A SPATIAL-TEMPORAL DE-INTERLACING ALGORITHM

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ABSTRACT

In this paper, we proposed a spatial-temporal de-interlacing algorithm for conversion of interlaced video to progressive video. Our proposed algorithm estimates the motion trajectory of three consecutive fields interpolates the missing field along the motion trajectory. In the motion estimator, the unidirectional motion estimation and the bi-directional motion estimation processes are combined by multiple objective minimization technique. The unidirectional motion estimation estimates the motion trajectory by comparing the blocks from opposite parity fields while the bi-directional motion estimation compares blocks from the same parity fields. By combining the two motion estimations, the motion trajectory can be accurately predicted. In addition, a quality analyzer is proposed to evaluate the visual quality of the reconstructed frame, which chooses the appropriate interpolation scheme in order to provide maximum de-interlacing performance. Simulation results show the proposed algorithm has better performance over existing de-interlacing algorithm.

1. INTRODUCTION

Interlaced video has been widely adopted by current TV transmission standard, including PAL, NTSC and SECAM, because it can reduce large area flicker without an increase in transmission bandwidth. However, it introduces several visual artifacts such as edge flicker, interline flicker, and line crawling. In contrast, progressive video has been adopted by PC community and internet-broadcast, because it does not has the visual artifact in interlaced video and simplified many image-processing tasks [1]. In order to provide compatibility with existing TV transmission standard, de-interlacing is needed to convert interlaced video to progressive video.

De-interlacing algorithms can be classified into three categories: spatial de-interlacing algorithms, motion adaptive de-interlacing algorithms and motion compensated de-interlacing algorithms. Spatial de-interlacing algorithms include line doubling, vertical averaging and edge-based line averaging (ELA), which utilizes the spatial correlation between pixels to interpolate the missing field [2]. Motion adaptive de-interlacing algorithms analyze the characteristic of the motion in order to choose the appropriate interpolation scheme [3,4]. In particular, spatial interpolation is used in motion area while temporal interpolation is used in static area. Motion compensated de-interlacing algorithms estimate the motion trajectory and interpolate the missing field along the motion trajectory. In [6], a phase correction filter is proposed to allow matching of disparity fields for the motion estimation process. In [5], a motion vector smoothing scheme is proposed to improve the accuracy of estimated motion field.

In this paper, we propose a spatial-temporal de-interlacing algorithm. It combines two different motion estimation algorithms: unidirectional motion estimation and bi-directional motion estimation to estimate the motion trajectory. In addition, a quality analyzer is proposed to select the appropriate interpolation scheme.

This paper is organized as follows. The proposed algorithm is described in Section II. Section III shows the simulation results. Finally, concluding remarks are given in Section VI.

2. THE PROPOSED SPATIAL-TEMPORAL DE-INTERLACING ALGORITHM

The proposed algorithm consists of four main components: a spatial interpolator, a multiple objective motion estimator, a temporal interpolator and a quality analyzer (Fig. 1). First, the spatial interpolator exploits the spatial correlation to interpolate the missing field. Next, the multiple objective motion estimator estimates the motion trajectory by adopting multiple objective minimization technique. The temporal interpolator then interpolates the missing field along the motion trajectory according to the result of motion estimator. Finally, the analyzer evaluates the reliability of the estimated motion trajectory and the visual quality of the reconstructed frame in order to select the appropriate interpolation scheme.

2.1. Spatial Interpolator

The spatial interpolator exploits the spatial correlation to interpolate the missing. One well-known spatial interpolator

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is edge-based line averaging (ELA) [2]. The ELA interpolator utilizes the directional correlation between pixels to estimate the edge orientation and interpolates the missing field along the edge direction. It performs well in regions with a dominant edge because the edge direction can be estimated accurately. However, in high frequency region or horizontal edge region, poor visual quality may results due to inaccurate estimation of edge orientation. In order to guarantee minimum reconstruction quality, vertical averaging is used in our spatial interpolator. In vertical averaging, the missing pixel is interpolated by the nearest neighbours, which generally have the highest correlation. Although the reconstructed image by vertical averaging shows little sawtooth artifact, the interpolated pixels has a value very closed to the original pixels.

