Motion Compensated Frame Rate Up-Conversion Using Modified Adaptive Extended Bilateral Motion Estimation

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***Abstract*— In this paper, a novel frame rate up conversion (FRUC) using modified adaptive bilateral motion estimation (MAEBME) is proposed. Traditionally, extended bilateral motion estimation (EBME) carries out bilateral motion estimation (BME) twice on the same region, therefore has high complexity. Adaptive extended bilateral motion estimation (AEBME) is proposed to reduce complexity and increase visual quality by using block type matching process and considering frame motion activity. In MAEBME algorithm, calculated edge information is used to detect a global scene cut change, and then is used in block type matching process whether to use EBME. Finally, overlapped block motion compensation (OBMC) and motion compensated frame interpolation (MCFI) are adopted to interpolate the intermediate frame. OBMC is adopted adaptively by considering frame motion activity. Experimental results show that this proposed algorithm has outstanding performance and fast computation comparing with the anchor algorithms.**

***Index Terms*—frame rate up conversion, overlapped block motion compensation, global scene change detection, block type matching, frame motion activity**

I. Introduction

Frame rate up conversion (FRUC) is used in various display devices with the purpose of increasing frame rates. Liquid crystal display (LCD) has annoying motion blur effect in sequences with dynamic motion [1]. This is because of its hold-type display characteristics which tend towards support the light intensity for a longer moment than cathode ray tube (CRT). Audiences have difficulty in tracking an object which has fast motion in LCD. Since image from previous frame still remains on the display. This results in annoying effect, which is called ghost effect. FRUC is the ideal technique which is applied to reduce this problem. This obvious motion blur is moderated by doubling the frame rates. FRUC algorithm is also useful in a limited bandwidth condition. In a narrow bandwidth channel, an encoder has to decrease transmission data rating. Therefore an encoder transfers only one of even and odd frames. At a decoder side, missed frames are to be interpolated using FRUC technique.

Various FRUC algorithms have been proposed [2]. Frame repetition and frame averaging are the simplest. These algorithms are easy to implement but have problems such as motion jerkiness. To reduce these bad effects, techniques which consider motion compensation can be applied. Such techniques are called motion compensation frame interpolation (MCFI). Motion compensated frame rate up conversion (MC-FRUC) is a famous algorithm [3]. Motion estimation (ME) process produces motion vectors (MVs) by using the block matching algorithm (BMA) because of its low complexity. But BMA suffers from various artifacts, e.g., blocking artifact and halo effect.

Extended bilateral motion estimation (EBME) carries out full search on both original and overlapped grid [4]. EBME algorithm is a slow algorithm and difficult to adopt in real-time applications. In adaptive extended bilateral motion estimation (AEBME) algorithm, the novel block type matching procedure is proposed to accelerate the ME procedure [5]. The calculated edge information using sobel mask is used in block type matching procedure. Based on the block type matching, a decoder will decide whether to use EBME.

The proposed modified adaptive extended bilateral motion estimation (MAEBME) is an enhanced version of conventional EBME and AEBME algorithms. We use simple global scene cut change detection to skip unnecessary ME procedure. In scene change frame, conventional motion compensation (MC) based FRUC algorithm is improper. So frame repetition algorithm is applied. Overlapped block motion compensation (OBMC) technique is adopted during frame interpolation process to reduce the blocking artifacts that may be occurred by irregularity of MVs [6]. Simple frame motion activity check is conducted to employ OBMC selectively. Finally, MCFI is adopted to restore the missing frames.

The rest of the paper is organized as follows: Section II presents simple description of EBME. Section III describes our proposed algorithm in details. The experimental results and test conditions are provided in Section IV. Finally, we conclude the paper in Section V.

II. Extended Bilateral Motion Estimation

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A. *Bilateral Motion Estimation*

The bilateral motion estimation (BME) as illustrated in Fig. 1, is executed under the assumption that motion of object is temporally symmetric from the intermediate frame's point-of-view.

