A Hybrid Technique for De-interlacing Based on Motion Compensation Reliability

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Abstract: Although motion compensated interpolation (MCI) improves the vertical resolution of de-interlaced frames effectively, it often introduces serious defects like feathering artifacts. In this paper, we propose an arbitration rule between MCI and intra-field interpolation for de-interlacing to avoid the motion compensation artifacts (MCAs) produced by erroneous MCI. In the proposed de-interlacing method, we check the MCI results by using the proposed MCA detection method and decide whether the MCI results are reliable or not. And then, we use the reliability of MCI results to combine two de-interlacing methods. The proposed arbitration method is more elaborate than conventional methods since we directly detect the artifacts in MCI results and the reliability of MCI results is used as one of the important factors of the proposed arbitration weights. Experimental results show that the proposed method achieves better image quality than the conventional methods in terms of both subjective and objective measures.

1. Introduction

Interlaced video is a technology that was developed in the early days of television (TV) in order to transmit image data within an available bandwidth. On the contrary, almost all recent flat panel displays such as liquid crystal display (LCD) and plasma display panel (PDP) use progressive video formats. For these high-end progressive display devices, a de-interlacing algorithm that provides compatibility between different video formats is absolutely needed. Moreover, as advanced media like HDTV are developed, the requirement for high quality de-interlacing algorithms that ensure the quality of converted images without uncomfortable visual artifacts is also growing significantly.

Over the last three decades, a number of de-interlacing techniques have been proposed [1]-[10]. Among them, the most advanced de-interlacing algorithms are based on motion compensated interpolation (MCI) [6]-[10]. MCI refers to the process of finding motion information from a video sequence, and then using the information to perform interpolation along the estimated motion trajectory. MCI is known to be one of the best solutions to improve the resolution of a frame. However, the fundamental problem of MCI is that if an error occurs, it is clearly visible in the sequence since human eyes are very sensitive to temporal irregularities. The spurious errors can lead to an underestimation of MCI methods in spite of their fine qualities. Since the quality of converted frames is highly influenced by the estimated motion vectors (MVs), finding true motion is vital for MCI based de-interlacing (MCD) techniques. However, in practice, the estimated MVs are not always accurate and artifacts caused by erroneous MVs usually occur in MCI results. Therefore, almost all sophisticated MCD algorithms combine MCI with an intra-field method to avoid motion compensation artifacts (MCAs). Intra-field and MCI methods are highly complementary to each other. However, it should be noted that both methods also have their inherent shortcomings. Thus, the combination rule should be designed carefully to overcome both the low-resolution problem of intra-field methods and fatal visible artifacts induced by erroneous MCI simultaneously. This paper proposes a sophisticated combination rule to combine intra-field and MCI methods adequately using the motion compensation reliability (MCR).

The organization of this paper is as follows. In Sec. 2, the proposed MCD algorithm is described in detail. First, the MCA detection method used to determine MCR is described. Subsequently, we propose the adaptive arbitration method based on motion vector reliability (MVR) assisted by MCR. In Sec. 3, experimental results of various sequences are presented and comparisons with other algorithms are made. Finally, conclusions are presented in Sec. 4.

2. Proposed De-interlacing Method Based on Motion Compensated Interpolation

Weighting coefficient that combines intra-field interpolation and MCI is one of the most important factors of MCD algorithms. The coefficients should be designed to remove MCAs without degrading image resolution. In this paper, the combination rule is based not only on MVR but also on the reliability of MCI results. Although MVR is very useful in motion related applications, it cannot always guarantee desirable MCI results. Thus, the proposed algorithm introduces the reliability of MCI results to supplement MVR. We call the reliability of MCI results "Motion Compensation Reliability (MCR)" and it is measured by detecting MCAs in MCI results. MVR is measured by using the MVs of neighboring blocks and the displaced pixel differences along the estimated motion trajectory, and then it is readjusted by MCR. Considering MCR, the proposed de-interlacing method can achieve better performance than conventional MCD algorithms.

