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一個利用動作補償來達成影片更新率提高的新方法

A New Method for Frame Rate Up-Conversion Based on Motion Compensation

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Abstract

Frame rate up-conversion (FRC) is a conversion between any two display formats with different frame rates. For improving visual quality, the frame rate required for high definition television (HDTV) is much higher than the current frame rate. That is, the frame rate should be up-converted in HDTV.

In this thesis, we present a frame interpolation algorithm for FRC. In the proposed scheme, forward motion estimation (ME) is performed to generate the motion vectors (MVs) that determine how the frame will be interpolated. Based on the naturally perceptual scene, we set a threshold for ME, and only refer to one frame information when the interpolation frame is constructed in the process of motion compensated (MC). To solve the problem of overlapped and hole regions introduced in MC, a weighted average compensation technique is presented to process the overlapped regions, and a block based algorithm is provided to process the hole regions. Moreover, the overlapping block ME improves the quality of FRC. Finally,

experimental results of the proposed method are compared with the results of the hierarchical motion compensated frame interpolation (HMCFI) method. The PSNR of the interpolated frames by the proposed method and by HMCFI are near enough, however, the proposed method provides a better perception result.

一個利用動作補償來達成
影片更新率提高的新方法

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摘要

近年來新的電視系統的興起，為了追求更好的影片品質，新的電視播放系統有著較高的更新率(frame rate)。為了讓更新率較低的影片可以順利地在新系統播放，更新率的提高(frame rate up-conversion)是必要的。在這篇論文裡，我們將利用影片壓縮的技巧內插生成補圖，來達到更新的提高。為了容易研究與使用，我們亦發展了一個方便使用的系統。

誌謝

首先對於我的指導教授 陳玲慧老師獻上最真誠的感謝，在她細心、耐心的教導之下，讓我能夠體驗體會到學習的樂趣與研究的精神。

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CHAPTER 1

INTRODUCTION

Frame rate up-conversion (FRC), a conversion between any two display formats with different frame rates, is one of main issues that have arisen in recent years with the emergence of new television and multimedia system [1]. For improving visual quality, the frame rate required for HDTV is much higher than the current frame rate (e.g., 24, 25 or 30 frames/sec) for currently available motion pictures. The frame rate should be up-converted in HDTV and multimedia PC environments. Moreover, FRC technique can be used for video transmissions.

In recent years, simple FRC algorithms such as frame repetition and linear interpolation have been already used. A noted solution [2] for conversion is widely accepted interoperability practice called “3-2 pulldown”. This technique converts the frame rate from 24 frames/sec up to 60 frames/sec by a 3:2 frame repeating sequence. However, some “jerkiness” would be produced when conversion from low and medium resolution to high resolution sequences as in HDTV. Besides, linear interpolation causes blurring in the moving areas of the video sequence depending on the amount of motion.

The motion compensated interpolation (MCI) technique provides a better solution for high quality FRC [3]. Motion estimation (ME) and motion compensation (MC) are employed in MCI [4-5]. Motion estimation is used to find motion vectors (MVs) that represent the motion information of objects in an image sequence, while motion compensation is used to generate the interpolated frame according to MVs from ME. Hence, the correctness of MVs affects the quality of FRC using MCI. There are some algorithms proposed for the true motion estimation [6-7]. And several FRC approaches [8-12] using motion information have been proposed.

FRC using block-based motion compensation may produce overlapped and hole regions in the interpolated frame, as shown in Fig. 1-1. To avoid the above-mentioned shortcoming, a kind of new motion compensated frame interpolation (MCFI) algorithms [10-11,13] is proposed. It [11] compensates the interpolation frame block

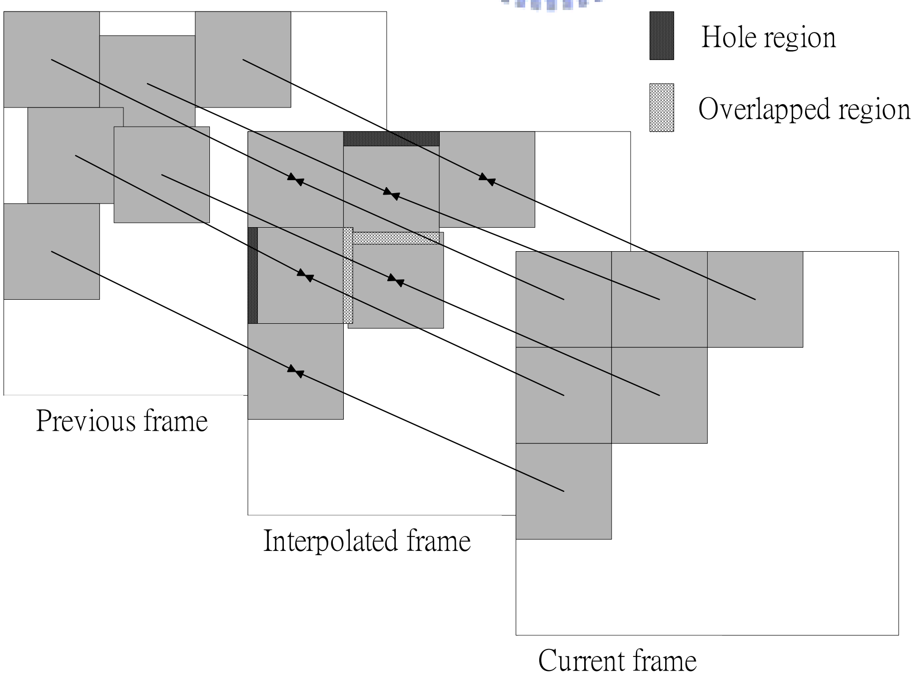


Fig. 1-1 Hole and overlapped regions in the interpolated frame.

