An Efficient Motion Adaptive De-interlacing and Its VLSI Architecture Design

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Abstract

This paper presents an efficient motion adaptive de-interlacing technique that consists of two main steps, i.e. 4-field extended Gaussian filtering motion detection and adjustable window ELA de-interlacing. Four consecutive interlaced fields are used to detect motion accurately. With a Gaussian filter, the motion detection can eliminate the influence of noise. And, an adjustable window ELA de-interlacing is adopted, which can reconstruct image with high quality even in areas with horizontal edge and texture. Experimental results show that the proposed algorithm outperforms previous methods both objectively and subjectively. Based on our method, the high speed VLSI architecture has been designed and implemented. The operating frequency of the chip is 126MHz that it could process format conversion in real-time for both SDTV and HDTV applications.

1. Introduction

At present, there are two kinds of video format, i.e. interlace video and progressive video. With recent advances of HDTV and Multimedia Devices, we need much more progressive videos for our display devices such as LCD-TVs, Plasma Display Panels, etc. High quality de-interlacing becomes an important technology, which converts original interlaced video sequences into progressive frames without artifacts.

In the past few decades, many methods for de-interlacing have been proposed. These methods can be roughly categorized as non-motion compensated and motion compensated ones [1]. Although motion compensated methods produce the best reconstructed quality, they are too computationally expensive for real-time video applications. Therefore, we should introduce non-motion compensated methods, especially for real-time applications such as video compression and digital TV.

Various non-motion compensated de-interlacing methods have been proposed. These methods include temporal, spatial and motion-adaptive schemes. The simplest temporal method is directly combining two interlaced fields into one progressive frame. However, the line-crawling effect will occur in the motion area. The edge-based line average (ELA) [2], [3] is a spatial method widely used since it exhibits fairly good performance with simple calculation. However, the shortcoming of ELA-based methods is that they may deteriorate the picture quality in static area and are sensitive to the high frequency area.

To solve the aforementioned problems, motion adaptive techniques have been developed. Motion adaptive de-interlacing methods separate the picture with a motion detector first, then adopt temporal filter in the static area and spatial filter in the motion area. Motion adaptive de-interlacing methods can provide high-resolution and flick-free pictures with acceptable computational complexity. Therefore, they are widely used in real-time video applications. Motion adaptive methods are dependent on accurate motion detection, any false detection can conclude visible artifact. Vertical temporal (VT) median filtering is an implicitly adaptive method, which can adapt to different area without motion detection.

In this paper, a motion adaptive de-interlacing method based on adjustable window ELA (AW-ELA) with accurate motion detection is proposed. The remainder of this paper is organized as follows. In section 2, the proposed motion adaptive de-interlacing method is detailed. Section 3 shows the experimental results and comparison with previous methods. Section 4 aims to describe the architecture design of proposed method in ASIC hardware. Section 5 gives the conclusion and remarks.

2. Proposed motion adaptive de-interlacing

The proposed method is a motion adaptive de-interlacing based on adjustable window ELA (AW-ELA). This method applies a novel same parity 4-field motion detection, which can detect motion accurately with considerable noise resistibility. As ELA-based algorithms are potential to misleading artifacts, we design the adjustable window ELA to adapt to areas with different frequency characteristics.

2.1. 4-field extended Gaussian filtering motion detection

Various methods have been proposed to improve the motion detection (MD). In [4], a 3x1 block match in vertical direction motion detection is applied. However, it's unable to detect horizontal motion and sensitive to video noise. In [5], a five directional temporal interpolation is applied to detect horizontal motion, and a morphological operation is proposed to reduce noise. In [6], a median filter in 5-field motion detection is proposed to detect motion more accurate. In this paper, we propose a 3x3 block match in 4-field motion detection, which is illustrated in Figure 4.

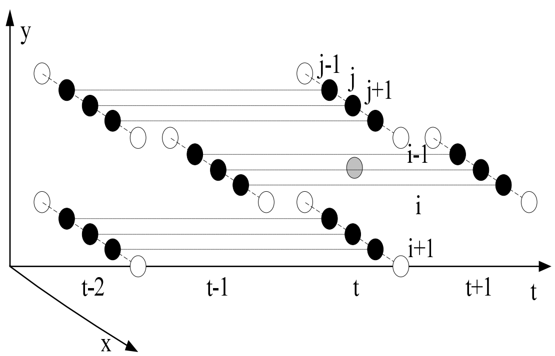


Figure 4. 4-field extended Gaussian filtering motion detection

The pixel difference is defined as follows.

$$Diff(i,j)=\begin{cases}|X(i,j,t)-X(i,j,t-2)| \text{ or} \\ |X(i,j,t+1)-X(i,j,t-1)|\end{cases} \tag{1}$$

and

$$DF=\begin{bmatrix} Diff(i-1,j-1), Diff(i-1,j), Diff(i-1,j+1) \\ Diff(i,j-1), Diff(i,j), Diff(i,j+1) \\ Diff(i+1,j-1), Diff(i+1,j), Diff(i+1,j+1)\end{bmatrix} \tag{2}$$

$$GF=\begin{bmatrix} 0.0751, 0.1238, 0.0751 \\ 0.1238, 0.2042, 0.1238 \\ 0.0751, 0.1238, 0.0751\end{bmatrix} \tag{3}$$