Below, we let f and F be interlaced and de-interlaced image sequences, respectively. $F(i,j,n)$ is produced by:

$$F(i,j,n) = \begin{cases} f(i,j,n), & \text{if } \; i\%2 = n\%2 \\ f_{\mathrm{r}}(i,j,n), & \text{otherwise} \end{cases}, \tag{1}$$

where (i,j) and n are spatial indices and a temporal index, respectively. $\%$ denotes the modulo operation and f_{r} represents a reconstructed field created by the de-interlacing technique.

f_r is reconstructed by using the following equation:

$$f_r(i,j,n) = \frac{a_s \cdot f_s(i,j,n) + a_t \cdot f_t(i,j,n)}{a_s + a_t}, \quad (2)$$

where f_s and f_t represent the reconstructed fields produced by intra-field interpolation and MCI methods, respectively. f_s is calculated by:

$$f_s(i,j,n) = \frac{f(i-1, j+ed, n) + f(i+1, j-ed, n)}{2}, \quad (3)$$

where ed represents the direction of the highest spatial correlation, and it is determined by vector matching process. f_t is obtained as:

$$f_t(i,j,n) = \frac{f_{fwd}(i,j,n) + f_{back}(i,j,n)}{2}, \quad (4)$$

where $f_{fwd}(i,j,n)$ and $f_{back}(i,j,n)$ are defined as:

$$\begin{aligned} f_{fwd}(i,j,n) &= f\Big(i + \frac{mv_r}{2}, j + \frac{mv_c}{2}, n-1\Big), \\ f_{back}(i,j,n) &= f\Big(i - \frac{mv_r}{2}, j - \frac{mv_c}{2}, n+1\Big), \end{aligned} \quad (5)$$

where $\vec{mv} = [mv_r, mv_c]^T$ represents MV estimated between the $(n-1)$-th and the $(n+1)$-th fields with the same parity.

a_s and a_t in (2) represent weighting coefficients that we use to control the contribution of the two methods. If MCAs are observed in the MCI results, a_s should be larger than a_t to adopt the results of the intra-field method f_s. However, if the MCI method yields valid results, a_t must be larger than a_s to offer higher spatial resolution. The proposed weighting coefficients are composed of three factors, expressed as:

$$\begin{aligned} a_t &= a_{mvc} \cdot (1 - a_{pd}) \cdot (1 - a_{edc}), \\ a_s &= (1 - a_{mvc}) \cdot a_{pd} \cdot a_{edc}, \end{aligned} \quad (6)$$

where a_{mvc} and a_{pd} represent the reliability terms of the estimated MV, and a_{edc} represents the reliability term of the EDI method. The values of the three factors vary within the range of $[0, 1]$. a_{mvc} is set according to the consistency of MVs on a block-by-block basis, and a_{pd} is related to the displaced pixel differences along the motion trajectory. Both the motion vector consistency and the displaced pixel differences are readjusted by MCR to supplement MVR. As the key element of the proposed arbitration method, the MCR is measured by the proposed MCA detection algorithm. a_{edc} takes into account the edge direction consistency of the EDI results and enhances the visual quality of the edges.

2.1 Proposed MCA Detection

In the proposed MCA detection algorithm, we analyze five pixels in the vertical direction $\big(f_t(i-2,j,n)$, $f(i-1,j,n)$, $f_t(i,j,n)$, $f(i+1,j,n)$, and $f_t(i+2,j,n)\big)$ to decide whether MCAs occur or not. In general, since regions suffering from MCAs contain consecutive rising and falling characteristics of pixel values in the vertical direction, this pattern provides a guideline for detecting the artifacts. In order to measure the degree of MCAs effectively, regardless of the contrasts of the pattern, all the intensities of the five pixels are adjusted in the range between zero and R. Let $f'(k)$ denote the adjusted value of $f_t(i+k,j,n)$ or $f(i+k,j,n)$. By using the adjusted values $f'(k)$, four vertical differences, vd_1, vd_2, vd_3, and vd_4, are obtained as:

$$\begin{aligned} vd_1 &= \big|f'(-2) - f'(-1)\big|, \\ vd_2 &= \big|f'(-1) - f'(0)\big|, \\ vd_3 &= \big|f'(0) - f'(1)\big|, \\ vd_4 &= \big|f'(1) - f'(2)\big|. \end{aligned} \quad (7)$$

We check the upper four pixels and the lower four pixels to detect the rising and falling pattern, and then the degree of MCAs is calculated by using the vertical differences in (7). The degrees of MCAs obtained from the upper four pixels and from the lower four pixels are denoted by $mca_u(i,j)$ and $mca_l(i,j)$, respectively. $mca_u(i,j)$ is expressed as:

$$mca_u(i,j) = \begin{cases} \min\{vd_1, vd_2, vd_3\}, & \text{if } S(-1) = 1 \text{ and } S(0) = 1 \\ 0, & \text{otherwise} \end{cases}, \quad (8)$$

and $S(l)$ is defined as:

$$S(l) = \begin{cases} 0, & \text{if } f'(l-1) \le f'(l) \le f'(l+1) \text{ or } f'(l-1) \ge f'(l) \ge f'(l+1) \\ 1, & \text{otherwise} \end{cases}. \quad (9)$$

