Simplified Frame Rate Up-conversion Algorithm with Low Computational Complexity

Ho Sun Jung, Un Seob Kim, and Myung Hoon Sunwoo*

School of Electrical and Computer Engineering, Ajou University
San 5, Woncheon-Dong, Yeongtong-Gu, Suwon, 443-749, Korea
*R&D Center, Telechips Inc.
E-mail: Sunwoo@ajou.ac.kr

ABSTRACT

This paper proposes the efficient Frame Rate Up-conversion (FRUC) that has low computational complexity. The proposed algorithm consists of motion vector (MV) smoothing, selective average based motion compensation (SAMC) and hole interpolation with different weights. The proposed MV smoothing constructs more smooth interpolated frames by correcting inaccurate MVs. The proposed SAMC and hole interpolation effectively deal with overlaps and holes, and thus, they can efficiently reduce the degradation of the interpolated frames by removing blocking artifacts and blurring. Experimental results show that the proposed algorithm improves the average PSNR of the interpolated frames by 4.15dB than the conventional algorithm using bilateral ME, while it shows the average 0.16dB less PSNR performance than the existing algorithm using unilateral ME. However, it can significantly reduce the computational complexity based on absolute difference by 89.3%.

Index Terms — Frame rate up-conversion, motion compensation, hole interpolation, frame interpolation

1. INTRODUCTION

Frame rate up-conversion (FRUC) interpolates new frames between original frames to increase the number of frames, and thus, FRUC can increase motion continuity. Therefore, it can be used for format conversion, low bit rate video coding and slow motion playback.

The FRUC algorithms [1]-[8] and [12]-[17] can be divided into two different methods. One method interpolates intermediate frames by simple repetition of frames or average of frames. However, this method interpolates improper frames that have poor motion continuity when video contains a lot of motion. The other method, in contrast, considers the movement of objects when it generates intermediate frames, which is called as motion-compensated frame rate up-conversion (MC-FRUC).

MC-FRUC consists of two steps: motion estimation (ME) and motion-compensated interpolation (MCI) [1], [2]. The ME step generates motion vectors (MVs) which represent object motion using vectors, whereas the MCI step uses MVs to generates intermediate frames.

The block matching algorithm (BMA) is widely used for ME because BMA is simple to implement. BMA divides image into blocks and detects the movement of those blocks. Two kinds of ME are mostly used for BMA. One is the unilateral ME and the other is bilateral ME. Many FRUC algorithms using the unilateral ME have been proposed [1]-[8]. MVs obtained by the unilateral ME pass through the frame which is interpolated in one direction. Therefore, overlaps and holes are appeared when unidirectional ME is used. To reduce overlaps and holes, a number of algorithms have been proposed. Image and motion field segmentation was proposed in [1], [3], [6] and [7]. Image inpainting was proposed in [9]-[11]. These algorithms give high performance results but they also need high computational complexity. The bilateral ME, on the other hand, obtains MVs passing through a block in the intermediate frame, using the temporal symmetry between blocks of the reference and current frames. Therefore, the bilateral ME does not generate overlaps and holes. A number of algorithms using the bilateral ME has been proposed [12]-[15]. However, these algorithms show low PSNR performance results because ME based on an unknown block in the intermediate frame has limitation to find

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accurate movements of objects.

The conventional approaches for FRUC [1]-[8] and [12]-[15] are too complicated to implement or they cannot give reasonable performance with low computational complexity. Consequently, the algorithm compromising the computational complexity and PSNR performance is needed for real-time applications. Hence, this paper presents a highly efficient FRUC algorithm that can be used in real-time applications. The proposed algorithm is composed of MV smoothing, Selective Average based Motion Compensation (SAMC) and hole interpolation. Moreover, it uses the predicted MV for MV smoothing to remove outliers and employs a new MC algorithm considering the location of pixels to reduce blocking artifacts. In the hole interpolation, the proposed algorithm uses intra prediction of H.264/AVC to obtain smoothing image at the borders of objects and background having regular patterns.

The remainder of this paper is organized as follows. Section 2 introduces the existing algorithms. Section 3 describes the proposed algorithm. Section 4 shows the experimental results and evaluates the performance of the proposed algorithm. Finally, Section 5 concludes this paper.

2. EXISTING ALGORITHMS

As mentioned previously, two kinds of ME, such as unilateral ME and bilateral ME, are used for motion compensated interpolation. Fig. 1 shows the unilateral ME. An interpolated frame is generated between two frames such as the current frame and the reference frame according to the motion information of contents. Because the obtained MVs are passed through an interpolated frame, overlaps and holes can be appeared. Therefore, unilateral ME requires a huge computational complexity to handle these overlaps and holes.

