are also provided for a reference. Note that, for the natural image pair (Aqua), the RD gain of FSBM is relatively small, as compared to those of *Room*.

As expected, using selective OBDC in half-pixel accuracy reduces the blocking artifacts on the decoded target image. The energy level of the DCD frame is maintained (or slightly increased according to β), while estimating a consistent DV field using smoothness constraint within causal neighbors. The energy level of the DCD frame is further reduced by estimating the target block in half-pixel accuracy. Note that the smoothness term also reduces the increased rate of the DV field due to the half-pixel search. The compensation efficiency is improved and computational complexity reduced by adaptively applying OBDC. Selective OBDC reduces blocking artifacts as well as the rate of the DCD frame, by summing neighboring compensated blocks using changing OBM window. The incorporated half-pixel accuracy further reduces the energy level of the DCD. Consequently, the proposed modified OBM scheme results in an improved overall encoding performance, *i.e.* a lower bit rate for the DV field and DCD frame, while maintaining perceptual quality. According to the experimental results, the proposed modified OBM scheme obtain higher PSNR, about 0.5-1 dB, as well as better perceptual quality, over conventional OBM schemes.

4 Discussion

We presented a novel hybrid DE scheme, modified overlapped block matching with MRF model and half-pel search, for stereo image coding. As shown in our experimental results, the proposed hybrid approach is more efficient than conventional FSBM schemes using OBM or MRF. As expected, MRF-based DE allows a smooth DV field estimation and selective OBDC in half-pixel accuracy results in better compensation by reducing the

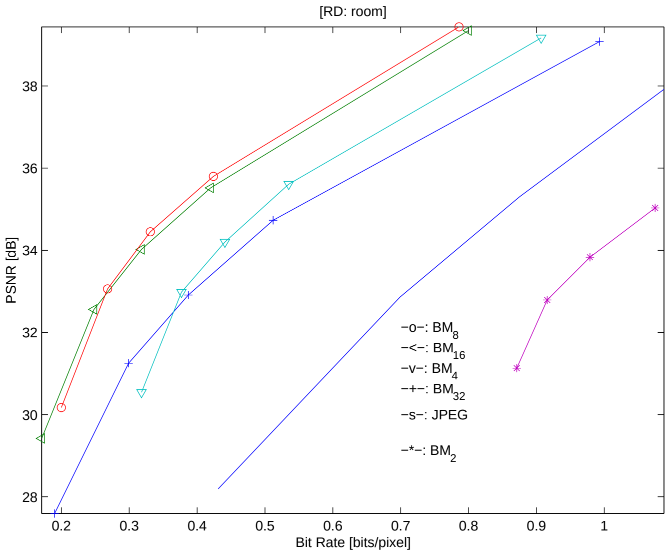


Figure 9: RD plot of FSBM with different block sizes. In the plot, ‘-s-’ denotes a square-mark line, and ‘-¡-’ and ‘-v-’ denote the direction of triangle in the triangle-mark line. The subscript represents the block size. Note that the RD performance of the smaller block (*e.g.* 2×2) is worse than that of JPEG, because the rate for the DV field is too high.

energy level of DCD frame as well as blocking artifacts. As a result, the proposed OBM scheme provides higher PSNR as well as better perceptual quality, over conventional OBDC, at the same rate. It is also worth noting that obtaining a smooth disparity is useful for multi-view video coding since the robustness against noise can help reduce the temporal redundancy between two consecutive disparity fields. The results of the proposed schemes also can be applied into video coding without loss of generality. However, there remain several problems to be improved. The overall encoding performance could be improved by combining the proposed DE scheme and the dependent bit allocation scheme proposed in [4, 5]. New coding scheme taking the statistics of the DCD frame into account, instead of JPEG, can further improve the encoding efficiency.

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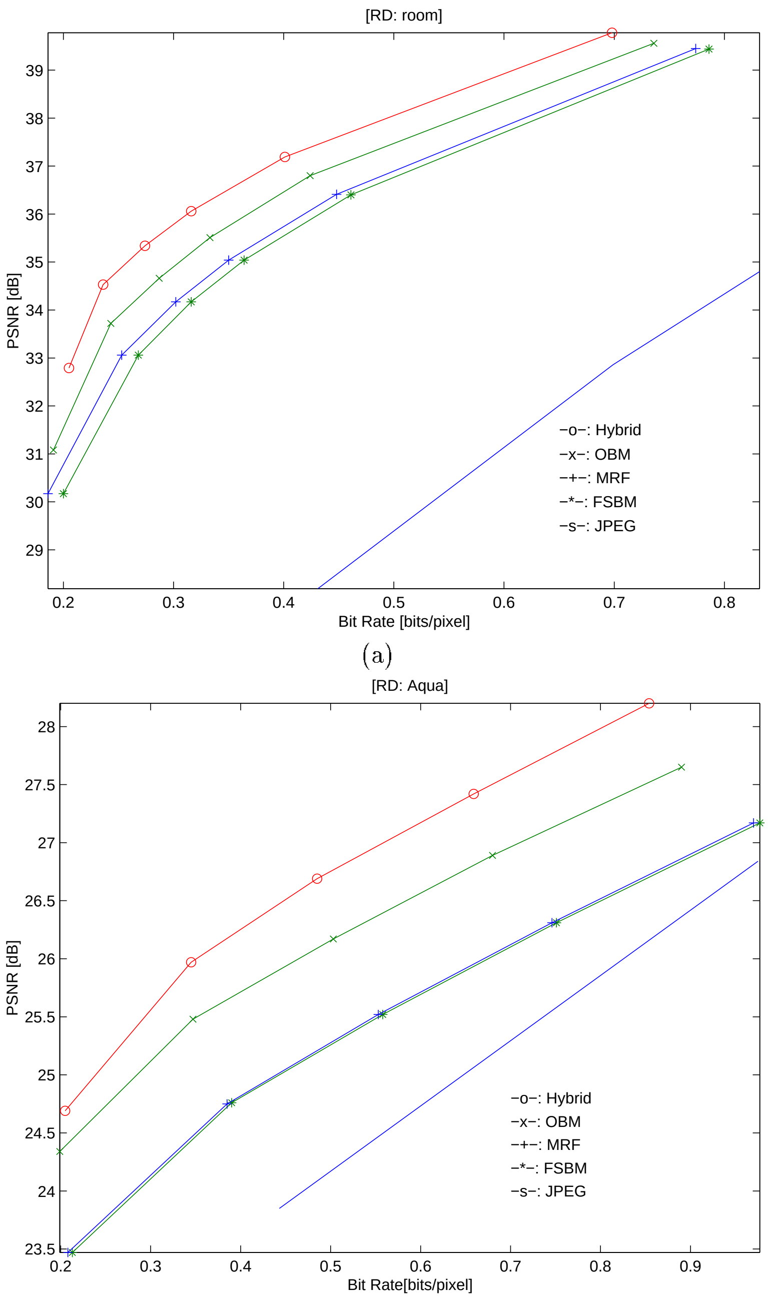

(a)

(b)

Figure 10: The resulting RD plots. (a) *Room* (b) *Aqua*. Various DE/DC methods (block size of 8×8, quality factor for the reference image Qf_1=80): The proposed hybrid scheme is compared with JPEG, FSBM, FSBM with MRF, and OBM. In the plot, '-s-' denotes the square-mark line.

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