If the rising and falling pattern is detected, $S(l)$ returns 1, and otherwise it returns 0. In the same manner as mca_u, mca_l is determined as:

$$mca_l(i,j) = \begin{cases} \min\{vd_2, vd_3, vd_4\}, & \text{if } S(1) = 1 \text{ and } S(0) = 1 \\ 0, & \text{otherwise} \end{cases}. \quad (10)$$

Finally, the maximum value between $mca_u(i,j)$ and $mca_l(i,j)$ is chosen to be the final MCA measurement $mca(i,j)$ as shown by:

$$mca(i,j) = \max\big\{mca_u(i,j), mca_l(i,j)\big\}. \quad (11)$$

If the value of $mca(i,j)$ is large, it is decided that the MCR of the current pixel is low. Otherwise, it is decided that the MCR is high. If the MCR is low, we have to readjust the MVR to combine the MCI with the EDI more accurately.

2.2 MVR Assisted by MCR

The MVR is measured using two approaches in this paper: a block-by-block approach based on MV analysis, and a pixel-by-pixel approach based on the displaced pixel differences. The former approach uses the MVs of neighboring blocks. When a block has a different MV from those of its neighboring blocks, it is likely to include multiple objects moving in different directions. Therefore, it is better to give more weight to the results of intra-field interpolation when the MV is inconsistent with its neighboring MVs. To measure the motion vector consistency of the current block, blocks with similar MVs to the current block are counted over the $M_{\text{bw}} \times N_{\text{bw}}$ neighboring blocks, and this is denoted as cnt_{sb}. By using cnt_{sb}, the first factor a_{mvc} in (6) is determined as:

$$a_{\text{mvc}} = g(cnt_{\text{mca}}) \cdot \frac{cnt_{\text{sb}}}{cnt_{\text{tb}}}, \tag{12}$$

where cnt_{tb} represents the total number of neighboring blocks and $g(cnt_{\text{mca}})$ represents the term of MCR. The function $g(\cdot)$ is a monotonically decreasing function, and cnt_{mca} refers to the number of pixels whose $mca(i,j)$ values are bigger than $\frac{R}{2}$ in the 4 by 4 block area. cnt_{mca} shows how many pixels suffer from severe MCAs in the region. $g(cnt_{\text{mca}})$ is used to adjust motion vector consistency since consistent motion vector fields cannot always guarantee fine MCI results. In (12), if the value of cnt_{mca} is large, a_{mvc} has a relatively small value even though cnt_{sb} is large. Thus, the final result is similar to that of an intra-field method used to correct artifacts. If there is no MCA in the region, a_{mvc} is only dependent on cnt_{sb}.

The latter approach uses the displaced pixel difference along the estimated motion trajectory. The pixel difference is calculated as:

$$pd = \left| f_{\text{fwd}}(i,j,n) - f_{\text{back}}(i,j,n) \right|. \tag{13}$$

$mca(i,j)$ is added to pd to consider MCR additionally. That is, the pixel difference assisted by MCR $pd_{\text{mca}}(i,j)$ is set as:

$$pd_{\text{mca}}(i,j) = pd + mca(i,j). \tag{14}$$

From $pd_{\text{mca}}(i,j)$, the second factor a_{pd} in (6) is determined as:

$$a_{\text{pd}} = \min\left\{ \frac{pd_{\text{mca}}(i,j)}{C}, 1 \right\}, \tag{15}$$

where C represents a positive constant. If the value of $mca(i,j)$ is large, $pd_{\text{mca}}(i,j)$ and a_{pd} also become larger. Thus, the proposed combination rule gives more weight to the result of intra-field interpolation. If there is no MCA in the region, the value of $mca(i,j)$ is small and a_{pd} is only dependent on the displaced pixel differences.

2.3 Edge Direction Consistency of the EDI method

The EDI method is independent of motion vector errors and guarantees the smoothness of images in regions with inaccurate motion information. The other advantage of the EDI method is that it improves the visual quality of edges when the direction of edges is estimated correctly. In this paper, it is supposed that the estimated edge direction is correct when a pixel shows a similar edge direction to its neighboring pixels. To obtain edge direction consistency, pixels with similar edge directions to the current pixel are counted over the $M_{\text{pw}} \times N_{\text{pw}}$ neighboring pixels, and this is denoted as cnt_{sp}. Then, we obtain the third factor a_{edc} in (6), which is expressed as:

$$a_{\text{edc}} = \max\left\{ \frac{cnt_{\text{sp}}}{cnt_{\text{tp}}}, 0.5 \right\}, \tag{16}$$

where cnt_{tp} represents the total number of neighboring pixels. a_{edc} improves the quality of edges when more than half of the neighboring pixels show similar edge directions to that of the current pixel.