by block. To find the blocks in the (k-1)th (previous) and kth (current) frames to be used for interpolation, start with the estimated motion vector (**Vb**), as shown in Fig. 1-2(a). Using the assumption of linear motion , we estimate that each block will have moved one half of its motion vector distance in the interpolated frame. Before interpolating a block in the interpolated frame, one block from each of the (k-1)th (previous) and kth (current) frames is searched as shown in Fig. 1-2(b). Although the method can keep the overlapped and hole regions off, a new problem occurs. It is that the motion of the compensated block is not always the same as the estimated block motion. To handle this problem, a refinement of the MVs using bi-directional motion estimation has been proposed [10]. However, some blurring regions would occur

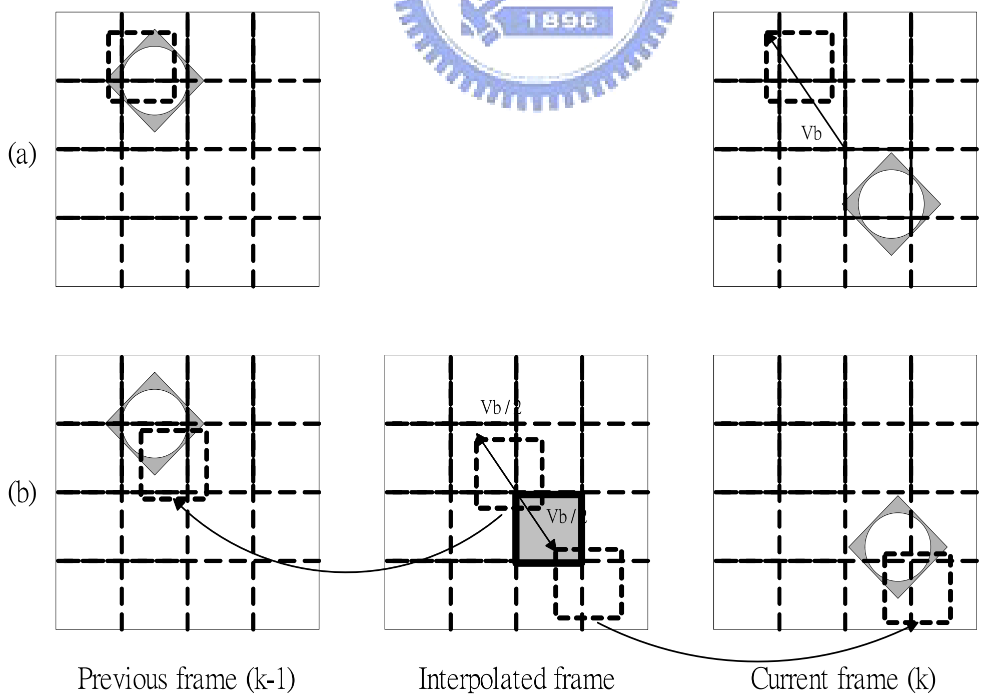


Fig. 1-2 (a) Estimatied MV, Vb, computed during ME, (b) Interpolation using blocks from (k-1)th and kth frames.

since there are not similar enough blocks in motion estimation. Other methods to estimate the MV field are hierarchical MCFI (HMCFI) [1,14-15]. An approach [1] based on the Gaussian/Laplacian pyramid structures has been proposed to improve visual quality of interpolated frames. It focuses on refinement of the MCFI based on a hierarchical progressive video scheme. However, this method requires large and complicated operators since frames are decomposed into lowpass and highpass components and the operators are quite different at top, intermediate and bottom levels. Beside the effect on the top level affects the quality of the interpolated frame so much. In [1,10-11,13], the block used to compensate to the interpolated frame is usually formed by a linear combination from two frames. It would introduce incomplete or overlapped shadow in the interpolated frame, since the blocks picked to combine are not exact the same.

In this thesis, a new FRC based on MCI algorithm is proposed. To avoid unnatural shadow, we construct the interpolated frame by only referring to one frame. To get a better visual perception, there is a threshold used to abandon the MVs that provide a large prediction error. To solve the problems of overlapped and hole regions that are introduced in motion compensation, a weighted average compensation technique is employed to process the overlapped regions, and a block-based algorithm is developed to fill the hole regions. The paper is organized as follows. In Section II, the proposed method will be described. Experimental results will be presented in Section III. Finally, the conclusions will be given in Section IV.

CHAPTER 2

THE PROPOSED METHOD

Fig. 2-1 shows the block diagram of the proposed method. It consists of two phases: forward motion estimation and motion compensated interpolation, and overlapped and hole regions processing. First, to determine how to interpolate the new frame, the motion vectors are generated by forward motion estimation. Second, the interpolation frame with motion vectors introduced from the first phase will be constructed. Based on the natural perception, the information for interpolation only refers to one frame. Third, the overlapped regions are processed by using the weighted average compensation. Finally, we segment the interpolation frame into blocks and compensate the hole regions block by block. In what follows, we will describe the details of the proposed method.

