A FRAME RATE UP-CONVERSION METHOD WITH QUADRUPLE MOTION VECTOR POST-PROCESSING

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ABSTRACT

We propose a frame rate up-conversion method with quadruple motion vector post-processing scheme (QMVPS). By considering occlusion and hole problems, we adopt the hybrid motion estimation (ME) method which is a combination of bilateral ME and unilateral ME in both directions. To produce better quality-interpolated frames, the motion vector (MV) outliers of the both unilateral MV fields are detected and corrected by prior-information-based MV refining method and the bilateral MV field is smoothed by using vector extrapolation and weighted summation. Moreover, the selection and determination criterion, which is composed of matching ratio of blocks and ladder-style analysis, is proposed to select and decide the denser bilateral MV field. Experimental results verify the superiority of our work in both objective and subjective performances compared with other conventional ME and MV post-processing methods.

Index Terms— Frame rate up-conversion, interpolation, MV refining, MV smoothing, outliers, .

1. INTRODUCTION

Frame rate up-conversion (FRUC) is a technique that uses the time-space relativity of original adjacent frames to generate new video frames and inserts them into the original sequence to increase the frame rate of the video. When the frame rate is higher, the video will be more fluent and the texture of frames will be better.

Motion-compensated FRUC (MC-FRUC) is most commonly used, which consists of two major steps: motion estimation (ME) and motion compensated interpolation (MCI). The performance of MC-FRUC is highly dependent on the accuracy of the estimated motion information. In order to get more accurate motion vectors (MVs), various ME and MV post-processing (MVP) algorithms have been developed. For motion estimation, the 3D recursive search algorithm [1] is proposed to generate smooth MV fields by using the MVs of the spatial-temporal neighboring blocks. The TC-SBP algorithm [2] demonstrates the enhancement of the MV accuracy by using the spatial and temporal candidates. However, the MCI requires MVs that are estimated from the viewpoint of the interpolated frame rather than original frames, so these algorithms can cause holes and overlaps. As a comparison, the authors of [3-5] proposed the bilateral ME algorithms (bi-ME) which estimates MVs from the viewpoint of the interpolated frame to avoid holes and overlaps but also suffers from temporal symmetry which leads to incorrect ME. Recently, to alleviate the occlusion problem, many approaches perform the unilateral MEs (UMEs) in both the forward and backward directions [6-8]. However, these algorithms do not use reliable decision criteria to select the more accurate bi-MV. For MV post-processing, the neighboring block MVs are used [6] [9] to refine outliers. Chan *et al.* [10] adopts the median filter on the MVF to correct outliers. Huang *et al.* [11] employs the MV reliability and deals with MVs hierarchically. However, these methods all only consider the spatial relativity, so they still probably produce the false MV correction, especially the MVs in holes and overlaps regions.

Because of these deficiencies of the above existing ME and MVP methods, we propose a hybrid motion estimation method and a quadruple motion vector post-processing scheme to get more reliable motion information.

The major contributions of our proposed method can be summarized as: 1) UME is performed on the both forward and backward directions to solve occlusion problems; 2) A prior-information-based MV refining algorithm is proposed to improve the reliability of unilateral MV (UMV) field; 3) The selection and determination criteria to decide the final bi-MVs is proposed in accordance with matching ratio of blocks and ladder-style analysis; 4) MV smoothing based on vector extrapolation and weighted summation is proposed to improve MV accuracy; 5) An improved bidirectional MCI (BMCI) is employed to suppress blocking artifacts of interpolated frames (IFs). Experimental results show that the proposed method yields better performance, comparing to conventional ME and MVP algorithms.

The rest of the paper is organized as follows. We present the proposed method in Section 2. In Section 3, the experimental results are presented. Finally, conclusions is discussed in Section 4.

2. PROPOSED METHOD

Fig. 1 shows the flow chart of the proposed FRUC method. The proposed method includes three steps: two-pass UMEs in forward and backward directions, quadruple MV post-processing and improved BMCI. The proposed method uses poly-directional ME to avoid overlaps, holes and occlusion problems, also uses MV refining to make UMVs (MV_f and MV_b) more reliable, next further uses minimum residual error and motion range band to make two selections of MVs, then uses adaptive MV smoothing to get more accurate bi-MVs, and at last uses improved MCI to get interpolated frames.

