HIGH FRAME RATE MOTION COMPENSATED FRAME INTERPOLATION IN HIGH-DEFINITION VIDEO PROCESSING

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ABSTRACT

Numerous MCFI methods have been proposed to increase the frame rate in the past ten years. However, these methods usually focus on how to double the frame rate and involve complex computation, complicated time-consuming iterations, and are difficult to implement for real-time High-Definition (HD) videos. In this paper, a fast one-pass processing method is proposed for high Motion Compensated Frame Interpolation in HD videos. This approach is based on our basic MCFI scheme, slightly increases complexity, and achieves 4x Frame Rate Up Conversion. Relative Motion Estimation (RME) is also proposed to enhance the accuracy of motion search.

1. INTRODUCTION

Digital displays such as Liquid Crystal Display (LCD) and plasma display televisions have become prevalent in recent years. Sports broadcasting and movies are two prime factors responsible for this popularity. However, motion blur and judder appear as objects move rapidly or color dramatically changes on a wide range of LCD devices because of slow response time and sample-and-hold drive nature [1]. Motion Compensated Frame Interpolation (MCFI) [2][3] or Frame Rate Up Conversion (FRUC) is an effective method to reduce judder for digital displays, especially for low response time devices, such as LCD HDTVs. New frames are interpolated and inserted between original or decoded frames to smooth motion blur and enhance the visual quality. Due to the widespread popularity of digital displays, more and more high quality LCD devices with high frame rate have emerged in the market. However, current video sources in the market are usually limited to 30- or 60-fps. In addition, the bandwidth of current broadcast channels or home theater media devices make it impossible to transmit a 120- or 240-fps high definition compressed video bitstream. Media storage and decoding power are also a problem for this system. Hence, high Frame Rate Up Conversion, such as 240-Hz or higher, has become an indispensable research topic stemming from current double frame rate technology. Fig. 1 shows an example of inserting three frames in order to generate a 4x frame rate video.

Numerous MCFI methods, such as [4][5], have been proposed to increase the frame rate in the past ten years. However, these methods usually focus on how to double the frame rate and involve complex computation, complicated time-consuming iterations, and are difficult to implement for real-time High-Definition (HD) videos. Considering these problems, the proposed method and architecture adopts a fast one-pass and low-complexity processing flow to approach 4x MCFI processing in high resolution videos. The proposed 4x architecture is established based on our previous work in [6] and follows this fast low-complexity design to develop high Frame Rate Up Conversion with slight increase of computational complexity.

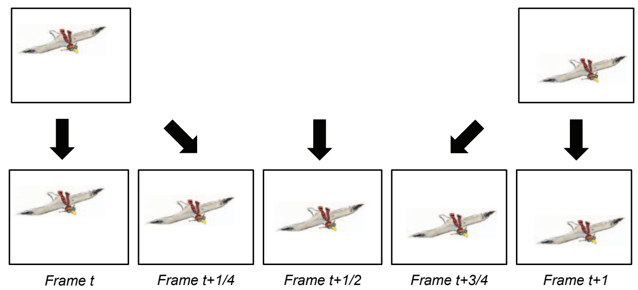

Fig. 1. An example of 4x Frame Rate Up Conversion (FRUC).

2. HIGH FRAME RATE TECHNOLOGY

To reduce blurring, most 120Hz LCD displays use a system called MEMC (Motion Estimation and Motion Compensation) or MCFI to insert in a new frame between each of the original frames and employ pull-down technology for display. Although MEMC is the most popular approach to increase the original frame rate, there are several different methods to achieve higher frame rate up conversion after performing MEMC.

2.1. Hierarchical MEMC

The first method is the hierarchical MEMC method shown in Fig. 2(a). This is an easily modified method based on existing MEMC or MCFI modules. This process adopts the MEMC method to generate the 2x frame rate interpolated frame t+1/2 between any two original frames, frame t and t+1, and then it reapplies the MEMC method to generate 4x frame rate interpolated frame t+1/4 and frame t+3/4. This method can easily apply to the existing 2x Frame Rate Up Conversion system, but the complexity dramatically increases. Not only will the computational complexity of one 4x hierarchical MEMC method be three times higher than that of a 2x MEMC approach, but memory requirement increases three times. This method is used for small resolution video or lower frame rate video for practical reasons.