Our spatial interpolator is defined as follows:

$$f_s(x,y,t)=\begin{cases} f(x,y,t) & ,if\ \ y \bmod 2 \neq t \bmod 2 \\ (f(x,y-1,t)+f(x,y+1,t))/2 & ,else \end{cases}$$

2.2. Multiple Objective Motion Estimator

The multiple objective motion estimator employs two different motion estimation algorithms: unidirectional motion estimation and bi-directional motion estimation. The unidirectional motion estimation estimates the motion trajectory by comparing the blocks from opposite parity fields while the bi-directional motion estimation compares block from the same parity fields. Each motion estimation process has its weakness and produces inaccurate motion trajectory in different situations. By combining both algorithms, the accuracy of the estimated motion trajectory can be improved significantly.

2.3. Unidirectional motion estimation

Unidirectional motion estimation estimates the motion trajectory by defining dissimilarity measurement between two opposite fields. The current missing field is first interpolated by vertical averaging, and then the blocks in current field are matched with the blocks in the previous or next field.

Let the current field be field t, which is divided into N-by-M blocks, and let C_p and C_n be the dissimilarity measurement between two blocks B, which is defined as follows:

$$C_p(u,v)=\sum_{(x,y)\in S(B)} |f(x+u,y+v,t-1)-f_s(x,y,t)| \qquad (1)$$

$$C_n(u,v)=\sum_{(x,y)\in S(B)} |f(x-u,y-v,t+1)-f_s(x,y,t)| \qquad (2)$$

where $S(B)$ is the spatial location of block B satisfying y mod 2 = t mod 2.

The estimated motion vector $u_i{*},v_i{*}$ is

$$(u_i{*},v_i{*}) \;=\; \arg \min_{(u,v)} \; C_i(u,v)$$

where i can be p or n, which stand for previous field or next field.

The unidirectional motion estimation can estimate the motion trajectory in smooth or vertical edge region accurately, because the spatial interpolated field $f_s(x,y,t)$ gives a good approximation of original frame. However, for area with horizontal or diagonal edges or in texture region, the estimated motion vector tends to deviate from the true motion vector and produces de-interlaced frame with sawtooth artifact, which is inherited from the spatial interpolation.

2.3. Bidirectional motion estimation

Bidirectional motion estimation assumes an object move in constant velocity within a small time interval. Figure 2 shows a object in field t-1 moves to a new position in field t+1 with a relative displacement of (+2u,+2v). If we assume the motion trajectory is linear, the relative displacement of the object in field t with respect to field t-1 and field t+1 is (+u,+v) and (-u,-v) respectively. With the estimated motion trajectory between field t-1 and field t+1, the position of the object at time t can be estimated.

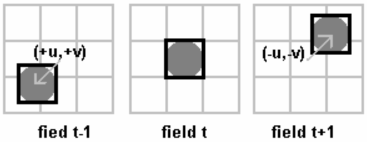

Fig. 2. The motion trajectory of a block over three consecutive fields.

Let field t be the current field, B be the current block in field t and let C_b be the dissimilarity measurement between two blocks, which is defined as follows:

$$C_b(u,v)=\sum_{(x,y)\in S(B)} |f(x-u,y-v,t+1)-f(x+u,y+v,t-1)| \qquad (3)$$

A small value of $C_b(u,v)$ suggests the two candidates blocks in the field t-1 and field t+1 are similar to each other and most likely belongs to the same object. Therefore, there is a large chance that the candidate motion trajectory passes through B. Hence, the estimated motion vector is the one which minimizes the dissimilarity measurement $C_b(u,v)$. The advantage of using bi-directional motion estimation is that it does not affected by the spatial interpolation error since the dissimilarity measurement is defined on the same parity fields only. However, the main draw back of the bi-directional motion estimation is the inability to distinct multiple motion trajectories, especially for large search range. Figure 3 shows an alternative motion trajectory that pass through the block B with a very small $C_b(u,v)$. There is a large chance that bi-directional motion estimation chooses the wrong motion trajectory and produces a very poor de-interlaced frame.

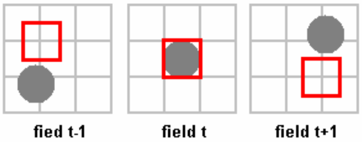

Fig. 3. An alternative motion trajectory with a small $C_b(u,v)$.