Where DF is defined as a Matrix composed by the pixel differences in a 3x3 window. GF is defined as a 2D-Gaussian matrix. The sigma value of this Matrix is set as 1. The motion status is described as the following equation.

$$M(i,j)=\begin{cases}1, & Diff(i,j)>th1 \vee DF \bullet GF > th2 \\ 0, & otherwise\end{cases} \tag{4}$$

Where th1 and th2 are thresholds, which are determined empirically. M(i, j)=1 represents the pixel as a motion pixel, while M(i, j)=0 represents the pixel as a static one.

The underlying assumption is that the luminance differences caused by motion are continuous, while differences caused by noise are separate. Therefore we utilize a 2d Gaussian filter to assist to detect the motions. Experiment shows that, by the adjustment of both threshold1 and threshold2, this method can detect motion accurately even with video noise. Further more, since the coefficients of Gaussian filter are constants, the hardware cost for multiplication is acceptable.

2.2. AW-ELA

Conventional ELA algorithm has several drawbacks, such as sensitivity to noise, bad performance for horizontal edge and artifacts caused by misleading direction. Several modified ELA methods have been proposed, in order to improve its performance. In [4], ELA is extended with a horizontal edge consideration. In [5], ELA is enhanced with two useful measurements to alleviate the misleading decisions. In [9], ELA is modified as an ELA-median interpolation with horizontal motion detection to make the edge sharper. In [6], ELA is extended to three dimensions and combined with texture detection to fit various areas.

Experiments show that ELA can solve horizontal edge problem with a wider window. However, this will cause the poor performance in area with high frequency. In order to achieve the high quality picture in various areas, an adjustable window ELA algorithm is designed, as showed in Figure 5.

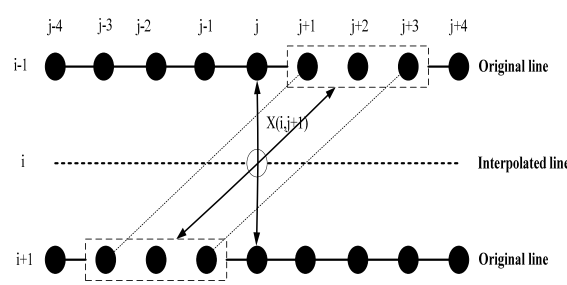


Figure 5. Adjustable window ELA de-interlacing

Equations for conventional ELA are rewritten as follows.

$$D(k) = \sum_{l=-f}^{f} \left| X(i-1, j-k+l) - X(i+1, j+k+l) \right| \quad (5)$$

Where $|k| \le \alpha$, $f \le \alpha$. Under the condition that $\alpha = 4$, $f = 1$, $D(k)$ is calculated, and the most correlative direction is also searched.

$$d\min = \arg\min D(k) \quad (6)$$

$$d^{'}\min = \arg\min D^{'}(k) \quad (7)$$

Where $D^{'}(k)$ is defined as $D(k)$ with $D(d\min)$ removed. The interpolation can be calculated as follows:

First, if $d\min = 0$,

$$X(i, j) = \big(X(i-1, j) + X(i+1, j) \big) / 2 \quad (8)$$

Second, if $d\min < 0$ and $d^{'}\min < 0$, or $d\min > 0$ and $d^{'}\min > 0$,

$$X(i, j) = \big(X(i-1, j - d\min) + X(i+1, j + d\min) \big) / 2 \quad (9)$$

Third, if both the conditions above are not met, we re-calculate interpolated pixel as the functions abovementioned with $\alpha = 1$ and $f = 0$. We can see that it's equivalent to the conventional ELA method. In order to improve the ELA performance, we use a median filter to calculate the final pixels.

$$X(i, j) = median\left\{ X_{ELA}, X_{VB}, X_{OF} \right\} \quad (10)$$

Where X_{VB} is defined as bilinear interpolation in vertical direction, X_{OF} is defined as the original pixel in the previous field.

In brief, we can describe the algorithm as follows. First, ELA with a 3x9 window is applied to search the most correlative direction. If it's dominant, pixel value is interpolated in that direction. A wide window can recognize the horizontal edge accurately. If it's suspicious, this pixel could be in texture region. Then, ELA with a 3x3 window is applied. In order to eliminate the misleading interpolation, a median filter is adopted to realize high performance in texture region.