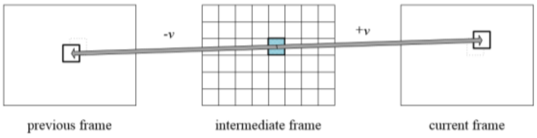


Figure 1. Illustration of the bilateral motion estimation

The conventional BMA suffers from holes and occluded areas during compensation. But in BME, there are no holes and occluded areas after reconstruction procedure. In BME, the block in intermediate frame is regarded as the center of search process. The search is processed by comparing a block at a shifted position in the previous frame and another block at the opposite position in the current frame. By computing the sum of bilateral absolute differences (SBAD), we can find the MV which minimizes SBAD by (1).

$$SBAD(v_x, v_y) = \sum_{v_x \in SR} \sum_{v_y \in SR} \left| f_{n-1}(x - v_x, y - v_y) - f_n(x + v_x, y + v_y) \right|$$
$$v = \arg \min_{(v_x, v_y) \in SR} \{SBAD(v_x, v_y)\} \qquad (1)$$

where (v_x, v_y) is the MV candidate, f_{n-1} and f_n are the previous and current frames, respectively. v is the selected MV, *SR* is the search range.

B. *Extended Bilateral Motion Estimation*

The computational burden of the BME is much lower than that of the BMA. Because the search range of the BME is one quarter of that of the BMA. However when the motion trajectory of an object is not symmetrical from the intermediate frame's viewpoint, the accurate MV cannot be estimated. The EBME performs the additional BME for the overlapped blocks to search for a more accurate MV. Fig. 2 illustrates how the EBME modifies the motion vector field (MVF). After EBME process, we can get MVF which is more precise than the original MVF. By comparing SBAD of the original block grids and the overlapped block grids, the final MVF will be decided.

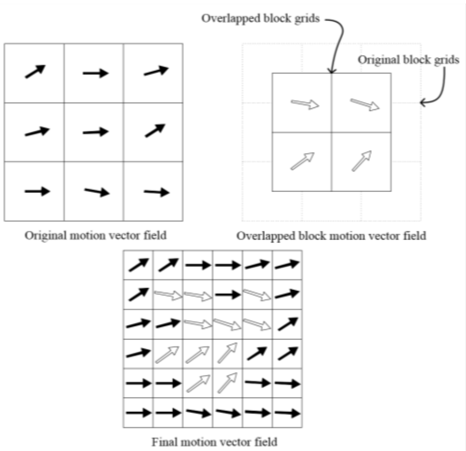


Figure 2. Illustration of the extended bilateral motion estimation

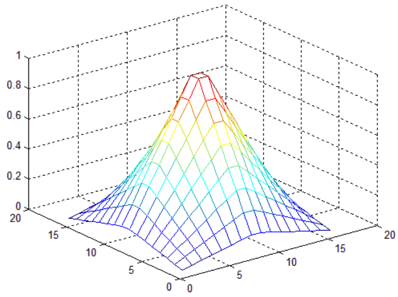


Figure 3. Bilinear window

C. *Overlapped Block Motion Compensation*

OBMC process can drastically reduce blocking artifacts and provide a good visual quality in almost all sequences under an assumption that we have the accurate MVF. To enhance a visual quality, we employ Bilinear window, illustrated in Fig. 3, which is formulated as a linear estimator of pixel intensities given the limited block motion information. The coefficients of the filter are calculated by (2).

$$w(u,v) = w_u \cdot w_v,\ w_u = \begin{cases} \frac{1}{N}(u + \frac{1}{2}) & for\ \ u = 0, ..., N-1 \\ w_{(2N-1)-u} & for\ \ u = N, ..., 2N-1 \end{cases} \qquad (2)$$

D. *Motion Compensated Frame Interpolation*

In order to construct the intermediate frame, MCFI is employed by using the final MVs. The intermediate frame is interpolated by (3). We select a block to which we want to apply MCFI, and enlarge block's size to the window size for OBMC process. Then, OBMC and MCFI are conducted.

$$f_{n-\frac{1}{2}} = \frac{1}{2}\{f_{n-1}(x - v_{x,final}, y - v_{y,final}) + f_n(x + v_{x,final}, y + v_{y,final})\} \qquad (3)$$

where ($v_{x,final}$, $v_{y,final}$) is the final MV, and $f_{n-1/2}$ is the intermediate frame.

