VIDEO DEINTERLACING USING ADAPTIVE FUZZY FILTERS[*]

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This paper presents a new fuzzy motion adaptive video deinterlacer that is adaptive at pixel and frame level. It is mainly based on a decomposition of the corresponding fuzzy motion detector into two main modules: a linear spatio-temporal low-pass filter described by two separable 1D FIR filters and two fuzzy modules described by saturation functions. Moreover, the involved saturation parameters are on-line adjusted taking into account the motion quantity of each frame. Experimental results with several video benchmarks demonstrate the robustness and high-quality reconstruction of the presented algorithm.

1. Introduction

Deinterlacing is today a key technology in consumer TV that converts ordinary interlaced formats into progressive ones by reconstructing the missing lines. Some typical defects in video deinterlacing will cause uncomfortable visual artifacts and critical distortions in the output frames.

The most common deinterlacing methods are frequently grouped in two main categories: motion compensated and non-motion compensated methods. Motion compensated algorithms provide the highest reconstruction quality. They are computationally more expensive because they require the estimation of two-dimensional motion vectors and pixel shifting calculations. On the other hand, non-motion compensated methods are cheaper and can achieve a good compromise between performance and cost. A deep and general review of de-interlacing technology is made by Gerard de Haan in [1].

The rest of the paper shortly reviews the motion adaptive deinterlacing methods, presents the proposed adaptive fuzzy motion detector and shows the experimental deinterlacing results obtained using standard benchmark videos.

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2. Motion Adaptive Deinterlacing Methods

Non-motion compensated deinterlacing methods are also clustered in three main classes: temporal or inter-field, spatial or intra-field and spatio-temporal methods.

Temporal or inter-field techniques work better than spatial or intra-field techniques for static scenes, because when there is no motion, the missing lines are the same as the known previous ones. On the other hand, when there is motion in the scene, the previous lines contain information that is not coincident with the present data and ghosting, tearing or combing artifacts appear in the moving regions. For these moving areas, spatial interpolation gives better results.

Many spatio-temporal hybrid-deinterlacing techniques have been proposed to exploit the spatial and temporal correlation of video pictures and to overcome the artifacts associated with simple deinterlacers. The corresponding techniques called motion-adaptive (MA) algorithms, typically compute a motion-weighted combination of a temporal interpolation function $It(i,j,t)=(I(i,j,t-1)+I(i,j,t+1))/2$ and a spatial interpolation function $Is(i,j,t)=(I(i,j-1,t)+I(i,j+1,t))/2$:

$$Its(i,j,t) = (1-\alpha)It(i,j,t) + \alpha \, Is(i,j,t) \qquad (1)$$

where $Its(i, j, t)$ is the obtained luminance on the column i, line j and time t of the corresponding field, and $\alpha \in (0,1)$ is the involved motion value. To detect motion areas, it is necessary to estimate this weighting parameter α over each missing pixel. Most of these techniques are based on the computation of the absolute difference between the luminance of the two adjacent frames $h(.)$:

$$h(i,j,t) = \left| I(i,j,t+1) - I(i,j,t-1) \right| \qquad (2)$$

Unfortunately, due to several noise sources, the luminance difference does not become zero in all picture parts without motion. This implies that the corresponding motion detector should include some kind of additional low-pass spatio-temporal filtering in order to avoid some undesirable noise effects.

The considered low-pass fuzzy motion detector has been designed taking into account that the color carrier does not contain significant motion information and the moving objects size are frequently larger than pixels size.

3. Bilevel Adaptive Fuzzy Filter

The most important part of a reliable MA deinterlacer is the spatio-temporal motion filter. Motion detection failure can result in the use of inter-field data in moving parts of the video, where it can cause the appearance of combing artifacts. Alternatively, oversensitive motion detection can cause the motion detector to be triggered by noise, generating a spatial data interpolation in still parts of the picture. This can lead to noticeable loss of resolution in the video. Therefore, there is a need of a good balance between motion sensitivity and robustness in different video conditions.

To carry out this task, a fuzzy video motion detector was developed by D. Van de Ville [5,6] based on a set of 5 fuzzy rules (*FMD1*). The corresponding ASIC has received the 2003 European IST Prize Nominee. This paper uses an analogous philosophy but proposes a simpler and more robust adaptive fuzzy motion detector (*FMD3*) that greatly simplifies the corresponding computation and provides an outstanding picture quality in both moving and still image areas. The associated low computational cost gives the chance to easily accomplish the real time algorithm in software. We have implemented *FMD3* in a Pentium 4 PC equipped with MS DirectShow and the visual tool MS GraphEdit.