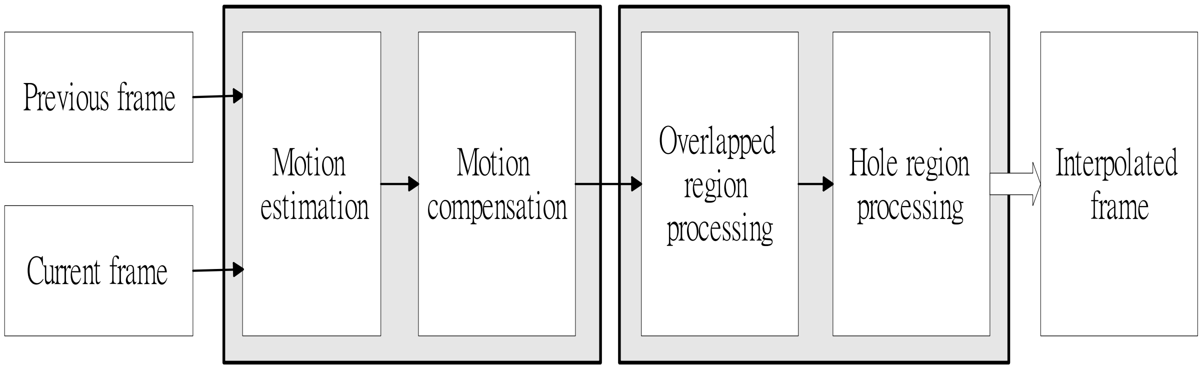


Fig. 2-1 Block diagram of the proposed method.

2.1 Motion estimation and motion compensated interpolation

A block matching algorithm is employed for forward motion estimation to obtain the motion vectors. Let **x** be the spatial domain index, n be the time domain index, and a frame image is denoted as $f(\mathbf{x}, n)$. Then the motion vector, **v**, of a macroblock (MB) is obtained by

$$\mathbf{v} = \begin{cases} \arg\min_{\mathbf{u}\in S} \{\xi(\mathbf{u})\}, & \text{if } \min_{\mathbf{u}\in S} \{\xi(\mathbf{u})\} \le t \\ null, & \text{if } \min_{\mathbf{u}\in S} \{\xi(\mathbf{u})\} > t \end{cases}, \tag{1}$$

where $$\xi(\mathbf{u}) = \frac{\sum_{\mathbf{x}\in B} [f(\mathbf{x}+\mathbf{u}, n-1) - f(\mathbf{x}, n)]^2}{\sum_{\mathbf{x}\in B} 1}, \tag{2}$$

B is a macroblock in the search area, S is the search range of ME and t is a threshold value for abandoning MVs. Note that if the motion of object is not linear, the difference between the estimated macroblock and the macroblock in the related search ranges will be large. That is, no appropriate motion vector can be found to estimate the macroblock. To solve the above shortcoming, in this thesis, there is a threshold used for abandoning this kind of motion vectors.

Fig. 2-2 shows how a frame is interpolated. For each macroblock **I** centered at **x** in

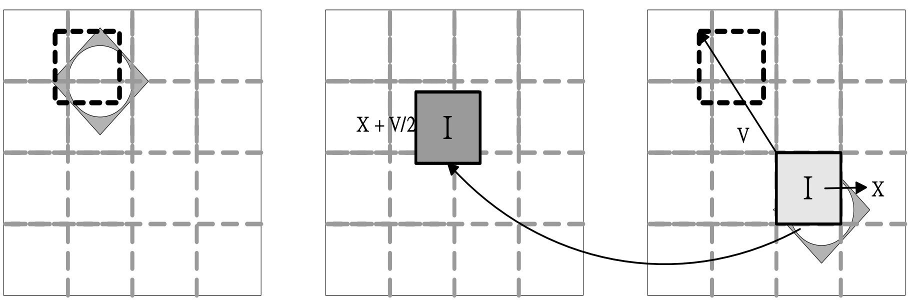


Fig. 2-2 Frame interpolation by the proposed method with MacroblockI inserted

frame n, we first find its motion vector **v**, then paste macroblock **I** in the interpolation frame $n-\frac{1}{2}$ with center located at $\mathbf{x}+\frac{\mathbf{v}}{2}$. That is the interpolated frame is generated by

$$f(\mathbf{x}+\frac{\mathbf{v}}{\mathbf{2}}, n-\frac{1}{2}) = f(\mathbf{x}, n), \tag{3}$$

where **v** is the estimated motion vector. To avoid unnatural shadow and blurring, our compensation only refers to one frame. Fig. 2-3 is an example of result after this step.

2.2 Overlapped and hole regions processing

Overlapped and hole regions are introduced in the interpolated frame since some adjacent motion vectors are not the same. Moreover, some hole regions are produced