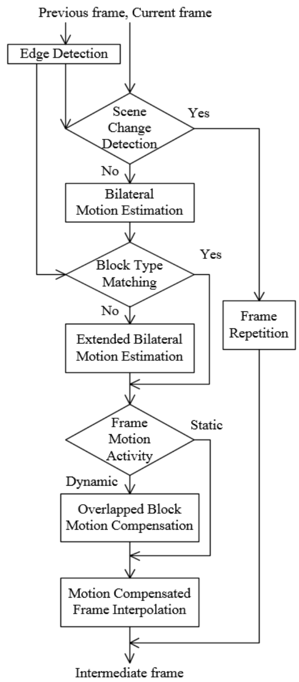
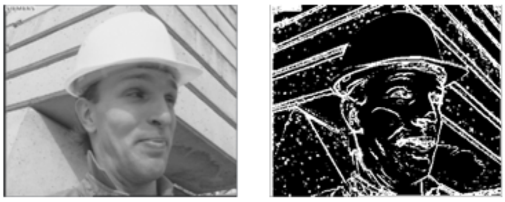


Figure 4. Flowchart of the proposed MAEBME algorithm



-1	0	1
-2	0	2
-1	0	1

-1	-2	-1
0	0	0
1	2	1

Figure 5. Sobel mask (x,y-axis)

III. The Proposed Algorithm

The flow chart of the proposed MAEBME algorithm is shown in Fig. 4. The proposed verification process is comprised of three components: scene change detection, block type matching and frame motion activity check.

A. Edge Detecion

Sobel mask is used to calculate edge information [7]. The operator uses two 3x3 kernels which are showed as Fig. 5 to calculate approximations of the derivatives. The mask is slid over an area of the image. The edge magnitude is calculated by (4).

$$M(x,y)=\left|g_x\right|+\left|g_y\right| \tag{4}$$

B. Scene Change Detection

Conventional scene change detection algorithms have high computational burden. Because of high complexity, they are not suitable for real-time applications. In FRUC algorithm, BME has already high complexity, so scene change detection part must be simple and powerful. So we proposed edge and pixel based simple global scene change detection algorithm.

There are several causes of false detection. Camera shake is a prime example. In this case, edge difference is high, but pixel difference is low. Through this fact the algorithm goes through two stages using the average of edge difference, avg_{ed}, and the average of pixel difference, avg_{pd}. First, we calculate frames' avg_{ed} using edge information. Second, we calculate frames' avg_{pd}. If avg_{ed} is larger than T_1 and avg_{pd} is larger than T_2, the intermediate frame is classified into a scene change frame. If the frame is a scene change frame, we skipped whole process of ME and MCFI. And we conducted frame repetition algorithm.

$$\begin{aligned} avg_{ed} &= \frac{1}{Width\times Height}\sum_{x\in Width}\sum_{y\in Height}\left|M_n(x,y)-M_{n-1}(x,y)\right| \\ avg_{pd} &= \frac{1}{Width\times Height}\sum_{x\in Width}\sum_{y\in Height}\left|I_n(x,y)-I_{n-1}(x,y)\right| \end{aligned} \tag{5}$$

where Width and Height are the width and height of frame, respectively. $I(x,y)$ is the pixel intensity.