In order to provide a reliable estimate of motion trajectory, the unidirectional motion estimation is combined with bi-directional motion estimation by the multiple objective minimization technique and a new cost function $C(u,v)$ is defined as follows:

$$C(u,v) = C_p(u,v) + C_n(u,v) + \mu C_b(u,v) \quad (4)$$

and the estimated motion vector (u^*,v^*) is

$$(u^*,v^*) = \arg \min_{(u,v)} C(u,v) \quad (5)$$

where μ is a constant that control the relatively importance of two motion estimation process.

It is worthy to point out that a combination of two motion estimation processes give more accurate motion trajectory because the weakness can be compensated by the other one. In area with horizontal or diagonal edges or in texture region, the unidirectional motion estimation gives an inaccurate motion vector. However, we find that the estimated motion vector is very closed to truth motion vector and the motion vectors give a very small $C_p(u,v)$ and $C_n(u,v)$. Since the bi-directional motion estimation is more robust in areas with edges and texture, $C_b(u,v)$ will be large if the motion vector is inaccurate. As a result, a linear combination of $C_p(u,v)$, $C_n(u,v)$ and $C_b(u,v)$ give a large value for inaccurate motion vector and a small value for the truth motion vector. For the multiple trajectories problem in the bi-directional motion estimation shown in fig. 2, it can be easily solved by including the $C_p(u,v)$ and $C_n(u,v)$ terms in the cost function. For the motion trajectories show in fig.2, the value of $C_p(u,v)$ and $C_n(u,v)$ will be very large because the candidate block pointed by the motion vector shows little correlation with the field t. Therefore, the cost function $C(u,v)$ will give a large value for the incorrect motion vector and a small value for the truth motion vector.

2.4. TEMPORAL INTERPOLATOR

Based on the result of the multiple objective motion estimator, the temporal interpolated field t is:

$$f_m(x,y,t) = \frac{f(x+u^*, y+v^*, t-1) + f(x-u^*, y-v^*, t+1)}{2} \quad (6)$$

2.5. QUALITY ANALYZER

The quality analyzer evaluates the reliability of the estimated motion trajectory and the perceptual quality of the de-interlaced frame. The reliability of the estimated motion trajectory is defined in terms of block dissimilarity. A large value of C(u,v) indicate the match is bad and the estimated motion vector is unreliable. To ensure the de-interlaced frame is visually good, the change in proportion of edge area before de-interlacing and after de-interlacing is compared with a threshold. A rapid increase in edge area indicates an incorrect estimated of missing field because original field and the interpolated field show little correlation. The mismatch will cause artificial vertical high frequency and leads to a large degradation on the visual quality (Fig. 4c).

The quality analyzer employs the laplacian filter for edge detection and the metrics for calculating the edges area adopts are shown as follows:

The vertical edge area $V_1(B,t)$ before de-interlacing is defined as:

$$V_1(B,t) = \frac{2}{NxM} \sum_{(x,y)\in S(B)} D_1(x,y,t)$$

where

$$D_1(x,y,t) = \begin{cases} 1 & ,if\ (-f(x,y-2,t) + 2f(x,y,t) - f(x,y+2,t)) > T_1 \\ 0 & ,else \end{cases}$$

The vertical edge area $V_2(B,t)$ after de-interlacing is defined as:

$$V_2(B,t) = \frac{1}{NxM} \left[\sum_{(x,y)\in S(B)} D_{2a}(x,y,t) + \sum_{(x,y)\in S(B)} D_{2b}(x,y,t) \right]$$

where

$$D_{2a}(x,y,t) = \begin{cases} 1 & ,if\ (-f(x,y-1,t) + 2f_m(x,y,t) - f(x,y+1,t)) > T_1 \\ 0 & ,else \end{cases}$$

$$D_{2b}(x,y,t) = \begin{cases} 1 & ,if\ (-f_m(x,y-1,t) + 2f(x,y,t) - f_m(x,y+1,t)) > T_1 \\ 0 & ,else \end{cases}$$