2.2. MEMC with Backlight Scanning

The second method is MEMC with backlight scanning as shown in Fig. 2(b). This process adopts MEMC to generate the 2x frame rate

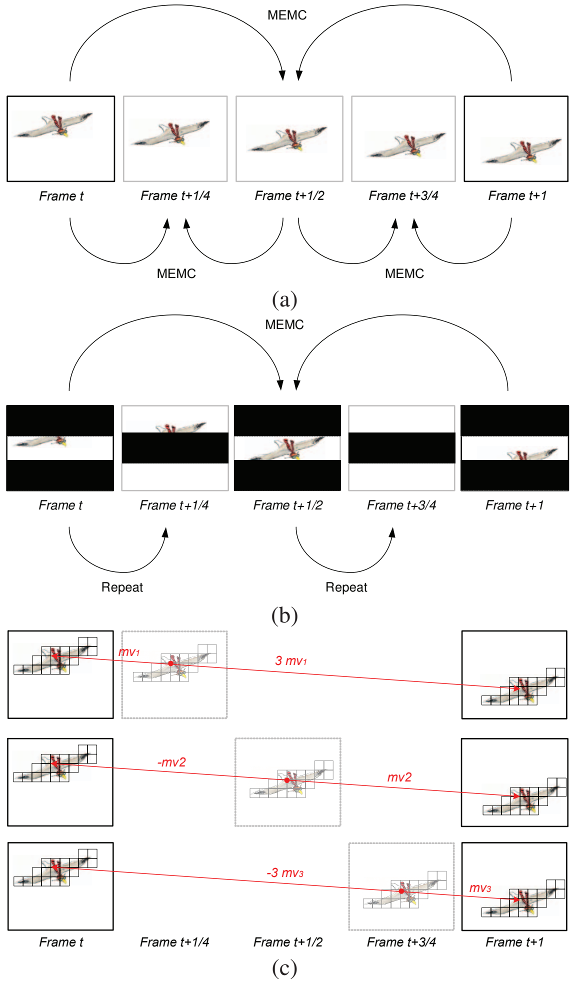

Fig. 2. Three methods to achieve 4x Frame Rate Up Conversion. (a) Hierarchical MEMC method. (b) MEMC method with backlight scanning. (c) Direct MEMC method.

interpolated frame t+1/2 between any two original frames, frame t and t+1, and then it repeats every 2x frames with backlight scanning. This technique that synchronizes the display's pixel updates to a cycling pattern of illumination generated by fluorescent tube or LED array backlight modules [7]. Developing an effective method to insert black data between image frames is one of the most viable ways to shorten the spatio-temporal integration time. In the case in Fig. 2(b), 50% of the data frame is blanked by black data, and this 50% luminance loss will dim the visual display. In order to reduce luminance loss, a sharpened or alternate gamma frames should be driven in order to maintain the luminance. Although this method can provide much lower complexity than pure MEMC, visual quality is lower than pure MEMC, especially on lower frame rate videos.

2.3. Direct MEMC method

The third method is direct MEMC, shown in Fig. 2(c), to achieve 4x frame rate up conversion. This method also employs pure MEMC method to look for true motions before interpolating inserted frames. It uses different ratio to search motions according to temporal distance among the current interpolated frame, previous original frame t, and next original frame t+1. This direct MEMC needs high computational complexity and memory requirement, and it might meet the problem of motion consistency. If motions of interpolated frames between two successive original frames are not consistent, motion judder and broken images will occur.

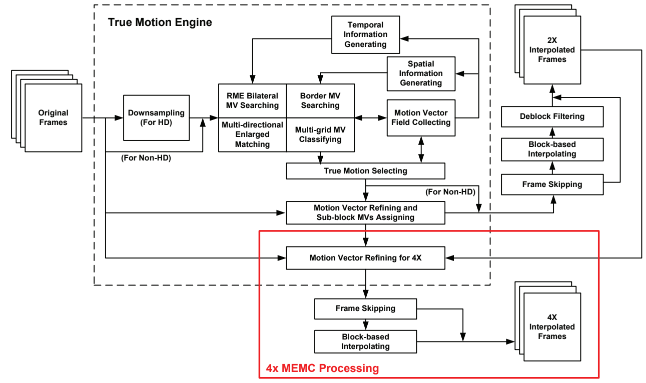

Fig. 3. Processing flow of the proposed method on 4x Frame Rate Up Conversion.