C. Block Type Matching

EBME process may predict non-true MV which indicates different objects in the previous and current frame. We have to check if the objects in each frame are same. The edge information which was calculated using sobel mask is used to check block type of each object. First we calculate the mean of edge values of each block by (6). If the edge value of pixel in each block is larger than the mean, the pixel is classified into the edge pixel. Otherwise, the pixel is classified into the flat pixel. If the percentage of edge pixels in the block is larger than T_3, the block is classified into the edge block. Otherwise, the block is classified into the flat block.

$$edge\_mean=\frac{1}{Width\times Height}\sum_{x\in Width}\sum_{y\in Height}M(x,y) \tag{6}$$

After BME, if the block types of the reference blocks of the intermediate block are different, EBME is performed. This block type matching process can improve an accuracy of indicating same objects in the previous and current frame.

D. Frame Motion Activity

Static images have the zero MVs for most blocks. If OBMC is applied in a static region, visual quality degradation is inevitable. Frame motion activity check is simple but efficient process, which can avoid image degradation. By checking frame motion activity, OBMC is applied depending on the characteristic of frames. After checking process, the frame is classified into a static or dynamic frame. First we calculate the average MV of all MVs in a frame using (7). If the average of MVs is larger than T_4, the frame is classified into a dynamic frame. In the opposite case, the frame is classified into a static frame. And then, OBMC is applied in dynamic frames.

$$\begin{aligned} |v_i| &= |v_{x,i}|+|v_{y,i}| \\ v_{avg} &= \frac{1}{M}\sum_{i\in frame}|v_i| \end{aligned} \tag{7}$$

IV. Experimental Results

The experiment is conducted using 150 odd frames of CIF (352x288) format sequences as input and 149 even frames are interpolated as a result. Original even frames are used as reference to calculate the peak signal to noise ratio (PSNR). The performance of the proposed MAEBME algorithm has been evaluated through the computation time evaluations. PSNR values of the intermediate frames are compared with EBME algorithm and AEBME algorithm. The average number of the conducted EBME is calculated to show the result of computational complexity reduction.

For experiments, we set the original block size to 16x16 pixels and the search range to -8 ~ +8. After EBME process, we set the block size to 8x8, OBMC filter size N to 16. The threshold T_1 and T_2 in scene change detection process is set to 0.35 and 0.15. The threshold T_3 in block type matching process is set to 0.6 and T_4 in checking frame motion activity process is set to 0.5. As the test sequences, we used 9 sequences which contain scene change frames.

A. Subjective Results

We compared the performance of MAEBME algorithm with the conventional EBME and AEBME algorithms. Fig. 6 shows original frame and the interpolated frames of EBME without OBMC, EBME with OBMC, AEBME, and MAEBME. Fig. 6 (b) and (c) show the importance of OBMC process. With OBMC, blocky effect has been disappeared. Fig. 6 (c) and (d) show that the results of EBME with OBMC and AEBME are similar because of considering block type and frame motion activity. Fig. 6 (e) shows that MAEBME is the only algorithm that has same frame with original frame. This result is caused by scene change detection.

