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Robust Video Frame Rate Up-Conversion (FRUC) Techniques

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***Abstract*-- Two challenging situations for video frame rate up-conversion (FRUC) are first identified; namely, when the input video has abrupt illumination change and/or a low frame rate. Then, a low-complexity robust FRUC algorithm is proposed to address these two issues. The proposed algorithm employs a translational motion vector (MV) model of the first- and the second- order and detects the continuity of these motion vectors (MVs). The superior performance of the proposed algorithm has been tested extensively and representative examples are given in this work.**

I. INTRODUCTION

This Video frame rate-up conversion (FRUC) has been a technique of great interest due to its diversified applications in consumer electronics. Most advanced FRUC algorithms adopt a motion interpolation technique to determine the motion vector (MV) field of interpolated frames. Generally speaking, today's FRUC techniques provide satisfactory results for most video sequences in preserving temporal continuity. However, we observe two challenging situations, where the performance of FRUC deteriorates severely. We will address these two situations and propose a low complexity solution in this work.

Most existing FRUC algorithms fail to provide good results when the input video sequence has some abrupt illumination change (*e.g.,* under a flashlight) and a lower frame rate (*e.g.,* 10fps or lower). Under these two conditions, the estimated MV field between frames is not accurate, which results in an adverse effect on the motion interpolation process of FRUC. To address the difficulty of a low input frame rate, we propose a new FRUC algorithm that employs the first- and the second-order translational MV model and detects the continuity of the MV field. To handle abrupt illumination change, we present a local intensity adjustment method. The superior performance of the proposed algorithm has been tested extensively and representative examples are given in this work.

II. PROBLEM STATEMENT

The abrupt illumination change interrupts the temporal continuity of the MV field. This phenomenon occurs due to significant brightness variation of the environment or the camera effect such as flash, fade in/out, etc. Without proper pre-processing, motion-interpolation-based FRUC algorithms cannot determine an accurate MV for frame interpolation. Fig. 1(a) illustrates the MV field overlaid on the compensated frame of the crew sequence using [4]. In this instance, the camera flash occurs at frame 30, which results in a disrupted

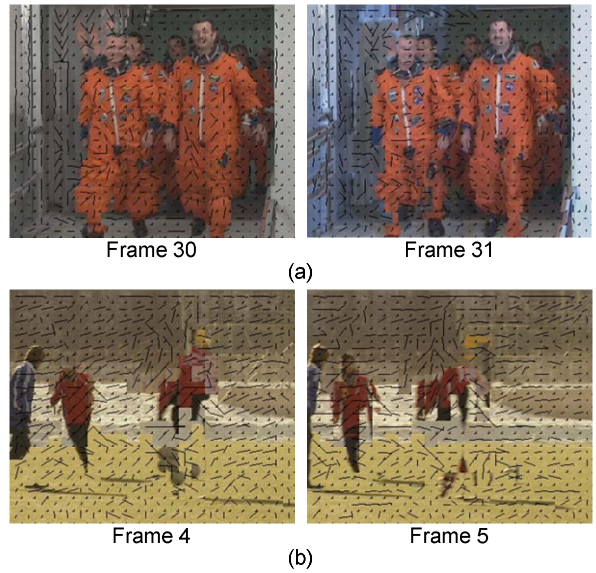

Figure 1: Examples of unreliable MV fields due to (a) abrupt illumination change (CIF Crew 15 fps) and (b) a low frame rate (CIF Soccer 7.5 fps).

MV field on both this frame and its next frame that uses it as a reference.

When the input frame rate is low, the temporal distance of two adjacent frames become larger. It is more difficult to get accurate MV estimation for each macroblock (MB) due to the lost information between frames. The linear translational MV assumption, which is exploited by many FRUC algorithms to interpolate up-sampled frames, may fail as the frame rate decreases. This is especially true for video with fast moving objects and inconsistent camera motion. We observe that the effect of the low frame rate on FRUC starts to manifest when the frame rate is dropped below 10 fps for video with fast motion. An example is shown in Fig. 1(b).

III. PROPOSED SOLUTION

To detect the abrupt illumination change, the first and the second differences of the frame luminance histogram are computed. Then, an adaptive thresholding technique [2] is used to determine the signal peak location. A large luminance change is claimed when we detect simultaneous peak signals within the same frame. Afterwards, we adjust the intensity of each MB in the detected frame locally by measure the average luminance difference of its neighboring macroblocks within a close proximity to its corresponding location in the previous frame.

For low frame rate video, the linear translational MV assumption may not hold at all macroblocks. However, there are still locations where this assumption may apply such as stationary background and slow-moving motion objects, etc.

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In order to identify them, we use the forward and the backward linear motion projection as described below:

$$f^{1^{st}}_{FP,t}(P_{t-1}(m,n)) = P_t(m + MVX_{t-1}(m,n), n + MVY_{t-1}(m,n)) \text{ , (1)}$$

$$f^{1^{st}}_{BP,t-1}(P_t(m,n)) = P_{t-1}(m - MVX_t(m,n), n - MVY_t(m,n)) \text{ , (2)}$$

where $f^{N^{th}}_{FP,t}$ and $f^{N^{th}}_{BP,t}$ are the N^{th} order forward and backward projection operations onto frame t, respectively, $P_t(m,n)$ is MB with location (m,n) in frame t and its corresponding horizontal and vertical MVs are denoted by $MVX_t(m,n)$ and $MVY_t(m,n)$, respectively. After the projection, we compare the actual MB with the projected images. If their first order difference is within the detection threshold, this MB is identified as a linear translation MB, and the projected images on the interpolated frame can be used for processing. If there exists an overlapping region of several projected images, pixel averaging can be employed.