3. PROPOSED HIGH FRAME RATE PROCESSING

Here, we will modify our previously proposed MCFI scheme in [6], with slight increase in complexity, to achieve 4x Frame Rate Up Conversion. The original proposed scheme adopts a motion-compensated approach to double the frame rate by inserting one interpolated frames between any two contiguous original frames. A new processing scheme is proposed and shown in Fig. 3, and the blocks enclosed by the red box are additional functional blocks to process 4x Frame Rate Up Conversion. Motion Vector Refinement for 4x in Fig. 3 is the major processing procedure to assign proper motion vectors for two additional interpolated frames. This module also belongs to the proposed true motion engine. Frame Skipping and Block-based Interpolating for 4x MEMC processing are similar to those in the previous proposed 2x MCFI scheme. Based on this proposed scheme, one interpolated frame is generated by 2x MCFI processing flow and two interpolated frames generated by 4x MCFI or MEMC processing flow.

In the proposed 4x MCFI scheme, true motion vector assignment from 2x motion candidates will be used for an N×N block (by default N=8 in the proposed architecture). Fig. 4 shows that the proposed block assignment method examines motions from the surrounding motions of the current 2x interpolated frame. True motions, $\overrightarrow{MV_i}$ when i equals 0 to 8, are checked with the SAD function from one original frame (frame t or frame t+1) and one 2x interpolated frame (frame t+1/2). This 4x motion assignment is formulated by

$$\begin{aligned}\overrightarrow{CMV\_4X_0} &= \arg\min_{\overrightarrow{v}\in S'} \sum_{x\in B} \left|f(x-\tfrac{1}{2}\overrightarrow{v},t) - f(x+\tfrac{1}{2}\overrightarrow{v},t+\tfrac{1}{2})\right| \\ \overrightarrow{CMV\_4X_1} &= \arg\min_{\overrightarrow{v}\in S'} \sum_{x\in B} \left|f(x-\tfrac{1}{2}\overrightarrow{v},t+\tfrac{1}{2}) - f(x+\tfrac{1}{2}\overrightarrow{v},t+1)\right|\end{aligned} \tag{1}$$

where B denotes a matching N×N block of the current interpolated position; S' is a set of motion candidates, including $\overrightarrow{MV_i}$ when i equals 0 to 8; $\overrightarrow{CMV\_4X_i}$ is the assigned motion vector for 4x im-

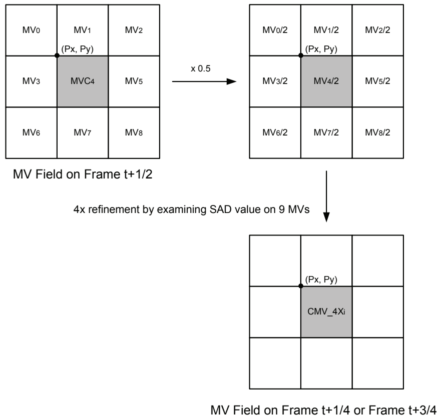

Fig. 4. Proposed MEMC method with motion refinement to achieve 4x Frame Rate Up Conversion.

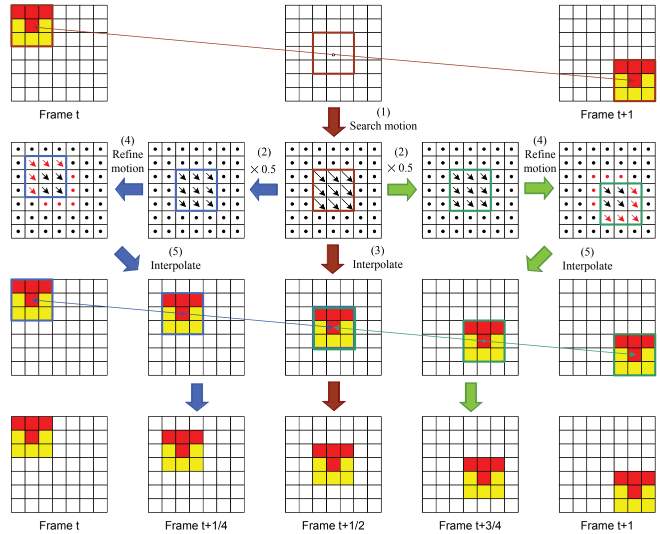

Fig. 5. Proposed MEMC method with motion refinement to achieve 4x frame rate up conversion.

