A RATIONAL FILTER FOR THE REMOVAL OF BLOCKING ARTIFACTS IN IMAGE SEQUENCES CODED AT LOW BITRATE

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ABSTRACT

In this paper a simple but effective operator for the reduction of blocking artifacts is presented.
The method is based on the Rational Filter approach: the operator is expressed as a ratio between a linear and a polynomial function of the input data. Such filters proved to outperform other conventional methods in other applications, such as noise smoothing [1], thanks to their capability of adapting gradually to the local image characteristics.
The filter is capable of biasing its behaviour in order to achieve good performance both in uniform areas, where linear smoothing is needed, and in textured zones, where nonlinear and directional filtering is required.
A detector of activity is embedded in the expression of the operator itself so that the biasing of the behaviour of the filter is smooth and not based on fixed thresholds.
The proposed method has been originally designed as a post–processing tool for frames of sequences coded at medium-low bitrate with the dynamic coding scheme proposed in [2], but gave good results also when applied to JPEG coded images.

1 INTRODUCTION

The post processing of images that have been degraded by coding represents an important application of spatial filtering techniques. Among the most typical artifacts that can be introduced by coding algorithms, blocking effect is an annoying side result of techniques in which blocks of pixels are treated as single entities and coded separately. In this case, correlation among spatially adjacent blocks is not taken into account in coding, which results in block boundaries being visible when the decoded image is reconstructed. For example, a smooth change of luminance across a border can result in a step in the decoded image if neighboring samples fall into different quantization intervals.

The characteristics of the human visual system contribute to a worsened perception of some of these artifacts. Our eye is naturally sensitive to edges –especially vertical and horizontal ones–, and tends to perceive them very clearly, particularly in uniform zones.

Linear and space invariant techniques prove inadequate; the local spectra and bandwidth of both the noise and the signal vary spatially, and the characteristics of the filters need to be locally adapted. Moreover, the nonlinear nature of the problem and the strong dependence on the behaviour of the human visual system (which is also nonlinear) suggests to explore the possibilities offered by nonlinear filtering techniques [3].

2 ADDRESSED PROBLEM

The algorithm presented in this paper was developed as a post–processing tool in the framework of the dynamic coding scheme presented by the Signal Processing Laboratory of the Swiss Federal Institute of Technology for the future MPEG4 standard [4]. In this scheme, frames are partitioned according to a variable depth quadtree structure, and each resulting block is coded with a technique selected within a repertoire. The partition of each frame, as well as the coding techniques, are selected so as to jointly optimize the bitrate and the resulting distortion. According to this philosophy, uniform areas tend to be divided in larger blocks, whereas detailed areas are split in smaller regions. Blocking effect represents an important issue in this framework, since adjacent blocks are not only treated independently, but are also likely to have been coded with different techniques, which further increases the occurrence of visible block boundaries.
This algorithm is specially dedicated to sequences dynamically coded at low bitrate, namely in the 24–64 Kb/s range. When the above mentioned dynamic coding algorithm is applied, the problem of the removal of blocking effect is twofold.
In uniform areas the main artifact consists in the luminance step between relatively large blocks with a slightly different grey level: in this case, due to the Mach band effect [5] the apparent brightness is no longer uniform inside each of the two blocks, and the change of luminance is perceived as a more abrupt step. In this case, good results can be achieved by simply smoothing a border by means of a linear operation affecting a 1 or 2 pixel wide strip on each side of the border. In detailed areas,

the dynamic coding algorithm tends to produce smaller blocks, and use more efficient coding techniques. In this case the removal of blocking artifacts must take a more delicate action and –where possible– exploit their very presence to perform a directional filtering which preserves the textures across the block boundaries.
In both cases, a local operator seems to be sufficient for an effective filtering action, still requiring a low level of computational complexity. The main issue is then to embed in the operator a reliable detector which biases the behaviour of the filter and adapt it to the local characteristics of the image. The flexibility of the rational filter fits well this need. In the dynamic coding scheme, information about the structure of the quadtree is sent along in the bitstream and is therefore completely known by the decoder; this knowledge will also be exploited by the proposed algorithm

3 THE PROPOSED METHOD

3.1 Rational filter

The basic concept underlying the Rational Filter, which was devised to perform edge-preserving noise smoothing, is to modulate the coefficients of a linear lowpass filter in order to limit its action in presence of image details. It has been demonstrated that this operator, despite its simplicity, is able to outperform conventional methods for many noise distributions [6]. Rational operators are formulated so that their input/output relation is the ratio of two polynomials in the input variables. Roughly speaking, the numerator has a lowpass behaviour, while the denominator is a function of the difference between couples of pixels within the filtering mask; if this difference is large, it is assumed that the mask is located across a signal transition, and the frequency response of the lowpass filter is automatically made less selective in the direction of the signal transition itself.