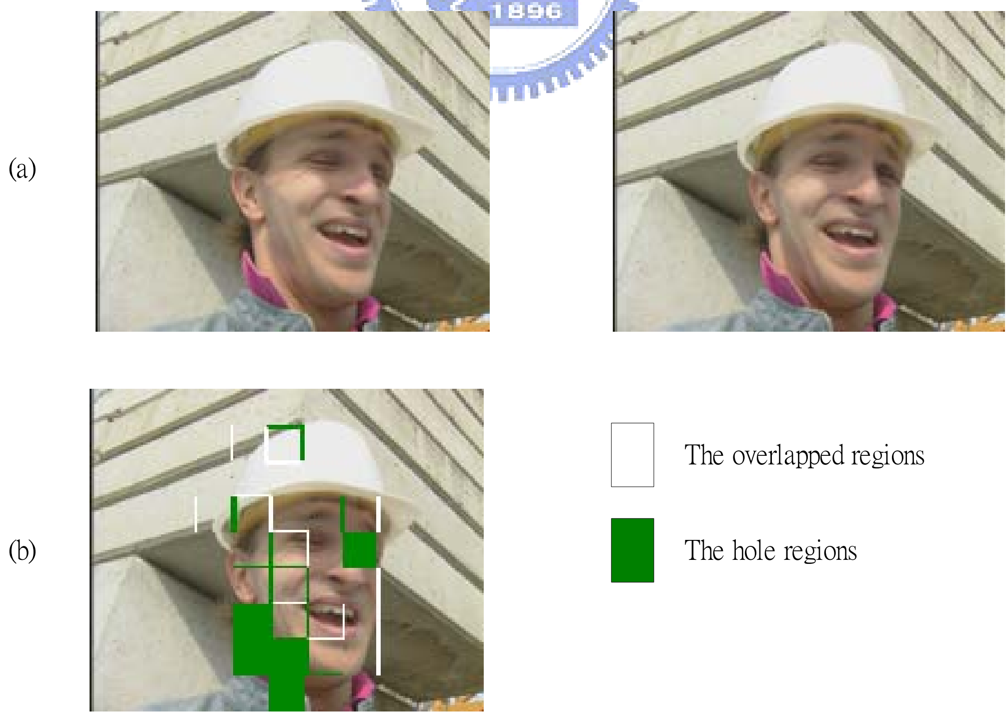


Fig. 2-3 (a) The previous and current frames. (b) The interpolated frame by the proposed motion estimation and motion compensated interpolation with frames of (a).

due to null motion vectors. Fig. 2-4 shows that the overlapped and hole regions are introduced in the interpolated frame. In this thesis, we use a counter array to detect the overlapped and hole regions [1]. Hole regions are pixels with the count value equal to zero while overlapped regions are pixels with the count value larger than one. A motion vector array is also needed for hole regions processing.

2.2.1 Overlapped region processing

For reducing blocking artifact, we use a weighted average way [13] to compensate the interpolated frame for overlapped region. It is calculated as

$$f(\mathbf{x}, n-\frac{1}{2}) = \frac{\sum_{\mathbf{v}} f(\mathbf{x}-\frac{\mathbf{v}}{2}, n) \cdot 1/\xi(\mathbf{v})}{\sum_{\mathbf{v}} 1/\xi(\mathbf{v})}, \tag{4}$$

where **v** is the motion vector of macroblock that covers the pixel **x**. That is, all motion vectors of macroblocks covering the same location **x** are utilized. For processing hole

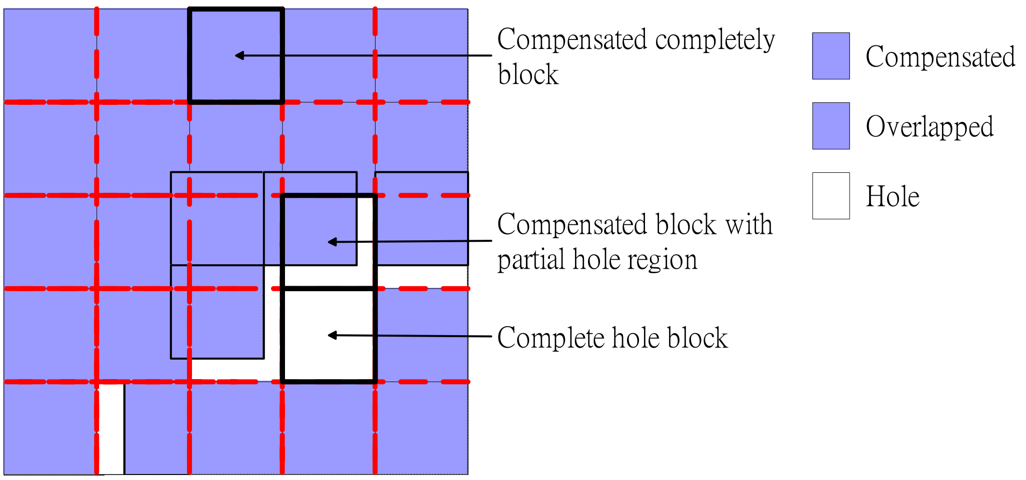


Fig. 2-4 Three types of blocks in the interpolation frame.

regions which will be described latter, a motion vector array is provided. For each pixel **x** covered by several motion compensated blocks, the array will only store the motion vector of the motion compensated block with minimum prediction error. As a result, the motion vector array is filled with motion vectors except for hole regions. Fig. 2-5 is an example of result after this step.

2.2.2 Hole region processing

To compensate the hole regions of the interpolated frame efficiently, the interpolated frame will be divided into blocks of the same size and the hole regions will be compensated block by block. Different kinds of blocks need different methods to compensate the hole region. As shown in Fig. 2-4, there are three kinds of blocks: compensated completely, compensated with partial hole region, complete hole region. In what follows, we will introduce two kinds of methods to perform hole region processing.