Figure 2 describes the proposed fuzzy motion detector *FMD3* with pixel and frame adaptation levels. The pixel-adaptation controller is mainly based on the serial composition of two linear 1D FIR low-pass filters and two nonlinear saturation functions. The corresponding saturation parameters (a,b,c,d) are on-line computed by the frame-adaptation controller, considering the normalized average motion β of each frame.

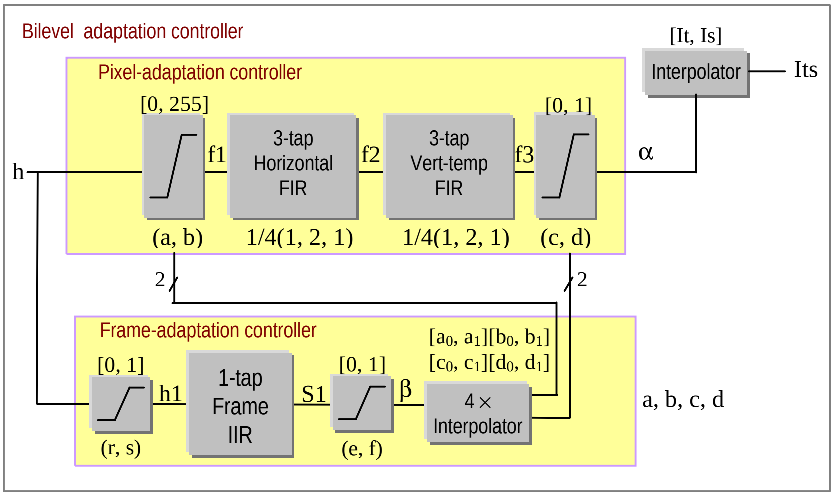

Figure 2. Basic block diagram of fuzzy motion detector *FMD3*

The basic structure of the uniform recurrence equations (URE´s) of *FMD3* algorithm, for the missing pixels in odd and even fields, is shown in Figure 3.

The saturation functions are used to specify diverse nonlinearities of the corresponding fuzzy filters [3]. This paper only considers simple piecewise-linear saturation functions $s_{x1,x2}(x)$ specified by the set of fuzzy rules:

$$\{\textbf{If } (x \text{ is } LOW) \textbf{ Then } s=0;\ \textbf{If } (x \text{ is } HIGH) \textbf{ Then } s=1\} \tag{3}$$

where the fuzzy labels *LOW* and *HIGH* belong to the corresponding trapezoidal fuzzy partition [2] defined by the coordinates (x_{min}, x_1, x_2, $\mathrm{x}_{\max}$).

General saturation or squashing functions are considered in this approach as powerful fuzzy primitives. Verbal labels such as “approximately linear with a little saturation on the left side” or “fairly crisp” have been utilized during the structural design of the corresponding saturation functions. We claim here that as we have accepted verbal labels and linguistic hedges [2] to describe membership functions, we can also accept an analogous fuzzy functional framework to directly specify basic nonlinear functions. During the design process, these fuzzy functional primitives were revealed as a very useful complementary fuzzy tool.