To achieve a strong noise cancellation while still maintaining image details sharp, multiple filter passes can be performed. In fact, near a detail the multipass operation is similar to the one of a lowpass filter having a large asymmetric mask covering only those pixels which have values similar to the one of the reference (central) pixel.

3.2 Algorithm description

The rational operator proposed in this paper is a quite simple one and operates on a 3×3 window, thus performing a mainly local action, according to the characteristics of the problem described in Sec. 2. The proposed operator is capable of biasing its behaviour towards that of a linear filter in uniform areas, while achieving a higher level of nonlinearity in uniform areas.

As an example, Fig. 1 sketches the situation when the grey level of a pixel located on the right side of a block boundary is evaluated.

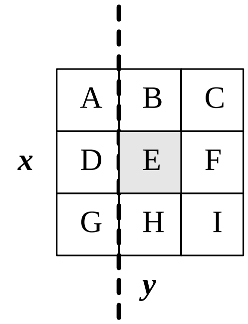


Figure 1: The 3×3 window of the rational filter

With reference to Fig. 1, let $L(x,y)$ be the luminance level of pixel in position (x,y), which will be altered by the filtering.

As a first step we define the grey level average μ_L and variance σ_L^2 of the 9 pixels in the window according to Eq. 1 and 2 respectively. Variance–based measurements proved to be a reliable and simple estimator of the degree of local activity [7] and have been used for this purpose also in the present work.

$$\mu_L = \frac{\sum_{\substack{i=-1,1 \\ j=-1,1}} L(x+i,y+j)}{9} \tag{1}$$

$$\sigma_L^2 = \frac{\sum_{\substack{i=-1,1 \\ j=-1,1}} [L(x+i,y+j) - \mu_L]^2}{9} \tag{2}$$

For the sake of simplicity, we shall now refer to the grey values of the 9 pixel in the 3×3 window with letters, according to the notation of Fig. 1.

The output of the filter E' results from the contribution of four terms:

$$\begin{aligned} E' = \quad & \frac{w[(A+I)/2]}{1+k'w(|A-I|^4)} + \\ & \frac{w[(D+F)/2]}{1+k'w(|D-F|^4)} + \\ & \frac{w[(G+C)/2]}{1+k'w(|G-C|^4)} + \\ & E\Bigg[1 - \frac{w}{1+k'w(|A-I|^4)} - \\ & \frac{w}{1+k'w(|D-F|^4)} - \frac{w}{1+k'w(|G-C|^4)}\Bigg] \end{aligned} \tag{3}$$

Where w is a constant weight (the criterium for the determination of this weight will be explained in the following), and the term k' is defined as:

$$k' = k\frac{\sigma_L^2}{\sigma_{Th}^2 + \sigma_L^2} \tag{4}$$

In Eq. (4) k is an external parameter and σ_{Th} is a value to be fixed based on the average variance of the image.

Let us now describe how the different elements of the formula contribute to the behaviour of the filter. The parameter k' plays an important role in determining the bias of the filter towards a linear or a non-linear behaviour. In particular, if $k' = 0$, the global expression of the filter becomes:

$$E' = w\left[\frac{(A+I)}{2} + \frac{(D+F)}{2} + \frac{(C+G)}{2}\right] + E(1-3w) \tag{5}$$

which corresponds to a linear filter, and suggests to choose 0.25 as an appropriate value for the weight w. Such a behaviour is appropriate when borders occur between uniform areas and linear smoothing proves efficient in order to reduce the Mach band effect, without the risk of damaging details.

If k' takes non–zero values, the behaviour of the filter becomes more and more nonlinear as k' increases. The denominators in Eq. (3) become more strongly dependent on the grey level differences evaluated in the three directions $|A-I|$, $|D-F|$, $|G-C|$. In this case the relative contributions of the four terms of Eq. (3) to the output value depend on the level of correlation in these three directions: such behaviour is highly desirable in detailed areas, where texture should be preserved and -possibly- exploited for the filtering. Let us consider a simple example in which the block boundary crosses a diagonal edge at 45 degrees: in this case it is quite likely that $|G-C|$ is considerably smaller than $|A-I|$ and $|D-F|$, therefore the output of the filter will be given by a combination of the value of pixel E and a directional correction obtained by averaging C and G.

It is therefore important to insert in the operator a mechanism that allows the value of k' to change according to the local characteristics of the image, i.e. taking very small values in uniform areas, while increasing in zones where edges or texture is present. Equation (4) describes the approach that has been chosen in order to achieve this goal. If σ_L is neglectable with respect to σ_{Th} (i.e. if the local activity of the image is low), k' tends to zero, and the behaviour of the filter is approximately the one expressed by equation (5). If on the other hand σ_L has the same order of magnitude of σ_{Th}, the filter will give the desired greater importance to the directional components.
To complete the description, we mention the fact that it is possible to run the filtering window along the borders a second time, one pixel inside each of the neighboring block; in this way the smoothing effect in uniform areas is further improved, still without visible degradation of the details.