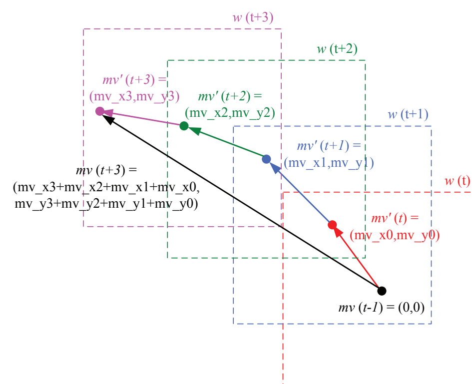

Fig. 6. Relative true motion vector search.

ages examined for the best matching when $i = 0$ for the first 4x interpolated frame and $i = 1$ for the second 4x interpolated frame. Two adjacent frames are denoted by $f(x,t)$ and $f(x,t+1)$, where x and t are spatial and time domain indices. The current 2x interpolated frame is denoted by $f(x,t+\frac{1}{2})$.

Fig. 5 demonstrates an example of how 4x true motion refinement can reduce artifacts from the broken object. The first step is to search true motions (1) for 2x frame rate images by MEMC method. Secondly, the Motion Vector Field (MVF) for 4x frame rate images (frame t+1/4 and frame t+3/4) take half of motion vectors from 2x frame rate images (2). The third step is to interpolate the 2x frame rate images with 2x true MVF (3) based on the original images before generating 4x frame rate images. The fourth step is to refine 4x true MVF with Eqn.(1) and assign a motion vector for each block (4). The final step is to interpolate 4x frame rate images with 4x assigned true motion field (5) based on one original image and one 2x frame rate interpolated image. MEMC with the proposed 4x refinement can approach a more accurate 4x MVF and generate more precise 4x interpolated images because the proposed refinement method takes more neighboring motion vector candidates into account and thereby improving the visual quality when compared with the pure motion trajectory method.

We also use a new ME method, Relative Motion Estimation (RME), in the proposed 4x FRUC algorithm. For large motion, it is often the case that the true motion vector is outside the search window w(t). There are several methods that can solve this problem. The first one is to increase the search range, but the computational complexity also become dramatically higher. Additionally, a larger searching window reduces the accuracy of true motion search. The second method is to repeat or average the block for the entire interpolated frame when the true motion search engine cannot find a reliable motion vector. It avoids broken images or objects when the selected motion vector is incorrect, but the visual quality will still be blurred. The third method or our proposed searching method, Relative Motion Estimation (RME), is shown in Fig. 6. We assume that any object should have a smaller acceleration than its velocity, and RME is a good method to track the motion if the acceleration is smaller than the RME search range, especially for a rapidly panning scene.

4. EXPERIMENTAL RESULTS

Several test sequences are processed with the proposed 4x MCFI method based on our implementation. Visual quality of these test sequences will be shown with two successive original frames, one 2x interpolated frame, and two 4x interpolated frames. We will zoom in on a specific area of each visual quality result so as to clearly observe the change over time. We also compare the proposed RME 4x methods with the original processing method when the motion vectors are larger than the search range from (0,0). By comparing with the results of normal searching strategy without skipping or skipping with averaging the images, the proposed method using RME can provide better visual quality when RME method can track the acceleration change within the RME search window.

Fig. 7 shows an example of the proposed 4x MCFI processing on FLIGHT (1080p). Fig. 7(a) and (b) are two original and successive frames from the test sequence, and Fig. 7(c) and (g) zoom in on the specific area of a seabird in order to observe the shape change. From these images, both wings spread and move from 7(c) to (g). Fig. 7(e) shows the result of the 2x interpolated frame, and Fig. 7(d)(f) show the results of the 4x interpolated

