LETTER

Edge-Based Motion Vector Processing for Frame Interpolation Based on Weighted Vector Median Filter

Ju Hyun PARK^{†a)}, Student Member, Young-Chul KIM[†], and Hong-Sung HOON[†], Nonmembers

SUMMARY In this paper, we propose a new motion vector smoothing algorithm using weighted vector median filtering based on edge direction for frame interpolation. The proposed WVM (Weighted Vector Median) system adjusts the weighting values based on edge direction, which is derived from spatial coherence between the edge direction continuity of a moving object and motion vector (MV) reliability. The edge based weighting scheme removes the effect of outliers and irregular MVs from the MV smoothing process. Simulation results show that the proposed algorithm can correct wrong motion vectors and thus improve both the subjective and objective visual quality compared with conventional methods.

key words: edge direction, weighted vector median filter, motion vector smoothing, motion compensated frame interpolation

1. Introduction

The application of Motion Compensated Frame Interpolation (MCFI) techniques to increase the video frame rate has gained significant attention. General MCFI methods conduct motion estimation between the previous and current frame and then generate the interpolated frame by averaging half of the obtained motion vectors. However, motion estimation may fail whenever there are multiple local minima in the sum of absolute different distributions due to deformable motion, noise, object occlusion, lighting variation, etc. [6]. As a result, employing these MVs without post-processing not only results in blockiness and ghost artifacts, but also generates deformed structures in the interpolated frames. Many motion vector processing schemes for post-processing have been proposed to eliminate these artifacts and derive true motion from the estimated MVs. The simplest method for MV smoothing is Vector Median Filter (VMF) [1] which can simply remove MV outliers and refine a MV using information about its neighborhood. *Alparone et al.* proposed using Adaptively Weighted Vector Median Filter (AWVMF) based on prediction residues to obtain a smoother motion field [2]. *Dane et al.* presented a method applying vector median and low pass filtering after MV classification based on the angle variance among its neighboring MVs [4]. In [6], *Ai-Mei Huang et al.* presented bidirectional MV processing based on the minimum difference between forward and backward prediction, by selecting the best MV from neighbors. All these works have focused on correcting

unreliable MVs in order to produce a smoother motion field. However, the results have been unsatisfactory, while correcting unreliable MVs by frame difference or angle variance is complex due to noise and complex motion.

This letter presents an edge-based approach for an MV smoothing method. First, the initial MVs will be refined by Angle Variance Difference (AD) and Side Matching Distortion (SMD). Second, edge information will be classified spatially across four directions using a Sobel filter and refined by a maximum frequent filter in order to generate a reliable edge direction. Finally, we will adopt a weighted vector median system to smooth an MV field. While WVMF [2] uses prediction residues based on the Displaced Frame Difference (DFD) ratio for weighting values, the weighting values in our method are generated based on edge direction.

2. Proposed Algorithm

Let consider the motion of a moving object when we divide a frame into blocks in order to estimate or smooth MVs. As shown in Fig. 1, when an object is moving from bottom-left to upper-right, MV_1 , MV_2 , and MV_3 of the outlined blocks require similar variances to avoid block artifacts, since the outlined blocks are part of a moving object. It means that the edge information of the outlined blocks represents a very similar direction, as shown in Fig. 1. So, in the proposed method, edge information is applied in a weighted vector median system. In the proposed WVM system, the MVs weighted by the edge information are included in a set of MVs, and then the minimized cumulative distance is calculated in order to find the best MV from the set.

2.1 MV Refinement

In AWVMF, the center vector is more likely to be chosen, since the highest weights are associated with the vectors producing the lowest DFD values, thereby following the shape

Fig. 1 The spatial correlations of a moving object based on edge direction: (a) previous frame, (b) intermediate frame, (c) following frame.

Manuscript received April 9, 2010.

Manuscript revised June 28, 2010.

[†]The authors are with the Department of Electronics and Computer Engineering, Chonnam National University, Gwangju, Rep. of Korea.

a) E-mail: jhpark@soc.chonnam.ac.kr

DOI: 10.1587/transinf.E93.D.3132

Fig. 2 13-tap weighted maximum frequent filter: (a) Horizontal direction, (b) Vertical direction, (c) Positive diagonal direction, (d) Negative diagonal direction.