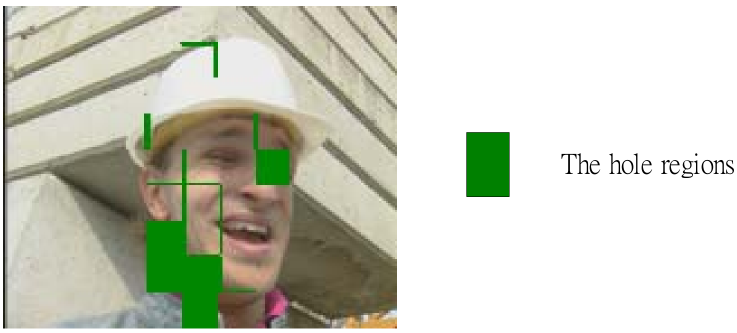
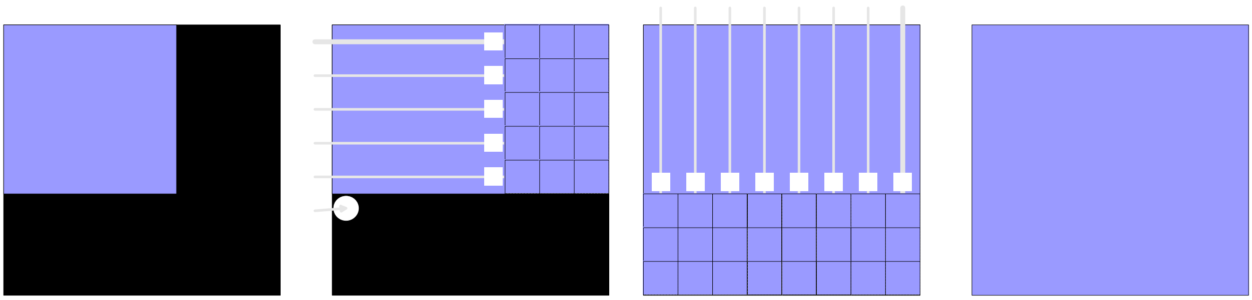


Fig. 2-5 The interpolated frame about Fig. 2-3(b) after processing of the overlapped regions by the proposed method.

2.2.2.1 The process of block compensated with partial hole region

Fig. 2-6 shows the flow diagram of the compensated method. Basically, the proposed algorithm detects the hole region in a block by scanning it row by row (column by column), and compensates the hole region by the motion vector of the adjacent pixel. The order of scanning direction and the start row (column) are shown as in Fig. 2-7 respectively. As shown in Fig. 2-6(b), if the first pixel on a row (or column) according to scan direction belongs to the hole region, stop the block scan and rescan from a new direction according to the proposed order. In our experiment, the effective scanning runs two directions at most. Since the second direction scanning can compensate the hole region totally referring to the information compensated in the first direction scanning if it needs (see Fig. 2-6(c)). Fig. 2-8 is an example of result after this step.



(a) (b) (c) (d)

Fig. 2-6 (a) A block with partial hole region (black part). (b) Scan the block row by row, and stop scanning when the first scanned pixel in a row belongs to the hole region. (c) Change the scanning direction and scan the block column by column. (d) The compensated block.

2.2.2.2 The processing of block with complete hole region

If the values of counter array on the four corners of a block are zeros, then the block is a complete hole region. In this thesis, based on the motion information from the block's neighbors, we propose a method to decide the motion vector, **v**, of the hole block (see Fig. 2-9). That is,

$$\mathbf{v} = \arg\max_{\mathbf{u}\in S}\{N(\mathbf{u})\}, \tag{5}$$

where $N(\mathbf{u})$ is the times of **u** occurring in S and S is the neighboring pixels around the

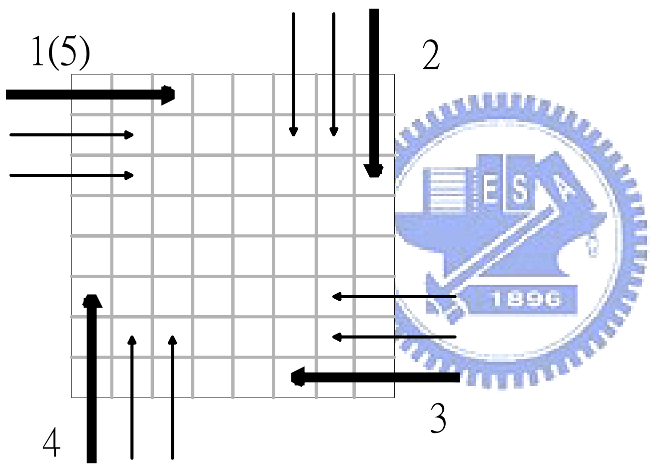


Fig. 2-7 The order of the block scanning direction with bold arrow indicating the first scanning row (column).

Fig. 2-8 The interpolated frame about Fig. 2-5 after processing of the compensated block with the partial hole regions by the proposed method.

hole block and shown in Fig. 2-9. Fig. 2-10 is an example of result after this step.

2.2.3 Motion estimation with overlapping

Since there are hole regions produced in motion compensation, overlapping processing block would reduce the hole regions. A frame is divided into several blocks with half block overlapping and each block is used to do motion estimation and compensation, as shown in Fig. 2-11. Based on this overlapping schema, the number of hole regions is reduced, and there are fewer blocking artifact. Fig. 2-12 is an example of result after this step.

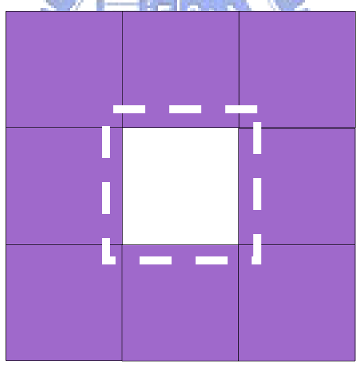


Fig. 2-9 The neighboring pixels marked by white color around block.

Fig. 2-10 The interpolated frame about Fig. 2-8 after processing of the complete hole block regions by the proposed method.

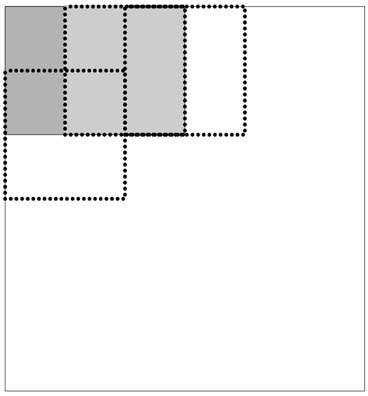


Fig. 2-11 Motion estimation using overlapping blocks.