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RECURRENCE EQUATIONS FMD3 (I)
For t=1..K   /* Video frames */
 For i=1..N, j=1..M  /*Frame pixels*/
  If (j and t are odd) or (j and t are even) Then
      $h(i,j,t)=|I(i,j,t-1)-I(i,j,t+1)|$  /* Motion input computation*/
End For i, j
 /* FRAME PARAMETERS COMPUTATION */
 $S1(t)=S_{i,j}\ sat_{r,s}(h(i,j,t)$  /Frame motion addition or average ( ´1/MN)*/
 $b(t)=sat_{e,f}(S1(t))$ /*Normalized frame motion to compute (a,b,c,d)*/
$a(t)=(1- b(t))a0+ b(t)a1$;  $b(t)=(1- b(t))b0+ b(t)b1$;
$c(t)=(1- b(t))c0+ b(t)c1$;  $d(t)=(1- b(t))d0 + b(t)d1$
 /* MOTION FILTER COMPUTATION */
For i=1..N, j=1..M  /*Frame pixels*/
If (j and t are odd) or (j and t are even) Then
    $f1(i,j,t)=sat_{a,b}(h(i,j,t))*255$  /*Input saturation*/
    /*1D 3-tap FIR low-pass filters: H and V-T*/
    $f2(i,j,t)=1/4( f1(i-1,j,t)+2 f1(i,j,t)+ f1(i+1,j,t))$
    $f3(i,j,t)=1/4(f2(i,j-1,t-1)+2 f2(i,j,t)+f2(i,j+1,t-1))$
   $a(i,j,t)= sat_{c,d}( f3(i,j,t))$  /*Output saturation 0_1*/
   /* SPATIO-TEMPORAL  INTERPOLATION */
   $Its(i,j,t)=(1-a(i,j,t))\times (I(i,j,t-1)+I(i,j,t+1))/2+ a(i,j,t) \times (I(i,j-1,t)+I(i,j+1,t))/2$
End If
End For i, j
End For t
/* FUNCTION DEFINITION: SATURATION */
Function sat(x)     /* sat(.): R→ [0, 1] */
  $sat_{x1,x2}(x)=\{(x<=x1)\rightarrow 0; (x>=x2)$® $1; (x-x1)/(x2-x1)\}$
End Function
```

Figure 3. URE´s of fuzzy motion detector *FMD3*

Saturation functions have been compiled into conditional piecewise functions. Parameters x_1 and x_2 simultaneously specify the threshold, gain and saturating regions of the corresponding variables.

In the considered fuzzy filters, the utilization of two saturation functions at the input and output of the filter, gives more flexibility to remove undesirable noise, for different video conditions, in the corresponding motion detector.

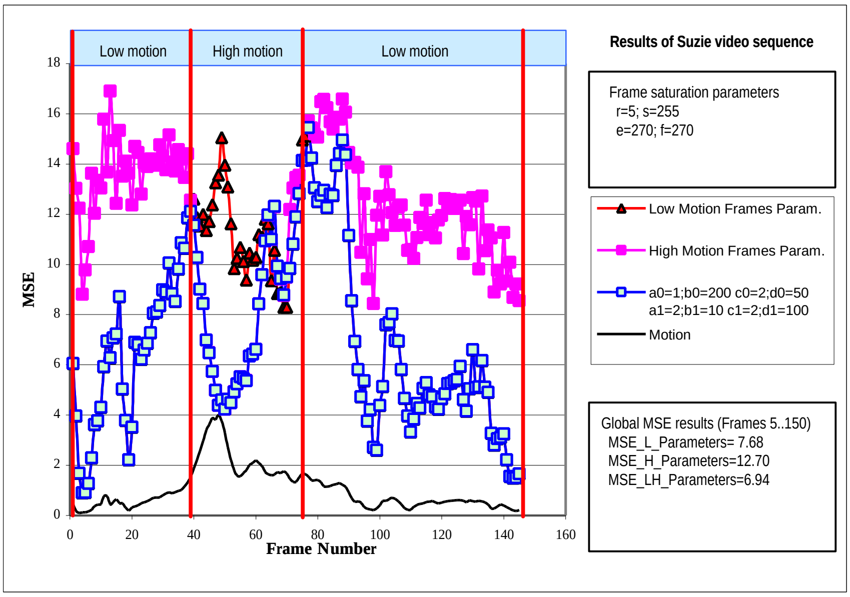

Figure 4. Comparison between non-adaptive and adaptive saturation methods

4. Experimental Results

The interlaced test sequences used were generated from standard progressive video benchmarks of size 176x144 pixels [4]. Figure 4 shows the MSE results for each frame of Suzie sequence from #5 to # 150. Three types of algorithms were analyzed: deinterlacing with fixed saturation parameters suitable for low motion frames: (a_0,b_0,c_0,d_0), deinterlacing with fixed saturation parameters suitable for high motion frames: (a_1,b_1,c_1,d_1), and deinterlacing suitable for low and high motion frames (algorithm *FMD3*), using adaptive saturation parameters: $(a,b,c,d)=(1-\beta)\times(a_0,b_0,c_0,d_0)+\beta(a_1,b_1,c_1,d_1)$.

The MSE values were obtained excluding border pixels because their contribution is not computed with the uniform filter mask defined.

The proposed method *FMD3* is much simpler and more robust than the referred algorithm *FMD1* [5,6] that gives lower video quality results i.e. for Suzie sequence: MSE_FMD1=7.61 versus MSE_FMD3=6.94. Moreover, algorithm *FMD1* is less flexible since it has only one non-adaptive saturation function and it is clearly more computational demanding.

The deinterlaced frames #8 (with low motion) and #48 (with high motion) of Suzie sequence, using the described algorithm *FMD3*, are shown in Figure 5

Figure 5. Deinterlaced frames #8 and #48 of Suzie sequence using the adaptive fuzzy filter considered

5. Conclusions

The obtained results show that the presented fuzzy motion detector algorithm *FMD3*, with bilevel adaptive structure, works very well for different kinds of interlaced video sequences and can be a reasonable trade-off for deinterlacing.

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