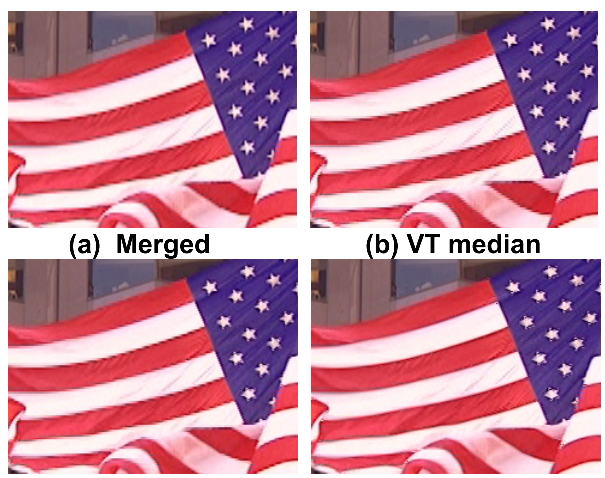
3. Experimental results analysis

Nine progressive video sequences in CIF format are used to evaluate the objective performance. Due to a lack of detail implementation code of existing de-interlacing methods in the literature, the performance of the proposed method is compared with that of well known methods. As shown in Table 1. The proposed algorithm achieves the highest PSNR performance in all sequences.

Table 1. PSNR Comparison

Sequence name	ELA	VT Median	Motion Adaptive	Proposed
Foreman	27.20	28.31	30.04	33.18
Mobile	23.87	25.48	25.32	25.51
Table Tennis	25.73	29.86	31.47	35.21
Container	25.34	33.13	35.24	37.92
Weather	25.58	35.55	37.27	40.51
Stefan	25.45	23.67	25.33	26.32
Silent	26.78	37.76	39.08	39.91
Coastguard	26.31	27.77	29.38	30.57
Mother Daughter	30.35	39.35	40.06	41.96

PSNR is not the only measure for evaluation the performance of de-interlacing quality, subjective performance is more important. As shown in Figure 6, the stripes are similar horizontal edges, while the stars are texture. The reconstructed picture with proposed algorithm has best quality than other methods. These pictures confirm proposed de-interlacing algorithm improves the subjective quality of reconstructed frames.



(a) Merged **(b) VT median**

(c) MA ELA **(d) Proposed method**

Figure 6. Subjective comparison of "Flag"

4. Architecture design and ASIC implementation

The proposed algorithm utilizes the low computational complexity of de-interlacing technique to promote higher quality video sequences on the progressive devices. The VLSI architecture has been designed to realize real-time interpolation for consumer video applications. The block diagram of this hardware architecture is showed in Figure 7.

An IC which contains the presented de-interlacing architecture has been fabricated. This chip is design for video format conversion and post-processing. This VLSI design is implemented by TSMC 0.18um mixed signal process. The key characteristic of this IC is shown in Table 2. The frequency of this chip is 126MHz, which can process format conversion for SDTV and HDTV in real-time. The chip photograph is shown in Fig. 8.

Table 2. Key characteristic of the proposed IC

Process technology	TSMC 0.18um
Die size	31.36 mm^2
Gate count	143,565
Maximum frequency	126MHz
Power consumption	1.2W
Package	FBGA280
Processing capability	1920x1080 @ 30Hz

5. Conclusion

A motion adaptive de-interlacing algorithm is presented in this paper. This algorithm combines a 4-field extended Gaussian filtering motion detection with an adjustable window ELA interpolation, which can provide accurate motion detection and superior picture quality. Experiments show that, this proposed de-interlacing method can achieve PSNR values up to 10dB better than other non-motion-compensated methods with low hardware complexity. And the VLSI architecture implementation is able to processing video de-interlacing in real-time.

6. Acknowledgements

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7. References

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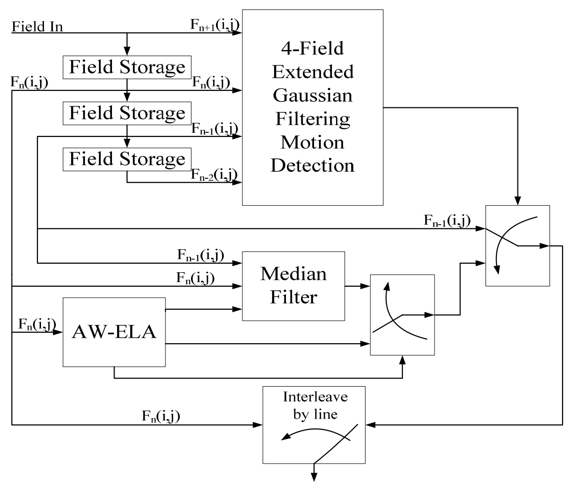

Figure 7. The block diagram of the proposed architecture design

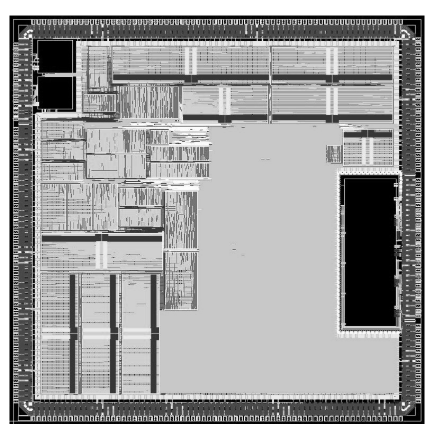

Figure 8. The chip photograph