Fig. 2-12 The interpolated frame about Fig. 2-3(a) after processing of the overlapped regions with half block overlapped.

CHAPTER 3

EXPERIMENTAL RESULTS

In this section, we present some experimental results. The experiments are focused on doubling the frame rate. The size of the marcoblock is set as 16×16 and the search range is ± 16 pixels for both horizontal and vertical directions. The threshold for abandoning motion vectors in motion estimation is set as 400. We select three different video sequences for testing. They are “calendar”, “foreman” and “table”. Test sequences are color sequences with YUV 4:1:1 format. The image size of test sequences is 176×144 quarter common intermediate format (QCIF). In order to show the brief and efficiency of the proposed method, we compare the results with an algorithm of hierarchical MCFI (HMCFI) [1].

3.1 Comparison with hierarchical MCFI

Fig. 3-1 is an example of scene with multiple motions. It contains camera zooming and panning. There are also several object motions such as horizontal translation (train), vertical translation (calendar) and rotation (ball). The speeds of motions are not fast. As shown in Fig. 3-1, especially Fig. 3-1(e) and Fig. 3-1(f), the interpolated frame by HMCFI is more blur than that by the proposed method. Since the interpolated frame by HMCFI is usually compensated by two frames with averaging while that by the proposed method is only compensated by one frame.

(a) (b) (c) (d) (e) (f)

Fig. 3-1 “Calendar” sequences : (a) previous frame, (b) current frame, (c) frame interpolated by the HMCFI, (d) frame interpolated by the proposed method, (e) an enlarged region of (c) by a factor of two, (f) an enlarged region of (d) by a factor of two.

Fig. 3-2 is an example of scene with motion of panning. The camera moves from left to right and the scene shifts to right with a medium speed. Although the motion is simple, some determinations of motion vectors are difficult. It is easy to find that

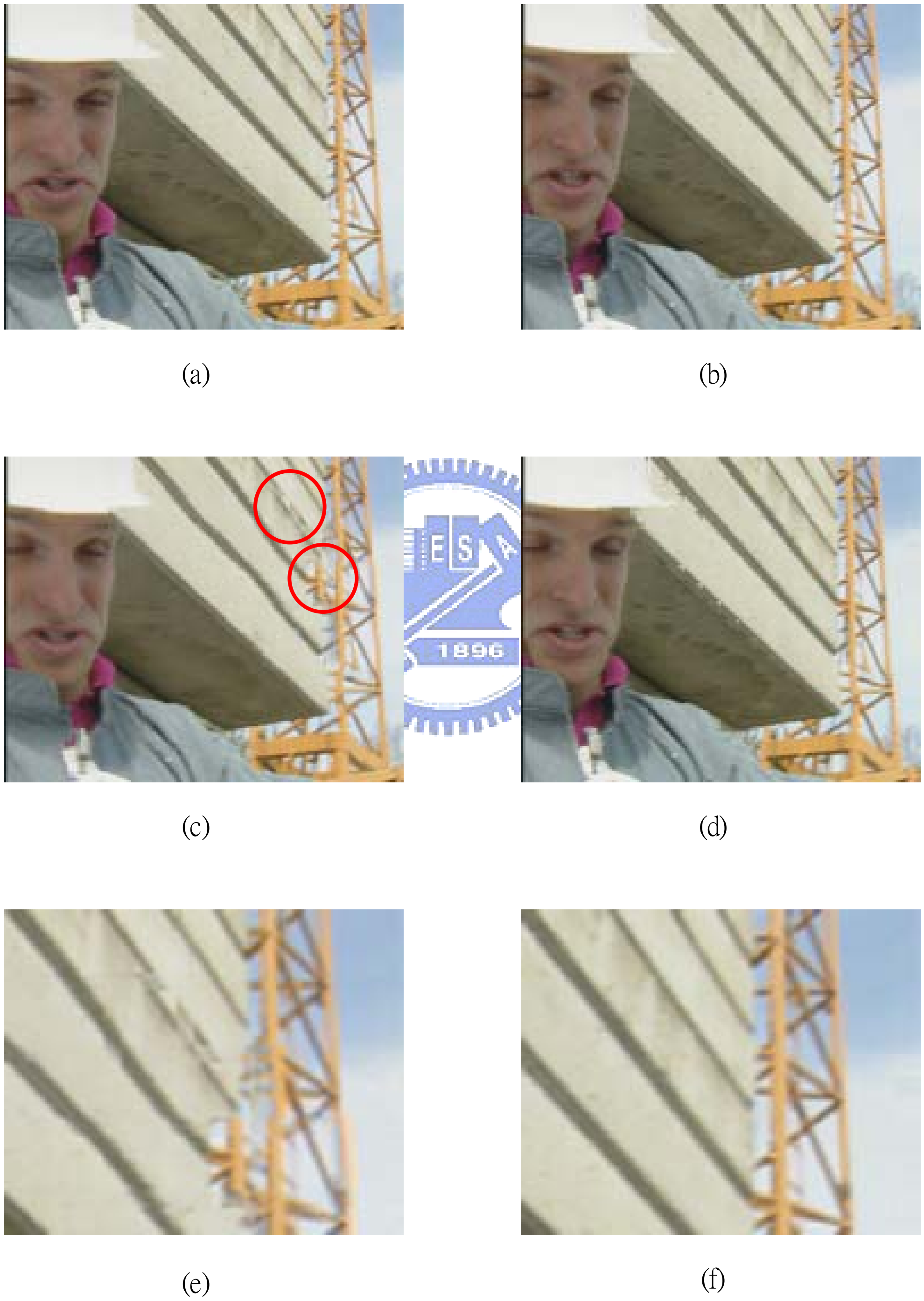
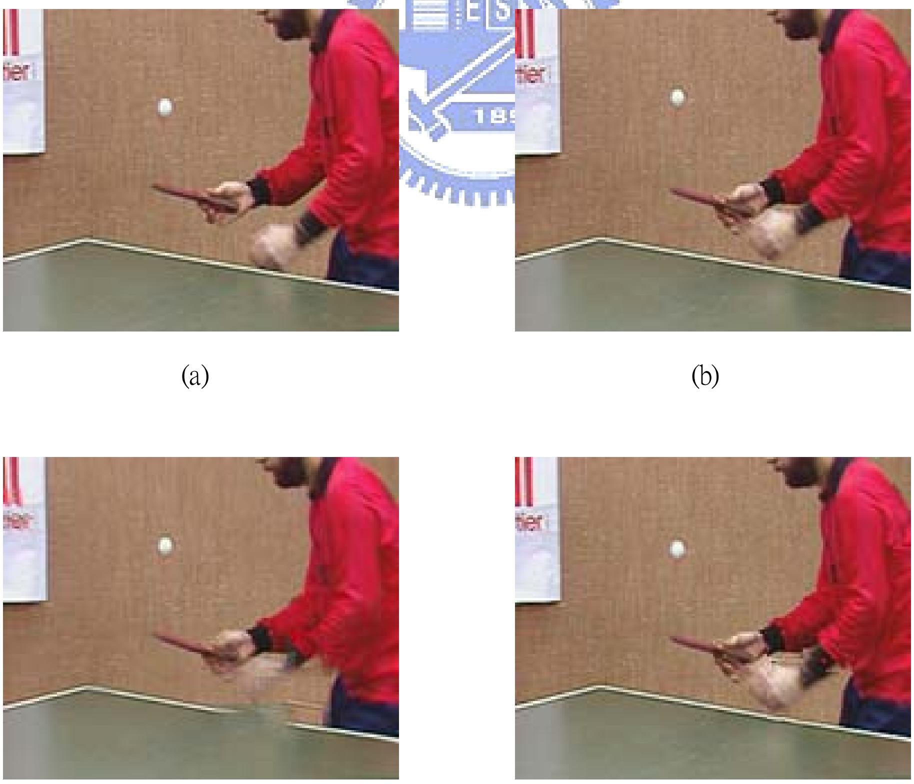