Next, we use the second-order translational model to detect locations with non-linear motion. The second-order detection threshold is set lower than the first-order one to ensure the accuracy of interpolated areas. Unlike many existing motion-projection-based FRUC algorithms such as [1], the proposed technique does not force every MB to select the best linear motion trajectory and/or interpolate the MV of every location since these strategies usually result in low quality of interpolated frames when the linear translation assumption fails. In the final step, the proposed FRUC is to use overlapped boundary block matching [3] to fill in an area which is dominated by the second-order model. The MV candidate is obtained from the neighboring area of the corresponding macroblocks in frames t-1 and t. This criterion is introduced to ensure the spatial continuity of interpolated frames.

IV. Experimental Results

In the experiment, we consider 1-to-2 frame rate up-sampling. To get the ground truth, we down-sample test sequences of 15 fps to sequences of a low frame rate (i.e., 7.5 fps). Based on obtained results, the proposed FRUC algorithm gains an average PSNR improvement of about 2.64dB and 4.51dB over the linear motion interpolation FRUC (MI) and the frame repetition (FR) schemes, respectively. The perceptual quality of interpolated frames yielded by the proposed algorithm is significantly better due to the imposed spatial smoothness condition. Furthermore, to perform video up-sampling with abrupt illumination change with the pre-processing technique described in Sec. III, MI and PR gain an averaged PSNR gain of 6.12dB and 6.54dB, respectively.

V. Conclusion

Two challenging problems for FRUC were discussed and low-complexity and robust FRUC techniques were proposed to handle these two cases. The main reasons for the failure of previous motion-interpolated FRUC algorithms were resulted

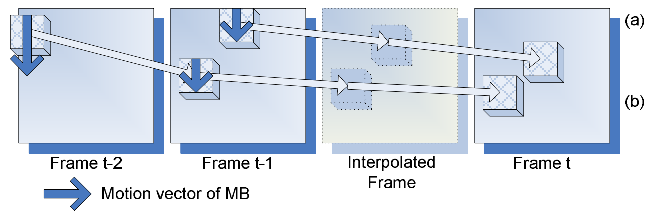

Figure 2: Example of forward motion projection (a) the first-order translation MB (b) the second-order translational MB.

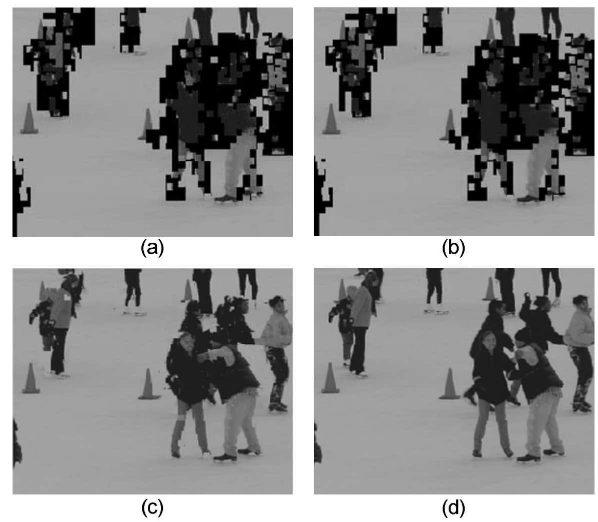

Figure 3: Illustration of proposed FRUC interpolation process (a) after the first-order translation detection (b) after the second-order translation detection (c) after OBMA and (d) the actual frame

Figure 4: Interpolated frames in the presence of flashlight: (a) before pre-processing (21.56dB), and (b) after pre-processing (28.81dB).

by unreliable MV estimation. Two low-complexity processing techniques were proposed to ensure robust MV estimation and, as a result, the quality of the up-converted video sequence has improved greatly.

References

[1] B.-T. Choi, S.-H. Lee, and S.-J. Ko, "*New Frame Rate Up-Conversion Using Bi-directional Motion Estimation*," IEEE Transactions on Consumer Electronics, Vol. 46, Issue 3, August 2000, pp. 603-609

[2] H.J. Zhang, A. Kankanhalli and S.W. Smoliar, "*Automatic Partitioning of Full-motion Video*," Multimedia Systems (1993) Vol. 1, No. 1, pp. 10-28.

[3] T. Thaipanich, P.-H. Wu and C.-C. J. Kuo, "*Low-complexity Video Error Concealment For Mobile Applications Using OBMA*," IEEE Transactions on Consumer Electronics, Vol. 54, Issue 2, May 2008, pp. 753-761.

[4] K. Simonyan, S. Grishin and D. Vatolin , "VirtualDub MSU Motion Estimation Filter – version 1.0"