of the block matching function around its absolute minimum [2]. It means that even though the center vector is wrong, it is likely to be used for AWVMF. So, the first step of the proposed method is to refine the initial MVs by AD and SMD in order to reduce the effect of wrong MVs according to:

$$AD = \frac{1}{M} \sum_{i=0}^{M-1} \left| \arccos \left(\frac{\vec{V}_c \cdot \vec{V}_i}{\sqrt{\vec{V}_c \cdot \vec{V}_c - \vec{V}_i \cdot \vec{V}_i}} \right) \right|. \quad (1)$$

$$SMD[B_{i,j}, V] = \frac{1}{N} \sum_{k=0}^{N-1} |f_n(g_k, V) - f_n(h_k)|, \quad (2)$$

$$f_n(s, V) = \frac{1}{2} (f_{n-1}(s - V) + f_{n+1}(s + V)).$$

Where g_k and h_k indicate the positions of the k th pixels at the boundaries in the current and neighboring blocks, and N and $B_{i,j}$ are the number of boundary pixels and intermediate blocks, respectively. Also, f_{n-1} , f_n , f_{n+1} , and V denote the previous, intermediate and following frames, and the initial motion vector, respectively. And $\vec{V}_c$ and $\vec{V}_i$ denote the motion vector of the current and neighboring blocks. In case of SMD, the top, bottom, left and right boundaries are included in the calculation.

2.2 Edge Classification and Refinement

The second step is to classify edge information across four directions: vertical, horizontal, positive and negative diagonal using a Sobel mask. In order to apply edge direction information on MV fields, one representative edge direction is then assigned to each 8×8 block, by comparing the maximum energy values of each of the four directions. After that, a 13-tap Weighted Maximum Frequent Filter (WMFF) is applied in order to refine the original edge directions, as shown in Fig. 2 and Eq. (3).

$$\hat{\theta}_{(i,j)}(direction) = \max \left\{ A, B, C, D, E, F, G, H, \theta_{(i,j)}, \theta_{(i,j)}, \theta_{(i,j)}, D_1, D_2 \right\}. \quad (3)$$

Where, $\hat{\theta}_{(i,j)}$ and $\theta_{(i,j)}$ are the refined and original edge direction of the current block, respectively. And, D_1 and D_2 denote the edge direction indicated by the current block, as shown in Fig. 2.

Fig. 3 The weighted MVs of the proposed 11-tap WVMF: (a) Horizontal direction, (b) Vertical direction, (c) and (d) Positive and negative diagonal direction.

2.3 Weighted Vector Median Filter

The final step is to adopt a weighted vector median system for motion vector smoothing. In the proposed system, we use a Weighted Vector Median Filter (WVMF) which is different with [2]. In our system, the MVs, which are weighted by the edge direction of the current block, are included in the WVM system, as shown in Fig. 3 and Eq. (4).

$$\overrightarrow{MV}_{(x,y)}(direction) = \left\{ \frac{A, B, C, D, E, F, G, H}{\overrightarrow{MV}_{(x,y)}, \overrightarrow{MV}_{d1}, \overrightarrow{MV}_{d2}} \right\}. \quad (4)$$

$$\vec{v}_{out} = \arg \min_{\overrightarrow{MV}_k} \sum_{i=0}^{K-1} w_i \left\| \overrightarrow{MV}_k - \overrightarrow{MV}_i \right\|. \quad (5)$$

Where, $\overrightarrow{MV}_{d1}$ and $\overrightarrow{MV}_{d2}$ denote the MVs which are weighted by the edge direction of the current block. And, given the set of vectors $\overrightarrow{MV}_{(x,y)}$, WVMF chooses $\vec{v}_{out}$ which is the minimized cumulative distance from the other elements of set $\overrightarrow{MV}_{(x,y)}$ as defined in Eq. (5). Also, w_i is a weighting factor computed by frame difference [2].

3. Experiment and Analysis

3.1 MV Refinement

In order to apply MV refinement, we need to calculate the average AD and SMD in order to determine the outlier MVs. In the proposed method, we set the threshold values, Th_{AD} and Th_{SMD} , as 45° and 2.5 for the average AD and SMD, by experimental results. So, if a MV is over Th_{AD} and Th_{SMD} , it is considered an outlier, and VMF is applied to the MV to remove it.

3.2 Performance

We present experimental results to evaluate the performance of the proposed method. In this experiment, the odd frames are skipped and interpolated by the frame rate up-conversion method using bidirectional motion estimation and OBMCI [3]. The edge direction contributes significantly to the performance of the proposed algorithm. So, the original edge information in Fig. 4 (a) needs to be refined by WMFF, as shown in Fig. 4 (b), which shows higher spatial correlation. We compare the proposed WVMF

Fig. 5 The experiment result of interpolated frame 5th of MOBILE sequence.