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Fig. 1. Flow chart of the proposed method

2.1. Forward and Backward Motion Estimation

Among various block matching algorithms (BMAs), we perform a faster search algorithm, termed as "Diamond-Search (D-S) [12]" on both forward and backward directions to solve occlusion problems. The forward and backward MV are denoted by v_f and v_b respectively in this paper.

2.2. Adaptive Forward and Backward MV refining

Because the minimum sum of absolute differences (SAD) of determining MVs represents residual energy rather than motion information of objects, outliers will exist among MVs. For this reason, the adaptive prior-information-based MV refining (APMVR) algorithm is proposed for v_f and v_b , as the first MVP.

The APMVR algorithm consists of two steps: detecting outliers and correcting outliers. As with the traditional detecting method in [3] [5] [10], we detect whether a vector is an outlier by calculating and comparing distances between the MV to be detected and the mean value of all blocks MVs in 3×3 window, as shown in Fig. 2(a).

Then, we use the APMVR algorithm to correct the outlier:

$$v_{pre} = (v_2 + v_3 + v_4 + v_5)/4 \tag{1}$$

where v_{pre} denotes the predictive MV of the block having the outlier, v_2-v_5 are the neighboring MVs which have been refined previously. Then we calculate the absolute difference (AD) between v_{pre} and $v_2 - v_9$ respectively. Next, we choose four MVs with the smallest AD among $v_2 - v_9$. At last, we calculate the mean value of the four selected MVs as the final refined MV.

Compared to the existing algorithm [5], our proposed algorithm utilizes more perfect prior information and neighboring MVs which have been refined previously, so as to provide more reliable UMVs.

2.3. Original frame MVc selection

In our proposed QMVPS, the second MVP is the selection of MVc of original frames. We take the minimum residual energy calculated from the viewpoint of original frames as the selection criteria. Because the metric values have been obtained in previous ME process, the second MVP can improve the accuracy of MV field without



Fig. 2. (a) 3×3 MVs window composed of 'B' and its neighboring blocks (b) UMVs projection on the interpolated frame

any increase in computational cost. The MVc set of original frame is obtained through following formulas.

$$SAD_{forward}(B_{i,j}, v_f) = \sum_{s \in B_{i,j}} |f_t(s) - f_{t+2}(s + v_f)|$$

$$SAD_{backward}(B_{i,j}, v_b) = \sum_{s \in B_{i,j}} |f_{t+2}(s) - f_t(s + v_b)| \quad (2)$$

$$v_{bi} = \begin{cases} \frac{v_f}{2}, if : SAD_{forward} \le SAD_{backward} \\ -\frac{v_b}{2}, if : SAD_{forward} > SAD_{backward} \end{cases}$$

where $SAD_{forward}$ and $SAD_{backward}$ denote the SAD values in forward and backward directions, respectively; $f_t(s)$ and $f_{t+2}(s)$ denote pixel values at position s in the current frame and referent frame. $B_{i,j}$ denotes the block in the *i*th vertical and *j*th horizontal position. v_f and v_b are forward and backward MV that have been obtained.

As mentioned above, the ME uses SAD as the metric, so the $SAD_{forward}$ and $SAD_{backward}$ in this procedure are not required to compute again, that have been computed and saved in previous ME process. In this condition, the proposed selection criterion reduces computation costs highly, at the same time improves the accuracy of MVs.

2.4. Ladder-style Scheme for IF bi-MVs Selection and Determination

In order to avoid holes and overlaps, we project the UMV field into the interpolated frame. In the process of projecting, the block 'B' to be placed in general is not overlapped entirely with the corresponding interpolated block 'A', as shown in Fig. 2(b). So the MV of block 'B' can not represent the true motion of block 'A' entirely. For this reason, we propose a ladder-style scheme which selects suitable MVs based on the direction and size of motion of the object as bi-MVc set and determines the most reliable one as final bi-MV of interpolated block 'A'.

2.4.1. Selection of bi-MVc

According to space-time information of adjacent blocks which are provided by MVs, we judge out the overlaps-blocks and holesblocks, and then select bi-MVc from the MVs of overlaps-blocks. For different block types, i.e. corner-blocks, border-blocks and middle blocks, the number of neighboring blocks (NBs) are diverse. For example, for a middle block 'B', when the direction of MVs of its eight NBs is the same as the direction of corresponding location arrow pointing, as shown in Fig. 3, it represents that there possibly will be an overlap between the NB to be placed and the block 'A'. If its size is also in the motion range, then the MV of this NB will be included in bi-MVc set. Similarly, other bi-MV candidates of this block are also obtained by the same way, as well as those blocks at other locations.