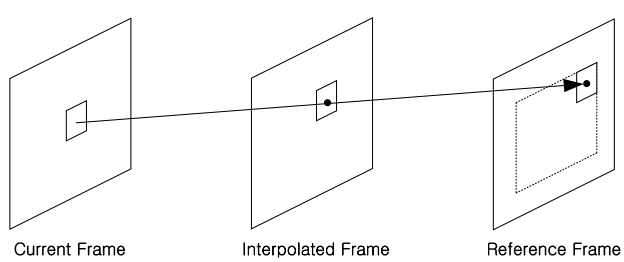
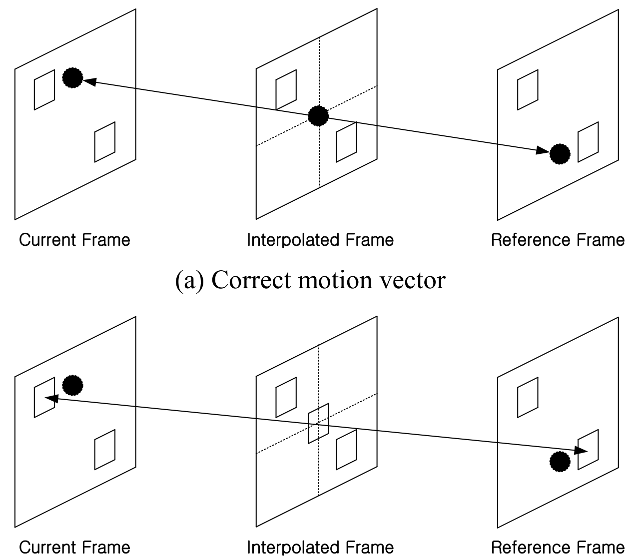


Figure. 1. Unilateral motion estimation.

Bilateral ME, On the other hand, has the limited prediction accuracy. Fig. 2 shows an example of this problem. Small squares represent stationary objects or back grounds of the same color, while the black circles indicate moving objects. Because bilateral ME uses the temporal symmetry between the current frame and the reference frame, the small squares can be detected as moving objects rather than black circles as in Fig. 2(b). This phenomenon limits the prediction accuracy and degrades the picture quality. The existing algorithms using bilateral ME [12]-[15] tried to overcome this problem. However, such attempts make algorithms more complex and the improvement of PSNR performance is minimal.



(a) Correct motion vector

(b) Incorrect motion vector

Figure. 2. Problem of bilateral motion estimation.

Conventional MV smoothing employs simple average calculation of neighboring MVs to obtain the threshold value that is used to detect outliers [14]. However, neighboring MVs also can be outliers, and thus, the average of these MVs may lead an inaccurate threshold value. Therefore, neighboring MVs which are outliers should be omitted to obtain the accurate refined MVs during MV smoothing.

The various overlapped block motion compensation (OBMC) methods are used to reduce blocking artifacts in the FRUC algorithms [14], [16]. However, these OBMC algorithms use too many weighting factors or additional computations and therefore the algorithms become too complex to implement.

Recently, the hole interpolation algorithm which considers correlation with neighboring pixels has been proposed [17]. The algorithm uses a trilateral filter to calculate correlation and it is based on the Markov random model and Euclidean distance. However, the Markov random model and Euclidean distance are too complex to implement as hardware. Therefore, a simple method considering correlation with neighboring pixels is needed for real-time applications.

3. PROPOSED ALGORITHM

This section presents the proposed MV smoothing, SAMC, and new directional hole interpolation algorithms for high performance and low complexity of FRUC.

3.1. Motion Vector smoothing using previous results

The MVs determined by the minimum SAD cannot exactly indicate the movement of objects because SAD is the value which represents the minimum residual energy rather than the movement of objects. Therefore, outliers which are MVs indicating wrong directions are appeared and they should be modified through the specific process, so called MV smoothing [14].

The proposed motion smoothing consists of 3 steps. First, the predicted MV of the current block should be obtained by considering MVs of neighboring blocks. The MVs of neighboring blocks can also be outliers and they should be omitted from computation. Thus, the proposed algorithm uses the results of MV smoothing previously processed, which is the main difference between the proposed algorithm and the existing algorithm [14]. Fig. 3 shows the calculation of the predicted MV and the predicted MV, *Vpred*, is given by

$$Vpred = \frac{1}{4}\left(V1' + V2' + V4' + V0\right) \qquad (1)$$

V0 is MV to be refined and *V1~V8* are the neighboring MVs. MV smoothing results *V1'*, *V2'* and *V4'* previously determined and current MV *V0* are used for calculation of the predicted MV to avoid iterative calculation.