Fig. 4 Edge direction map: (a) Original edge map, (b) Refined edge map.

and the conventional methods such as Vector Median Filter (VMF), Adaptively Weighted Vector Median Filter (AWVMF), Dane's MV processing (DMVP), and bidirectional MV processing (BMVP). For the test sequences, we use FOREMAN, TABLE, MOBILE, CREW and SILENT of CIF frame resolution. The original frame rate of test sequence is 30 frames per second, and the test sequence used for this experiment is 15 frames per second by skipping the odd frames.

For the subjective evaluation, we compare the interpolated frames constructed by the proposed algorithm to the conventional algorithms in order to visually evaluate the image quality. As shown in Fig. 5 (a), the interpolated frame without MV processing contains many wrong MVs at the region of the calendar numbers. VMF and DMVP in Fig. 5 (b) and (d) present smoother MV fields and reduced artifacts. However, there are blurring and ghost artifacts around the calendar numbers and ball, due to unmatched MVs. The AWVMF and BMVP in Fig. 5 (c) and (e) can eliminate the ghost effect around the ball, but MV processing fails at the region of the calendar numbers. The proposed method shows much smoother MV fields (See Fig. 5 (f)) while preventing block artifacts and ghost artifacts. For an objective comparison, we used both the average PSNR for 100

Table 1 The average PSNR (dB) and SSIM (%) comparison.

Sequence	No MV smoothing	VMF[1]	AWVMF[2]	DMVP[4]	BMVP[6]	Proposed
Foreman	31.72dB	32.78dB	32.97dB	32.01 dB	32.23dB	33.40dB
	90.93 %	92.87%	93.03%	91.61%	92.25%	93.42%
TABLE	29.03dB	31.57dB	31.89dB	31.21dB	31.68dB	31.95dB
	90.10%	93.91%	94.08%	92.53%	93.97%	94.28%
MOBILE	25.50dB	28.02dB	27.32dB	26.36dB	28.57dB	29.87dB
	90.40%	94.41%	93.53%	91.16%	94.56%	95.09%
SILENT	35.38dB	36.81dB	36.84dB	36.12dB	36.92dB	37.11dB
	95.90%	97.09%	97.10%	96.50%	97.14%	97.25%
CREW	29.64dB	30.86dB	31.04dB	30.13dB	31.06dB	31.37dB
	83.10%	86.69%	87.05%	84.50%	87.10%	87.97%

frames and structural similarity (SSIM) [5], which is known as a more efficient quality assessment than Peak Signal-to-Noise Ratio (PSNR), to compare the performance between the proposed and conventional methods. According to the simulation result in Table 1, our method outperforms the conventional methods in PSNR.

4. Conclusion

In this paper, an edge-based approach for MV processing was proposed for frame rate up-conversion applications. These results show that the proposed method outperforms the conventional methods in terms of both objective and subjective frame quality. In addition, we expect that the edge-based motion estimation can be enhanced more than is possible with the conventional motion estimation algorithm. It is one of our future research topics.

Acknowledgments

This research was financially supported by the Ministry of Education, Science Technology (MEST) and Korea Institute for Advancement of Technology (KIAT) through the Human Resource Training Project for Regional Innovation and also partly supported by the Ministry of Knowledge Economy (MKE), Rep of Korea, under the ITRC support Program supervised by the NIPA (NIPA-2010-C1090-1011-008).

References

- [1] E. J. Astola, P. Haavisto, and Y. Neuvo, "Vector median filters," *Proc. IEEE*, vol.78, pp.678–689, April 1990.
 - [2] L. Alparone, M. Barni, F. Bartolini, and V. Cappellini, "Adaptively weighted vector-median filters for motion-fields smoothing," *Proc. ICASSP*, vol.4, pp.2267–2270, May 1996.
 - [3] B.-T. Choi, S.-H. Lee, and S.-J. Ko, "New frame rate up-conversion using bi-directional motion estimation," *IEEE Trans. Consum. Electron.*, vol.46, no.3, pp.603–609, Aug. 2000.
 - [4] G. Dane and T.Q. Nguyen, "Motion vector processing for frame rate up conversion," *Proc. ICASSP*, vol.3, pp.309–312, May 2004.
 - [5] Z. Wang, A. C. Bovik, H.R. Sheikh, and E.P. Simoncelli, "Image quality assessment: From error visibility to structural similarity," *IEEE Trans. Image. Process.*, vol.13, no.4, pp.600–612, April 2004.
 - [6] A.-M. Huang and T. Nguyen, "Motion vector processing using bidirectional frame difference in motion compensated frame interpolation," *Proc. WoWMoM*, pp.1–6, June 2008.
-