The horizontal edge area $H(B,t)$ before de-interlacing is defined as:

$$H(B,t) = \sum_{(x,y)\in S(B)} D_3(x,y,t)$$

where

$$D_3(x,y,t) = \begin{cases} 1 & ,if\ (-f(x-1,y,t) + 2f(x,y,t) - f(x+1,y,t)) > T_1 \\ 0 & ,else \end{cases}$$

Furthermore, a block B is defined as an texture block if

$$V_1(B,t) > T_2\ and\ H(B,t) > T_3$$

and the texture indicator T(B) is set to 1

The final de-interlaced frame $f_d(x,y,t)$ is defined as follows:

$$f_d(x,y,t) = \begin{cases} f_s(x,y,t) & ,if\ T(B) = 0\ and\ C_b(u^*,v^*) > T_4 \\ f_m(x,y,t) & else \end{cases}$$

The texture block is interpolated in temporal domain because the texture region contains too much high frequency. The vertical averaging in the spatial interpolator cannot interpolate the missing field correctly due to small spatial correlation.

3. RESULTS

In this section, the proposed spatial-temporal de-interlacing algorithm is compared with other existing de-interlacing algorithms. Several well-known progressive video sequences are converted to interlaced video by alternative sub-sampling. The odd fields in odd frames and the even fields in even frames are removed. The interlaced video is then de-interlaced by different de-interlacing algorithms and the de-interlaced videos are compared with the original video sequences.

Table 1 shows the PSNR of de-interlaced videos of different de-interlacing algorithms, including vertical averaging (VA), ELA, EMC in [5] and the proposed algorithm. The proposed algorithm outperforms other existing algorithm because of its accurate estimation of motion trajectory and its ability to choose the appropriate interpolation scheme.

4. CONCLUSION

In this paper, a spatial-temporal de-interlacing algorithm is proposed. It employs two different motion estimation processes to increase the accuracy in estimating the motion trajectory and a content analyzer to select the appropriate interpolation scheme. Experimental results show that the proposed algorithm is more efficient than other existing algorithms.

5. ACKNOWLEDGEMENT

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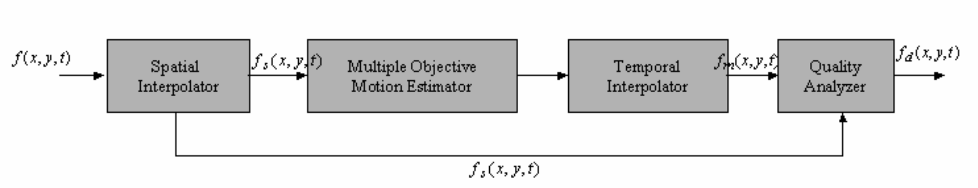

Fig. 1. The proposed de-interlacing algorithm

	VA	ELA	EMC	proposed
foreman	31.29	32.07	35.13	37.74
table	31.4	30.72	32.01	34.36
mobile	25.51	23.46	24.84	30.06
funfair	27.81	26.84	24.74	29.9
news	34.21	31.89	38.43	43.85

Table. 1. PSNR of the first 50 frames of different de-interlacing algorithm.

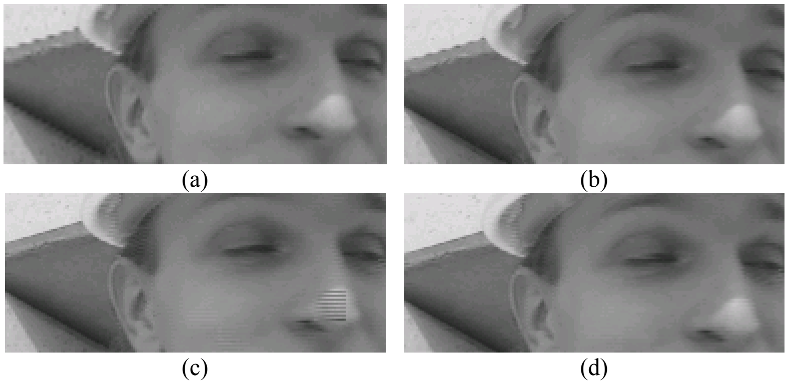

Fig. 4. Part of frame xx of the de-interlaced foreman sequence. (a) VA, (b) ELA, (c) EMC, (d) proposed.