Fig. 3. The range of NB-MVs for an overlap

2.4.2. Determination of bi-MVc

After selection, we determine the most reliable one as the final bi-MV by using the sum of the bidirectional absolute differences (SBAD) which is defined by formula (3). In contrast to the SAD, the MV determined by BSAD is better to reflect the true motion of the object. Thus, we estimate the reliability of each bi-MVc from the viewpoint of interpolated block by calculating BSAD values and select the one with the minimum BSAD value as the final bi-MV as in formula (4). Morever, in a special case, if all blocks to be placed are not overlapped with the block to be interpolated, that shows there is no bi-MVc for the interpolated block, so the final bi-MV of this block is to be obtained by using median filter for its all neighboring blocks MVs.

$$BSAD(B_{ij}, v_{bi}) = \sum_{s \in B_{i,j}} |f_t (s - v_{bi}) - f_{t+2} (s + v_{bi})| \quad (3)$$

$$v_{final.bi} = \arg \min_{v_{bi} \in V} \left\{ BSAD\left(B_{ij}, v_{bi}\right) \right\}$$
(4)

Where V denotes bi-MVc set of the block to be interpolated.

2.5. Border-blocks MV smoothing .

In terms of the particularity of border-blocks position, the MV extrapolation for border-blocks is proposed and completed by combining itself and its neighboring blocks. Due to the difference of block type, the blocks on the corner and on the edge have diverse extrapolation form. For example, the MV extrapolation graphs of the block at the top-left corner and the left edge are shown as Fig. 4(a) and Fig. 4(b) respectively. MV extrapolation makes the boundary block and its NBs become a 3×3 window commonly used. Then in order to carry out the following outliers detection and smoothing operation, we remark the serial number of MVs in the extrapolation window, as shown in Fig. 4(c).

Next, based on MV extrapolation window, we perform outliers s detection as the same as MV refining. Then we perform MV smoothing for MV outliers. In view of the specialty of the borderblocks and the repeatability of extrapolation vectors, the common smoothing algorithm like trilateral filtering [13], is not applicable for border-blocks. Based on this view, we propose a new MV smoothing scheme based on distance and MVs reliability.

Firstly we detect whether the NBs-MVs $(v_1 - v_8)$ of the outlier (v_0) in Fig. 4(c) are reliable and put the reliable NBs-MVs into a set T, then use those reliable NBs-MVs to correct the outlier. The correction process is completed through weighted summation for reliable NBs-MVs in set T that has been obtained in detection procedure. The weighted coefficients are determined by the distances between the reliable NBs and the block to be disposed. The proposed



Fig. 4. (a) MV extrapolation graph of the block at the top-left corner. (b) MV extrapolation of the block at the left edge. (c) MV extrapolation after remarking the serial number

method corrects the outlier (v_0) as in formula (5).

$$d_{i} = \begin{cases} 1, & i = 2, 4, 5, 7\\ 1/\sqrt{2}, & i = 1, 3, 6, 8 \end{cases}$$
$$v_{0m} = \left(\sum_{i \in T} d_{i} * v_{i}\right) / \left(\sum_{i \in T} d_{i}\right)$$
(5)

where T is the reliable NBs-MVs set, v_i denotes corresponding reliable vector, *i* represents subscript of corresponding MV in Fig. 4(c), d_i denotes the weighted coefficients and v_{0m} denotes the final bi-MVs of border-blocks.

2.6. Improved Bidirectional Motion Compensated Interpolation (Improved BMCI)

Our proposed FRUC scheme combines forward, backward and bi-directional motion estimation to provide MVs, so it does not produce any overlapped pixel and hole regions in the interpolated frames. Thus, in order to solve the block artifacts problem from block matching ME, the best MCI method is to carry out bidirectional MCI. However, using adjacent frames to interpolate directly can decrease the quality of interpolated frame. Thus, we propose an improved BMCI algorithm (IBMCI).