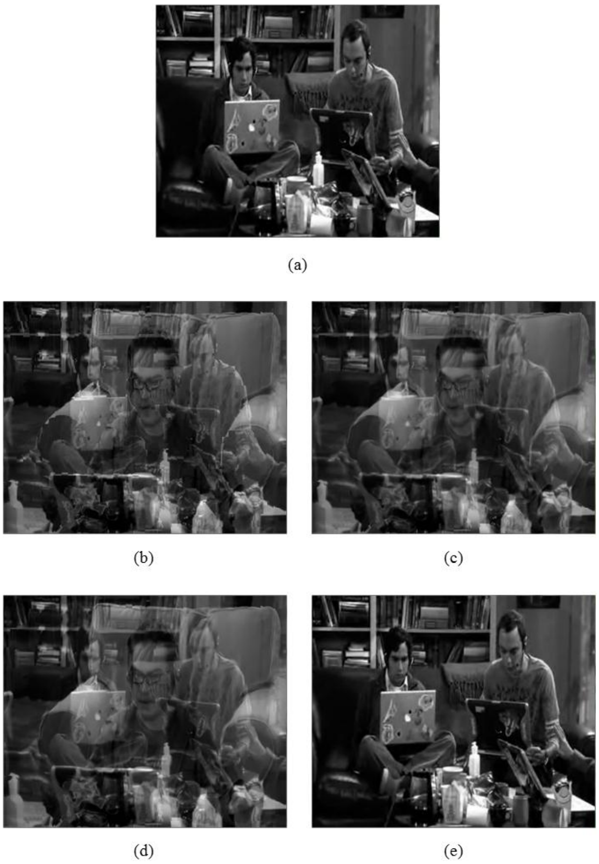


Figure 6. Subjective results for *Big Bang* (52th frame)
(a) Original (b) EBME without OBMC (c) EBME with OBMC
(d) AEBME (e) MAEBME

B. Objective Results

PSNR is used as the metric for objective performance evaluation. The average PSNR values for the results are presented in Table I. In Table II, computation times of test sequences are presented. The proposed MAEBME algorithm has much higher PSNR and consumes less time than the anchor algorithms by skipping whole process of ME and MC in scene change frames. In Table III, we presented PSNR difference and computation time gain.

Table IV shows the number of conducted EBME. The number of block type mismatch blocks has drastically decreased because of skipping EBME process and using frame repetition algorithm in scene change frames. It shows higher performance than the anchor algorithms.

TABLE I. PSNRS OF TEST SEQUENCES

Sequence	EBME	AEBME	MAEBME
Table	27.181	27.137	27.459
Big Bang	30.942	30.934	37.366
Family Guy	24.731	24.671	26.204
Friends	32.836	32.834	37.194
Wilfred	26.434	26.426	28.192
Ani. 1	33.774	33.843	34.208
Ani. 2	31.859	31.822	33.109
Daisy	31.902	31.928	34.926
Wild Life	27.120	27.101	30.438
Average	29.642	29.633	32.122

TABLE II. COMPUTATION TIMES OF TEST SEQUENCES

Sequence	EBME	AEBME	MAEBME
Table	27.269	14.592	14.520
Big Bang	20.882	11.166	10.873
Family Guy	22.582	12.068	11.705
Friends	21.655	11.651	11.326
Wilfred	20.904	11.655	11.320
Ani. 1	19.464	10.137	9.925
Ani. 2	20.931	11.233	11.000
Daisy	18.092	9.78	9.447
Wild Life	20.130	11.238	10.775
Average	21.323	11.502	11.210

TABLE III. PSNR DIFFERENCE AND COMPUTATION TIME GAIN

	EBME	AEBME	MAEBME
PSNR Difference(dB)	0	-0.009	+2.480
Computation Time Gain	1	1.854	1.902

TABLE IV. THE NUMBER OF CONDUCTED EBME

Sequence	EBME	AEBME	MAEBME
Table		6.631	6.094
Big Bang		6.691	4.953
Family Guy		6.544	4.954
Friends		11.007	8.658
Wilfred	357	15.812	14.215
Ani. 1		2.275	1.248
Ani. 2		8.161	6.899
Daisy		7.544	5.544
Wild Life		18.477	13.913
Average	357	9.238	7.386
Gain	1	38.645	48.332

V. CONCLUSIONS

This paper proposed MAEBME algorithm, FRUC algorithm which considers block type, frame motion activity and global scene change. The calculated edge information using sobel mask is used to detect global scene change and reused to decide whether to use EBME. The global scene change detection part is used to skip whole ME process. And the novel block type matching algorithm is used to reduce additional BME process. OBMC is selectively conducted by checking frame motion activity. Finally, the missing even frames are restored by conducting MCFI or frame repetition.

Experimental results show that this proposed algorithm has outstanding performance and fast computation comparing with the anchor algorithms.

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