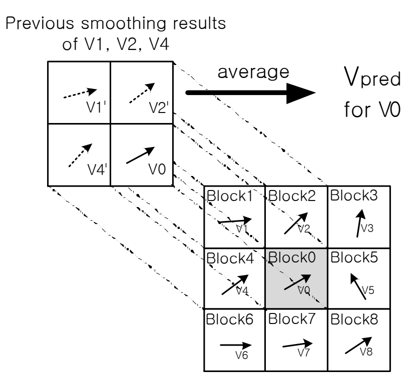


Figure. 3. Predicted motion vectors.

The final refined MV is determined by averaging of the neighboring MVs. The detailed operation is as follows. The outliers are recognized from the MVs of nine blocks including the current block *V0*. Thus, the predicted MV obtained in the first step is used for the outlier detection. Next, the Absolute Differences (AD) between the neighboring MVs and the predicted MV are calculated. The four MVs which have smaller AD than the others are selected for the final average calculation. Finally, the refined MV, *Vrefined*, is determined by averaging of the selected four MVs.

3.2. Selective Average based Motion Compensation

After MV smoothing, the MC process is performed with the results of MV smoothing. The interpolated frame F_i between the current frame F_n and reference frame F_{n-1} is given by

$$F_i(x,y) = \frac{1}{2}\left(F_n\left(x - \frac{v_x}{2}, y - \frac{v_y}{2}\right) + F_{n-1}\left(x + \frac{v_x}{2}, y + \frac{v_y}{2}\right)\right) \qquad (2)$$

where (x, y) and (v_x, v_y) represent the location of pixels and MV associated with F_n and F_{n-1}, respectively.

In case of unilateral ME, overlaps and holes are generated according to the trajectory of MVs and these make blocking artifacts

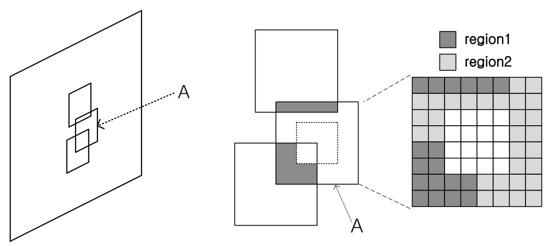


Figure. 5. Motion compensation of overlapped regions.

Therefore, the proposed algorithm performs MC with the region based partial average to reduce blocking artifacts. Fig. 5 shows one example. If the location of the current block *A* is determined by MV and the overlapped regions are occurred, the SAD values of the overlapped blocks are compared with each other. Then, if SAD of *A* is smaller than SAD of the neighboring blocks, the averaged pixels of the current block and neighboring blocks are taken for MC in case of region1 in Fig. 5. In addition, pixels of *A* are taken for MC in case of the central region excepting region1 and region2. The region1 in Fig. 5 represent the locations where the averaged pixels are taken. The pixels of the neighboring blocks, on the other hand, are taken for MC result when the SAD of *A* is larger than SAD of the neighboring blocks.

3.3. Hole Interpolation with different weights

The conventional FRUC algorithms using the unilateral ME [1]-[8] commonly use a median filter or a mean filter for hole interpolation. These filters show good performance at flat objects, however, they make blurring at the border of objects. Therefore, correlation with neighboring pixels should be considered to reduce this blurring and the proposed algorithm employs intra prediction of H.264/AVC to calculate correlation.

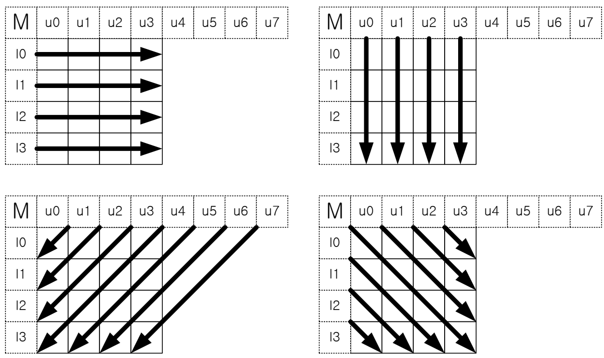


Figure. 6. Locations of pixels and direction modes used for intra prediction.

