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Original article

Frame interpolation with pixel-level motion vector field and mesh based hole filling

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Abstract

Most of the traditional methods are based on block motion compensation tending to involve heavy blocking artifacts in the interpolated frames. In this paper, a new frame interpolation method with pixel-level motion vector field (MVF) is proposed. Our method consists of the following four steps: (i) applying the pixel-level motion vectors (MVs) estimated by optical flow algorithm to eliminate blocking artifacts (ii) motion post-processing and super-sampling anti-aliasing to solve the problems caused by pixel-level MVs (iii) robust warping method to address collisions and holes caused by occlusions (iv) a new holes filling method using triangular mesh (HFTM) to reduce the artifacts caused by holes. Experimental results show that the proposed method can effectively alleviate the holes and blocking artifacts in interpolated frames, and outperforms existing methods both in terms of objective and subjective performances, especially for sequences with complex motions.

Keywords: Frame interpolation; Motion estimation; Motion vector field; Frame rate up-conversion; Triangular mesh

1. Introduction

Frame rate up-conversion (FRUC) increases the number of displayed images per second in a video or film sequence. It is typically used in low bit rate video transmission. The source video is temporally down-sampled to a low frame rate and transmitted at a low bit rate. At the receiver, the original frame rate is recovered with FRUC. FRUC is also used to produce smooth motion or to convert video and film between different frame rates.

A simple FRUC method is frame repetition or frame averaging, which produces blurring and motion jerkiness around moving objects. To handle those problems, frames could be interpolated using *motion-compensated frame rate up-conversion* (MC-FRUC) method. Generally, MC-FRUC is composed of two steps: *motion estimation* (ME) and *motion-compensated frame interpolation* (MCFI). It creates new frames by first estimating motion trajectories between adjacent frames and then interpolating new frames along the motion trajectories. The quality of the created frames depends on the accuracy of the motion trajectories and the performance of the MCFI algorithm.

In conventional MC-FRUC algorithms, *block matching algorithm* (BMA) [1] is typically applied to estimate motion vectors and the new frame is interpolated along the motion trajectories. However, there are at least two problems in these methods. The first problem is the holes and collisions caused by occlusions and motion estimation errors. The second is the blocking artifacts in the interpolated frame caused by block-level motion vectors.

To handle the above mentioned problems, a number of algorithms have been proposed. For instance, bidirectional ME [2] and *overlapped block ME* (OBME) [3] are proposed to

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increase the accuracy of the estimated MVs. In order to improve the accuracy of the estimated MVs, several post-processing methods were proposed, including vector median filtering [4], adaptive vector median filtering [5], reliability-based MV processing [6], multistage MV processing [7], and correlation-based MV processing [8].

To handle collisions, the depth order of objects are determined and used in [9] and [10]. To fill in holes, a median filter is employed in [9], spatial interpolation is used in [10,11], and image inpainting is utilized in [12–14], block-wise directional hole interpolation is proposed in [15,16]. These algorithms cannot handle holes well especially when the hole areas are large.

To reduce blocking artifacts, the *overlapped block motion compensation* (OBMC) [1,2] was proposed. However, if a block is on the boundary of an object, blocking artifacts could still occur. Another approach for alleviating blocking artifacts is to use pixel-level *MV selection* (MVS) [15,16]. Besides, Dikbas and Altunbasak [17] proposed the pixel-based bilateral MVF from unidirectional MVs to enhance the motion accuracy. Although the above methods alleviate somewhat blocking artifacts, the motion vector candidates for each pixel are still obtained from *block motion estimation* (BME). Since pixels in the same block may belong to different objects, the MVs obtained from BME are not robust enough.

Our scheme to frame interpolation aims to overcome the problems presented previously. Optical flow algorithm is applied to estimate bidirectional pixel-level MVs. Motion postprocessing method based on image segmentation is utilized to improve the robustness of MVFs. The occluded regions are detected by motion trajectory tracking, and the detected occluded regions in the intermediate frame are generated by referencing either the previous frame or the next frame, and the non-occluded regions are generated by referencing both frames. At last, a new holes filling method using triangular mesh is proposed to handle holes. Our experiments testified the effectiveness of the proposed approach compared with conventional block-based methods.

The rest of the paper is organized as follows. The proposed method is presented in Section 2. Experimental results are discussed in Section 3. Finally, this paper is concluded in Section 4.

2. Proposed method

The proposed method uses two adjacent frames Ft and $Ft+1$ to interpolate frame $Ft+1/2$. Fig. 1 shows the overall block diagram of the proposed method. Bidirectional pixel-level MVs are estimated using optical flow algorithm in [18]. Then we upsample the reference frames by a factor of 2 both in horizontal and vertical directions and double the float MVs. Motion postprocessing based on image segmentation is proposed to improve motion spatial consistency. The intermediate frame is interpolated based on the post-processed MVFs. At last, remaining holes in the intermediate frame is handled and the intermediate frame is down-sampled to original size.

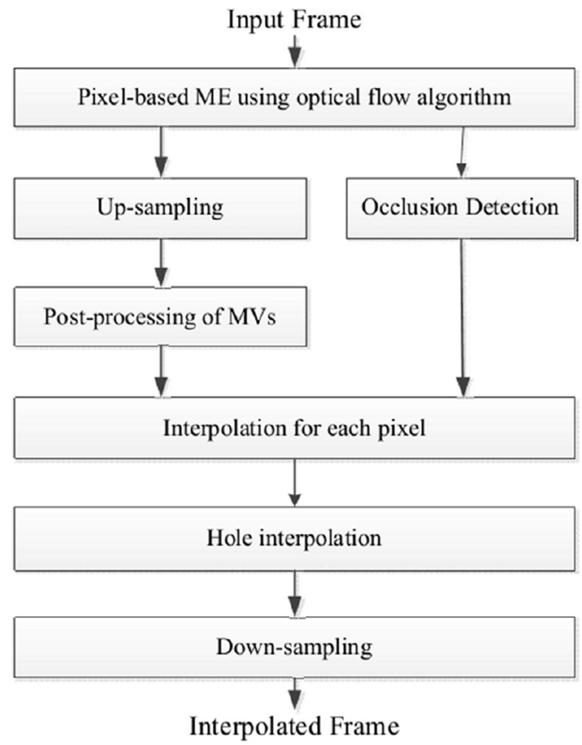

Fig. 1. The overall block diagram of the proposed system.

2.1. Bidirectional motion estimation

We use the optical flow algorithm proposed in [18] to estimate both forward and backward motion fields V_t^f and V_{t+1}^b between every two adjacent frames F_t and F_{t+1}. In the forward motion fields V_t^f, each motion vector is associated with a pixel in the previous frame and points to the next frame; whereas in the backward motion fields V_{t+1}^b, each motion vector is associated with a pixel in the next frame and points to the previous frame.

2.2. Up-sampling

The motion vector value obtained from optical flow is a float number. If it is round to integer, there will be jagged edges in the interpolated frame. Fig. 2(a) is an example of intermediate frame generated by integer MVs. To alleviate this problem, we up-sample the reference frames by a factor of 2 both in horizontal and vertical directions and double the float MVs before rounding. So the interpolated frame is also enlarged 2 times in both directions, we down-sample it to original size before outputting.

Fig. 2(b) shows the interpolated frame with the proposed method, from which we can see the artifact of jagged edges is mitigated.

2.3. Motion post-processing

On the other hand, since the MV of each pixel is estimated independently by optical flow. The MVs tend to be non-uniform even within the same object. In order to maintain