Fig. 3-2 "Foreman" sequences : (a) previous frame, (b) current frame, (c) frame interpolated by the HMCFI, (d) frame interpolated by the proposed method, (e) an enlarged region of (c) by a factor of two, (f) an enlarged region of (d) by a factor of two.

there are two faulted macroblocks marked by circles compensated with faulted motion vectors on the right-up corner in the interpolated frame by HMCFI. In this case, the proposed method provides a more precise motion estimation and a better compensation.

Fig. 3-3 is an example of scene with motion of zooming. The camera zooms from the near to the distant and the scene becomes larger gradually. Among the frames, the left hand moves fast. From Fig. 3-3(c), we can see that the shape of the left hand in the HMCFI interpolated frame is blurred seriously, even the table and the hand are indistinct. And the shape of the hand in the proposed interpolated frame approaches



(a) (b)

(c) (d)

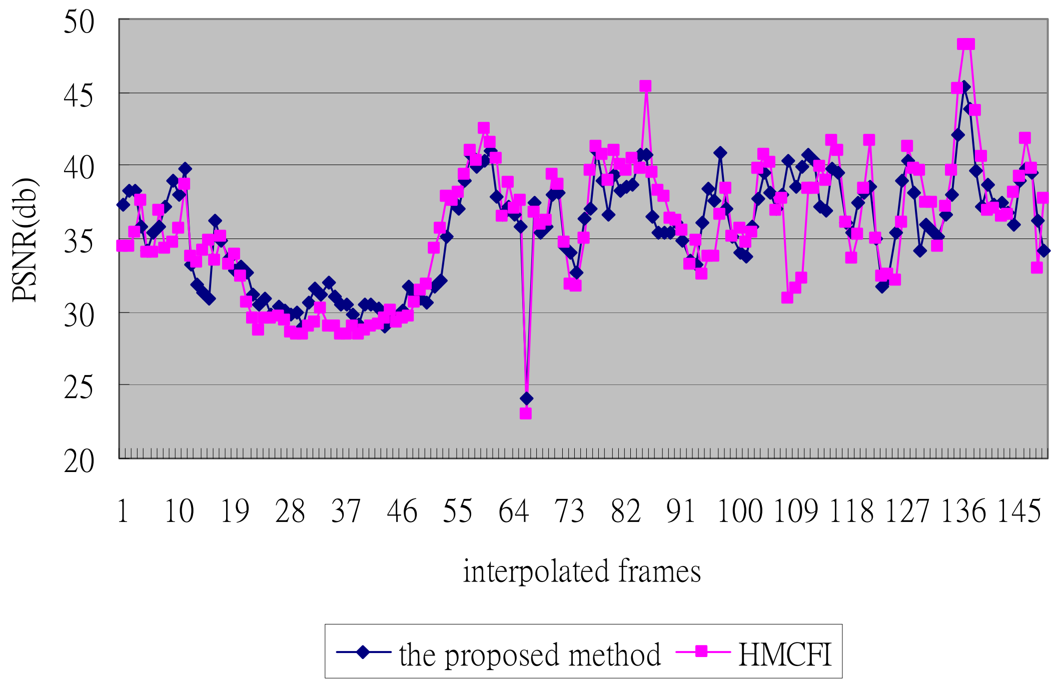
Fig. 3-3 "Table" sequences : (a) previous frame, (b) current frame, (c) frame interpolated by the HMCFI, (d) frame interpolated by the proposed method without overlapping.

the original one. The poster on the left up corner in the interpolated frame by HMCFI is more blurred than that in the proposed interpolated frame. This is due to that HMCFI adapt to two average compensation blocks from two frames.