Intra prediction of H.264/AVC analyzes nine directions of a 4×4 block, however, the proposed algorithm analyzes only four directions to reduce computations, which are horizontal, vertical, down-left and down-right modes. In Fig. 6, *u0 ~ u7*, *l0 ~ l3* and *M* are neighboring pixels used for prediction.

The proposed algorithm determines the best direction mode among four modes as follows. First, the predicted pixels are obtained as shown in Fig. 6. Then, SAD is calculated between the pixels which are not holes and the predicted pixels according to four direction modes. Next, one direction mode which has the minimum SAD is determined as the orientation of the block. After the orientation of the block is determined, holes are interpolated with the weighted average based on the orientation. The average calculation with weight 4 shows the best performance through various experiments.

4. EXPERIMENTAL RESULTS

The image quality of the interpolated frames is evaluated using PSNR. All sequences used for experiments are in the standard CIF (352×288) format and 30fps frame rate. The odd frames are removed and the new odd frames are constructed from the even frames using the proposed methods. For all of the experiments, full search ME is used with an 8×8 macro block and ±16 search range.

Table I shows PSNR performance comparisons with the existing algorithms [16], [17]. The Proposed FRUC algorithm including MV smoothing using previous results, SAMC and hole interpolation with different weights provides the average 0.16dB less PSNR performance than the algorithm proposed in [17] using the unilateral ME, highpass filter and trilateral filter. On the other hand, The Proposed FRUC algorithm provides the average 4.15dB better PSNR performance than VS-BMC [16], [17]. VS-BMC uses the bilateral ME and side match distortion (SMD) to reduce blocking artifacts. Especially, the proposed algorithm shows better performance than both VS-BMC and Trilateral filter in specific sequences that contain regular patterns such as Mobile and Container.

TABLE I. PERFORMANCE COMPARISONS WITH EXISTING ALGORITHMS

Sequence (dB)	VS – BMC [17]	Trilateral filter [17]	Proposed FRUC
Football	19.69	22.74	22.17
Tennis	25.38	29.58	27.95
Flower	22.56	26.96	27.92
Mobile	19.57	25.09	25.98
Paris	28.05	33.53	31.63
Container	38.65	41.87	43.13
Average	25.65	29.96	29.80

The numbers of calculations for each algorithm are calculated in terms of absolute difference (AD) needed for processing one macro block. Table II shows the AD comparison results, where *N* and *W* represent the size of macro block and the size of search window, respectively.

TABLE II. COMPUTATIONAL COMPLEXITY BASED ON ABSOLUTE DIFFERENCE

Algorithms	Absolute difference (AD)
Trilateral filter	$2\times\{N^2\times(2\times W+1)^2\}+\alpha=1{,}305{,}728+\alpha$
VS-BMC	$N^2\times(2\times W+1)^2+(N^2+4\times N)\times(2\times W+1)^2=174{,}240$
Proposed FRUC	$2\times\{N^2\times(2\times W+1)^2\}+(\frac{N}{2})^2\times4\times(\frac{N}{2})=139{,}648$

The trilateral filter uses the luminance SAD, highpass filtered image SAD, an 8 × 8 macro block, forward ME and backward ME with ±50 search range. Iterative calculation of the trilateral filtering is denoted by α. VS-BMC, on the other hand, uses an 8×8 macro block and a ±16 search window. Moreover, the second term is added because VS-BMC should perform iterative calculations and SMD. The proposed FRUC algorithms also use an 8×8 macro block and ±16 search window. The second term of the proposed FRUC, $(N/2)^2\times4\times(N/2)^2$, is added by the calculation of intra prediction for hole interpolation. Consequently, the number of operations in Table II shows that the proposed FRUC algorithms are more efficient than other algorithms [16], [17].

5. CONCLUSION

This paper proposes the new FRUC algorithm that can reduce computational complexity and improve PSNR performance. The proposed algorithm consists of three ideas. First, the new MV smoothing method which uses the previous results has been proposed. Using this method, the neighboring MV can be widely considered and outliers can be efficiently eliminated. Second, to reduce blocking artifacts, SAMC has been employed. SAMC can efficiently solve the overlaps problem. Therefore, it makes the quality of interpolated frame better. Third, hole interpolation has been proposed to consider the correlation with neighboring pixels. It reduces blurring at the border of objects and background having regular patterns. The proposed algorithms improve the average PSNR by 4.15dB over VS-BMC and have about 89.3% less computation than the existing Trilateral filter with slight loss of PSNR.

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