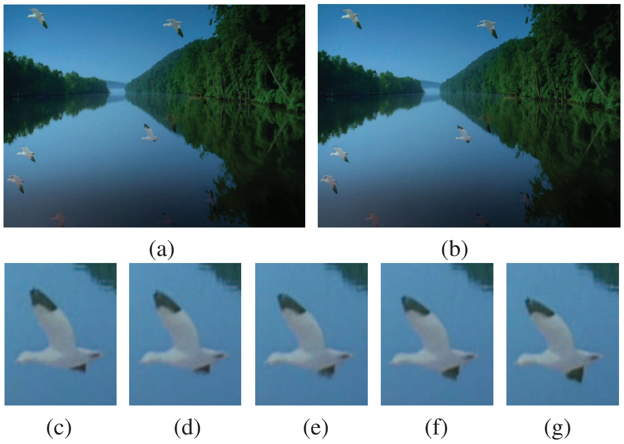

Fig. 7. Proposed 4x MCFI Processing in FLIGHT (a) original frame 924, (b) original frame 928, (c) zoom in on original frame 924, (d) zoom in on 4x interpolated frame 925, (e) zoom in on 2x interpolated frame 926, (f) zoom in on 4x interpolated frame 927, (g) zoom in on original frame 928.

frames. These demonstrate that the proposed 2x and 4x MCFI methods can successfully track the motion and generate the intermediate stages from Fig. 7(a) to (b). Fig. 8 shows another example on PRODUCERS (1440×960). (Please check the details and other test clips and visual quality comparisons on our website: http://videoprocessing.ucsd.edu/∼yenlinlee/icassp2010/)

Fig. 9 shows the artifacts and the results when processing on the frames with a normal motion search strategy. Fig. 9(a)(b)(c) present the results of this motion search window without RME. Because the motion in this case is larger than our predefined searching window [-30,+30] based on zero motion [0,0], it is impossible to find true motions in this case. Hence, Fig. 9(a)-(c) show a lot of broken blocks and artifacts with incorrect motions, and Fig. 9(d)-(f) can generate perfect interpolated images with RME. RME can find the true motion when its acceleration is smaller than the RME searching window, which allows it to interpolate unblurred images.

5. CONCLUSION

The proposed 4x architecture is established based on our previous work and follows this fast low-complexity design to develop high Frame Rate Up Conversion with slight increase of computational complexity. Relative Motion Estimation (RME) is also proposed to enhance the accuracy of motion search. Experimental results show that the proposed algorithm provides better video quality and achieves 4x MCFI processing.

6. REFERENCES

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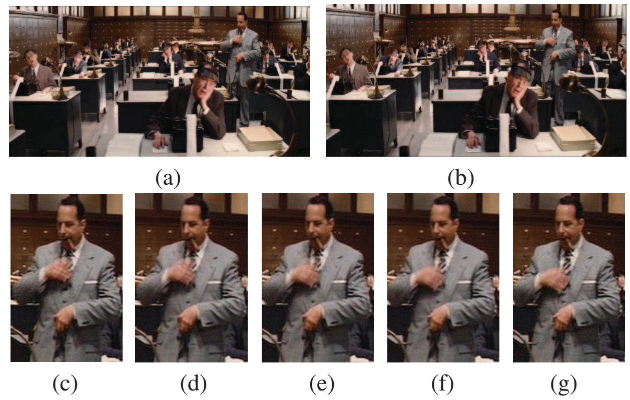

Fig. 8. Proposed 4x MCFI Processing in PRODUCERS (a) original frame 400, (b) original frame 404, (c) zoom in on original frame 400, (d) zoom in on 4x interpolated frame 401, (e) zoom in on 2x interpolated frame 402, (f) zoom in on 4x interpolated frame 403, (g) zoom in on original frame 404.

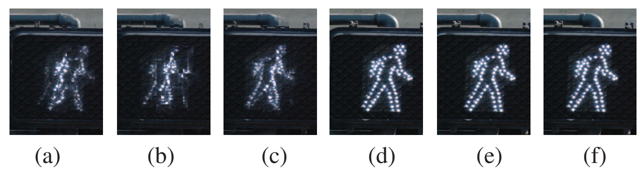

Fig. 9. Zoom in on the 4x MCFI comparisons in STATE (a) 4x interpolated frame 1581 with incorrect motions, (b) 2x interpolated frame 1582 with incorrect motions, (c) 4x interpolated frame 1583 with incorrect motions, (d) 4x interpolated frame 1581 with RME, (e) 2x interpolated frame 1582 with RME, (f) 4x interpolated frame 1583 with RME.

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