Our proposed algorithm is proposed based on the adaptiveweighted bidirectional motion compensated interpolation algorithm (WBMCI) [14]. The improvement of IBMCI comparing with WBMCI is to perfect the access of weighted coefficients so as to avoid weight extremes and get more rational weighted parameters. For some test video sequences, such as foreman sequence (200 frames), the IBMCI algorithm can improve the average PSNR of the interpolated frames by 0.43 dB compared with WBMCI algorithm.

3. EXPERIMENTAL RESULTS

To test and verify the performance of our proposed algorithm, several experiments are conducted using various video frame sequences and several relevant FRUC algorithms including the proposed method. We assess the performance of the proposed and the other relevant algorithms in terms of the quality of interpolated

 Table 1. AVERAGE PSNR AND SSIM VALUES OF THE PROPOSED METHOD AND OTHER CONVENTIONAL ALGORITHMS FOR

 6 TEST SEQUENCES

Test sequences		News	Foreman	Soccer	Coastguard	Bus	Akiyo
Proposed	PSNR(dB)	36.2089	33.7574	26.8691	31.6838	23.8229	45.9259
	SSIM	0.9763	0.9406	0.7829	0.8968	0.8396	0.9935
BiME	PSNR(dB)	30.3510	25.3660	19.6555	21.4831	16.2999	38.8830
	SSIM	0.9483	0.6965	0.4715	0.5218	0.3554	0.9794
TriFilter	PSNR(dB)	35.4863	30.9478	23.2473	30.6892	20.8591	45.5127
	SSIM	0.9742	0.9301	0.7044	0.9050	0.6428	0.9924
BMVR	PSNR(dB)	35.3817	31.4074	25.1078	29.6350	19.9170	42.8830
	SSIM	0.9736	0.9287	0.7724	0.8826	0.5819	0.9899





Fig. 5. Comparison of interpolated frames of soccer sequence (14th). (a) Original, (b) Proposed, (c) BiME, (d) Trifilter, (e) BMVR

frames including objective evaluation and subject evaluation. We use odd frames of consecutive video frames sequences as input and even frames are interpolated as a result. Original even frames are used as reference to calculate the peak signal to noise ratio (PSNR) and structural similarity index measurement (SSIM) as the objective evaluation.

According to the basis of our proposed method is bi-ME and bi-MC, so the BiME algorithm in [3] is added to the comparison algorithms to examine the performance of our proposed algorithm. Meanwhile, because the innovation of our proposed algorithm is the post-processing and improvement of bi-MV, so the conventional FRUC algorithms, i.e. TriFilter [13], and BMVR [15], are used to compare with the proposed method.

In our experiments, to demonstrate the better visual quality in local details of our proposed scheme, we select the 13th and the 15th frame of the soccer sequence as the original frames to generate the interpolated frame through different FRUC methods, which will be used to do a PSNR comparison with the original 14th frame, as shown in Fig. 5(a)-(e). Thus we can see the interpolated frames obtained from other algorithms exist obvious blocking artifacts or blooming compared with the IF obtained from proposed method.



Fig. 6. Comparison of PSNR by the proposed and the conventional methods for test sequences. (a) News, (b) Foreman, (c) Soccer, (d) Coastguard, (e) Bus, (f) Akiyo

Meanwhile, we use six test image sequences: News, Foreman, Soccer, Coastguard, Bus, Akiyo, to do simulations of multiple frames. The experimental comparison results of PSNR values for each sequence are shown in Fig. 6 and the average PSNR values and SSIM values are exhibited in Table 1. It can be observed that whether in the subjective vision or objective PSNR and SSIM values, our proposed method achieves better results for the six test sequences compared with the other three FRUC algorithms.

4. CONCLUSIONS

In this paper, we propose a quadruple MV post-processing scheme that aims at providing denser bi-MV field. Using the matching ratio of blocks to do selection from both UMV fields and then adopting the ladder-style analysis to do determination of bi-MV, all aim at improving the accuracy of final MVs. In order to reduce the motion blur and artifacts, we propose a prior-information-based MV refining method, a MV smoothing algorithm using extrapolation and weighted summation and an Improved BMCI scheme to construct IFs of high quality. Moreover, objective and subjective evaluations are performed, and it shows that in contrast to the other relevant FRUC methods, the proposed scheme can obtain interpolated frames which are free from blocking artifacts and has higher PSNR, SSIM values and better visual quality.

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