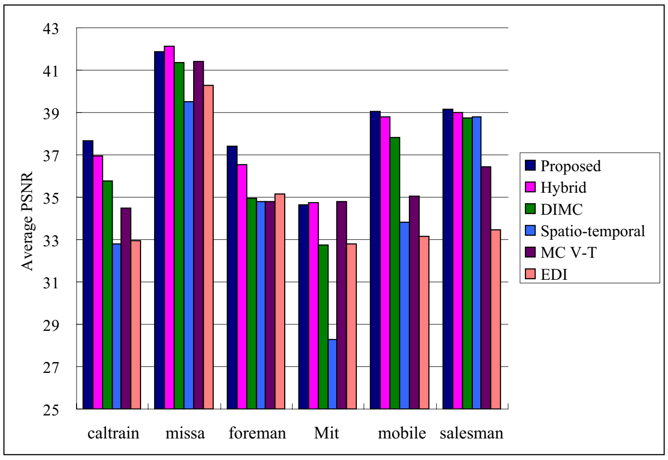

Figure 1. Average PSNRs of de-interlacing results for each sequence

3. Experimental Results

The performance of the proposed algorithm was tested with various well-known video sequences. We used several progressive format video sequences and interlaced format video sequences for experiments. For progressive sequences, we converted these sequences into interlaced format by removing every other line and evaluated the simulation result with both subjective quality and objective quantitative measure. The peak signal-to-noise ratio (PSNR) was used to measure the performance of the proposed algorithm quantitatively.

Fig. 1 illustrates average PSNRs obtained by various de-interlacing techniques. As shown in Fig. 1, the proposed method generally provides better PSNRs than conventional methods. Since *missa* sequence is a monotonous and static sequence, all the tested methods including the proposed method produce satisfactory PSNRs around 41dB. *Mit* sequence shows zoom-out motion. Since BMA is inefficient to handle non-translational motion such as zoom-in and zoom-out, the estimated MVs are not reliable in *Mit* sequence. Therefore, the results of the intra-field method dominate the de-interlaced images, so the PSNRs are directly influenced by the intra-field method. We observe that PSNRs are generally high when MCI results are combined with the results of the MC V-T filter instead of with the EDI results. However, the MC V-T filter often causes some staircase artifacts that are not observed when the EDI results are adopted. Thus, the proposed method with the EDI are comparable or better than the Hybrid method with the MC V-T filter when we incorporate both subjective and objective quality evaluations.

In Fig. 2, we present the magnified results of different de-interlacing methods for *salesman* and *calendar train* sequences. The result of a spatio-temporal method [4] shown in Fig. 2(b) reveals unpleasant artifacts. Although the method is very simple, the de-interlaced results of the method often suffer from low vertical resolution. Fig. 2(c) represents the result of the Hybrid method [6]. The Hybrid method improves the quality of reconstructed frames in most parts of the picture, but there are still many feathering defects in some regions. In

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

Figure 2. de-interlacing results of *salesman* and *calendar train* sequences (a) original image (b) spatio-temporal method (c) Hybrid method (d) proposed method

Fig. 2(c), the Hybrid method reveals MCAs at the hand of the man in the upper figure and at the ring and ball of the rotating object in the lower figure. On the contrary, the proposed method reduces visible artifacts that are observed in the result of the Hybrid method. The result of the proposed method, shown in Fig. 2(d), demonstrates that the subjective quality of reconstructed images is substantially improved by the proposed method over the conventional methods.

4. Conclusions

In this paper, we have proposed an adaptive arbitration method that combines intra-field interpolation and MCI methods by using MVR assisted by MCR. It was shown that the proposed de-interlacing method can remove or greatly reduce MCAs by considering not only MVR but also the MCR. The MCR contains information about MCAs and readjusts the MVR according to this information. Therefore, the proposed arbitration rule is more elaborate than conventional methods and it provides high quality video sequences while reducing severe MCAs. Simulation results with various test sequences indicate that the proposed algorithm outperforms conventional algorithms in terms of both visual and numerical criteria.

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