4 SIMULATIONS RESULTS

The proposed algorithm has been designed as a post-processing tool for image sequences coded with the dynamic coding algorithm, and will be inserted also at the encoder side as a part of the coding loop. However, the method proves efficient also for the removal of blocking effect generated by other coding algorithm, and tests have been performed on JPEG coded images.

(a) (b)

Figure 2: A frame of sequence *hall monitor* coded at 48kb/s. **(a)** Before post–processing. **(b)** After the reduction of blocking artifacts.

Figure 2(a) shows a frame of the MPEG4 test sequence *"hall monitor"* coded at 48kb/s. Figure 2(b) shows the same frame after the postprocessing has been performed: the blocking effect has been significantly reduced in uniform areas, while directional filtering in zones with texture or edges has prevented details from being damaged.

An objective evaluation of results is –as it is often the case in image processing– quite difficult to obtain. In particular, since a small portion of the total number of pixels is modified by the filtering, standard quality indexes are only marginally affected by the different methods. Furthermore, such parameters are incapable of rendering the quality level perceived by the human visual system (e.g. the Mach band effect): often images with a higher PSNR are not those with the best visual quality. However, we compared our numerical results with those of the methods reviewed in [8]. As a test image, *"Lenna"* coded with JPEG at 0.3 bpp has been chosen (Fig. 3(a)).

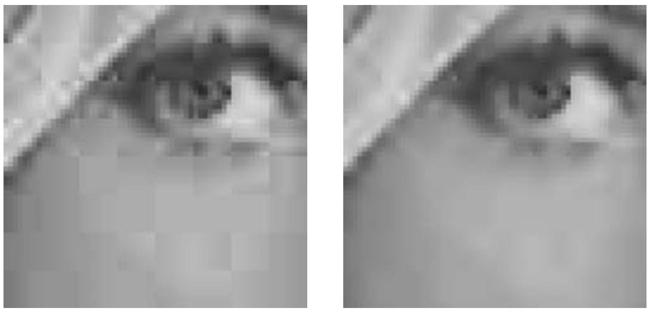
(a) (b)

Figure 3: Image *"Lenna"* coded with JPEG at 3bpp. **(a)** Before post–processing. **(b)** After the reduction of blocking artifacts.

The JPEG coded image shows a PSNR of 32.8 dB,

the method proposed in [3] achieves 33.0 dB, and the algorithm of Kuo and Hsieh [8] obtains 33.3 dB.
With the rational filter proposed in this work we achieve 33.4 dB, which can be further improved to 33.5 dB (Fig. 3(b)) by extending the filtering one pixel inside the block, as described in Sec. 3.2.
It should be pointed out that the proposed filter has a much lower computational complexity and a more compact expression than those mentioned above.

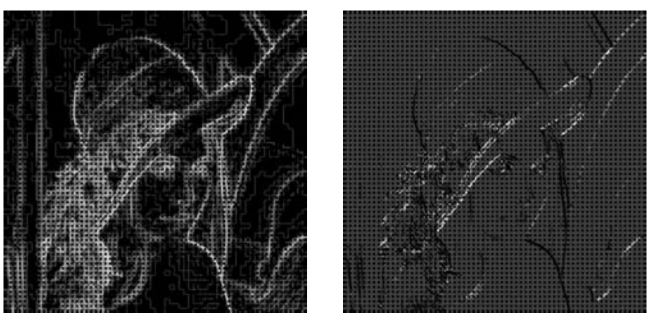
A detail of the images *"Lenna"* before and after post–processing is shown in Fig. 4(a) and 4(b) respectively. It can be seen that blocking effect has been significantly reduced, while detailed areas did not suffer any unwanted smoothing.



(a) (b)

Figure 4: A detail of image *"Lenna"* coded with JPEG at 3bpp. **(a)** Before post–processing. **(b)** After the reduction of blocking artifacts.

A more consistent proof of the good behaviour of the filter, however, is given by the two test images of Fig. 5.



(a) (b)

Figure 5: **(a)** Grey level is proportional to the local variance. **(b)** Lighter pixels represent the contribution of the diagonal term at 45 degrees, compared to the other directional label.

In Fig. 5(a) the grey level represents the amount of nonlinearity in the behaviour of the filter: it can be seen that white pixels evidentiate with good reliability areas with texture or edges. In Fig. 5(b), instead, the grey level represents the contribution of one of the diagonal terms (direction G-C in Fig. 1) when compared to the others: the filter follows rather faithfully the presence of details in that orientation.

5 CONCLUSION

In this paper an operator for the removal of blocking effect has been introduced. Despite its relatively simple structure, this operator, based on the concept of rational filtering, is capable of well adapting to the local characteristics of the images. The behaviour of the filter ranges from a quasi-linear one in uniform areas, to a strongly nonlinear one in detailed areas. The variance detector that regulates the filter behaviour is embedded in the filter itself, which allows a compact expression of the operator as well as a smooth adaptation.

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