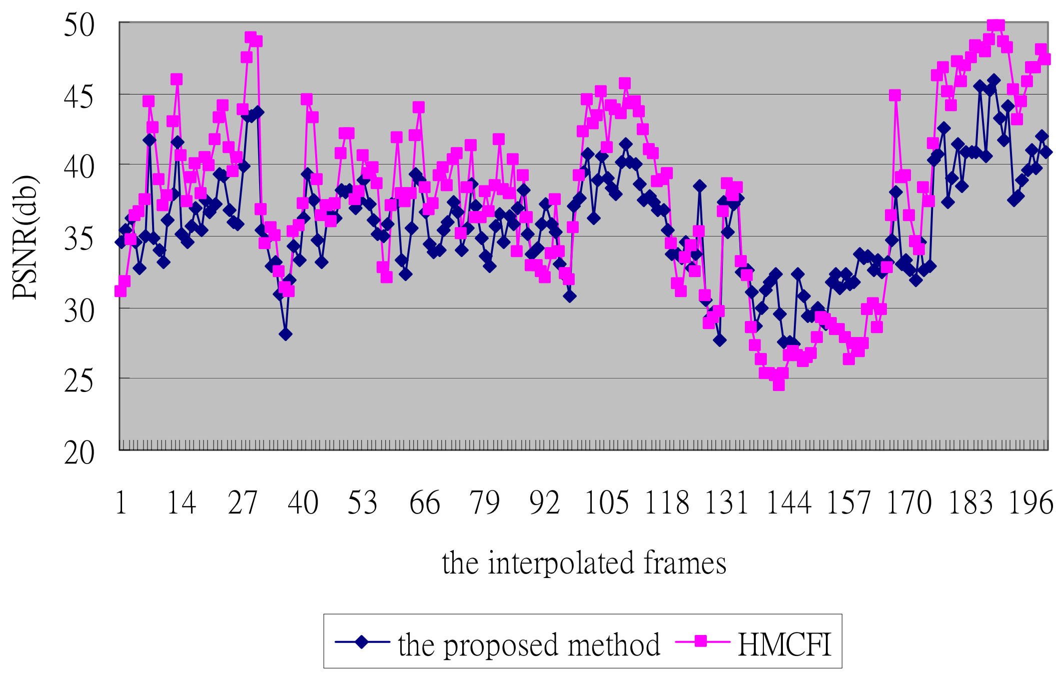
Fig. 3-4 shows the PSNR for the interpolated frames by the proposed method and HMCFI method. In order to compute the PSNR of an interpolated sequence, we drop the frames of even number on purpose and reproduce each dropping even frame by its previous and next odd number frames. And then we compare the interpolated frames with original ones. Fig. 3-4(a) is the result of the "foreman" sequence. The PSNRs of the proposed method are a little lower than those of HMCFI. It is due to that the frame constructed by the proposed method only refers to one frame. However, the interpolated frame by the proposed method is clearer from the visual point. Fig. 3-4(b) is the result of the "table". The PSNR of the 67th interpolated frame by the proposed method is much lower since a scene change appears here. From Fig. 3-4, we found that PSNRs of both methods in most parts are similar. However, the proposed method provides higher quality from visual point and is simpler than HMCFI.

3.2 Effectiveness of overlapping block

In order to reduce the hole regions produced from MC and the blocking artifact, we scan a frame by overlapping half block. To investigate how the overlapping



(a)



(b)

Fig. 3-4 The PSNR computation of the sequences: (a) the sequence of "foreman", (b) the sequence of "table".

schema affects on the perceptual quality of the interpolated frame, we simulated two types of frame rate up-conversion:

(a) the proposed method without overlapping block

(b) the proposed method with overlapping block

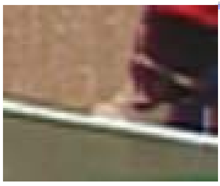
Fig. 3-5 shows that the perceptual quality is improved if the overlapping schema is used. In Fig. 3-5(e) and 3-5(f), we can see that, the interpolated frame produced with overlapping is smoother and has fewer block artifacts. It is obvious that the block overlapping schema does enhance the interpolation frame.

(a)

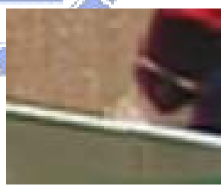
(b)

(c)

(d)



(e)



(f)

Fig. 3-5 “Table” sequence: (a) previous frame, (b) current frame, (c) frame interpolated by the proposed method without overlapping, (d) frame interpolated by the proposed method with overlapping, (e) and (f) enlarged regions of (c) and (d) by a factor two, respectively.

CHAPTER 4

CONCLUSIONS

In this thesis, we have presented a new motion compensated interpolated algorithm for frame rate up-conversion. The proposed method consists of two component: forward motion estimation and motion compensation, and overlapped and hole regions processing. To get a naturally perceptual and non-blur scene, two new concepts are provided. The motion vectors are abandoned when the prediction errors are too large, and the process of compensation only refers to one frame. Moreover, overlapping blocks make the hole regions fewer and the compensation precisely. Experimental results show that the proposed algorithm has a better visual quality.

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