Adaptive Directional Sharpening with Overshoot Control

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ABSTRACT

This paper presents an efficient solution for digital images sharpening, the Adaptive Directional Sharpening with Overshoot Control (ADSOC), a method based on a high-pass filter able to perform a stronger sharpening in the detailed zones of the image, preserving the homogeneous regions. The basic objective of this approach is to reduce the undesired effects. The sharpening introduced along strong edges or into uniform regions could provide unpleased ringing artifacts and noise amplification, which are the most common drawbacks of the sharpening algorithms. The ADSOC allows to the user to choose the ringing intensity and it doesn't increase the isolated noisy pixel luminance value. Moreover, the ADSOC works the orthogonally respect to the direction of the edges in the blurred image, in order to yield a more effective contrast enhancement. The experiments showed good algorithm performances in terms of booth visual quality and computational complexity.

Keywords: Adaptive, directional sharpening, ring control, high pass filters.

1. INTRODUCTION

The principal target of the sharpening [1] is highlight fine details in an image or enhance blurred images. Since not only edges or details but any discontinuity in the image could be enhanced by a trivial approach to sharpening, one of the most important objectives in the sharpening algorithm design is providing sharpening without introducing noise amplification and ringing effects. Considering the typical horizontal profile of an edge (Fig. 1), the target of the sharpening is making steeper such intensity profile.
The conceptually and computationally simplest approaches to the problem are the Unsharp Masking (UM) algorithms. Such methods are based on the idea of subtracting to the original image a blurred version of the image itself, in order to obtain the sharpened image. This idea corresponds to add a high passed version Z of the original image I to the input image itself, yielding the enhanced image Y:

$$Y(m,n)=I(m,n)+Z(m,n)\cdot\lambda$$

where λ is an "enhance factor", used in order to reduce the noise sensitive of the high-pass filter. A set of UM solutions are compared in the same condition in [2]. The results of such analysis show that the majority of the UM algorithms are very sensitive to enhancement factor thus, in order to obtain a good sharpening, this parameter must be estimated recursively by considering the statistics of neighboring pixel values, increasing the computational cost of the algorithm.

An appropriate filter definition is a basic issue for the sharpening approaches that uses sharpening masks to perform spatial filtering able to enhance the high contrast areas much more than the low contrast areas of the image. Using a filter properly defined, a good estimation of the local dynamics of the input image may be obtained performing an adaptive sharpening and avoiding noise amplification too. In [3, 4, 5] are described several methods that exploit the Human Visual System properties and accurate filter definition in order to achieve contrast enhancement. An *ad hoc* sharpening filter definition method is described in [6].

A solution for sharpening compressed images in the Discrete Cosine Transform domain has been proposed in [7]. Such technique is applied to images compressed using the JPEG standard. The sharpening is achieved by suitably scaling each element of the encoding quantization table to enhance the high-frequencies of the image. The modified version of the encoding table is then transmitted in lieu of the original, thus the sharpening is performed with no additional computation cost and without affecting compressibility.

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The wavelet domain is also suitable for sharpening algorithm development since wavelet domain processing provides local adaptation in smooth and non-smooth parts due to the theoretical link between wavelets and smoothness spaces, as discussed in [8].

Several solutions based on fuzzy logic have been also developed. In [9] a fuzzy bidirectional flow framework based on generalized fuzzy sets is proposed. The algorithm performs a fuzzy "inverse" diffusion along the gradient direction to the edges and it does a certain "forward" diffusion along the tangent direction on the contrary. A fuzzy operator is defined in [10], too. In this case, the target is sharpening the details of the input image by applying appropriate fuzzy rules to the input luminance values. Moreover, the fuzzy rules definitions allow the operator to be insensitive to noise.

Traditional edge sharpening methods mainly increase the intensity differences across an edge, but the edge width remains unchanged, thus this kind of approaches produce only limited effects for wide and very blurred edges. An algorithm that performs the sharpening across the edge and also reduces the edge width is presented in [11].

Since the contrast of edge in the image is usually achieved by raising the intensity of the brighter side of an edge and lowering the intensity of the darker side (Fig. 1), overshoots are introduced along both sides of the edges yielding the ringing effect. A solution for this problem is proposed in [12].

The algorithm proposed in this paper is based on a 5x5 high-pass filter and it's designed to restrict the main drawbacks of most of the sharpening techniques: the noise amplification is reduced due to the high-pass filter properties, whilst an over/undershoot control block allows to manage the ringing effect. Moreover, the algorithm has a low complexity cost, so it is suitable for real-time applications.

The rest of the paper is organized as follows: the Sections 2 describes the ADSOC in details; the Section 3 presents experimental results. Conclusions and final remarks are included in the last section.

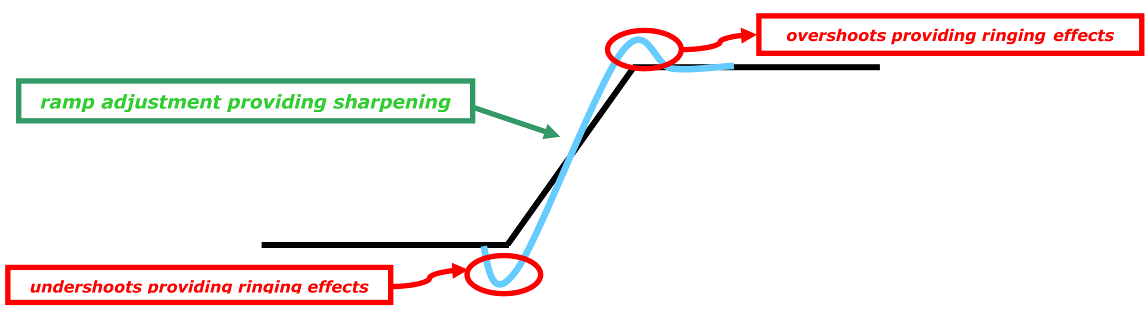

Fig. 1: Horizontal graylevel profile of an edge.

2. ALGORITHM DESCRIPTION

The Fig. 2 shows a simplified scheme of the Adaptive Directional Sharpening with Overshoot Control (ADSOC) algorithm. It consists on four basic steps:

1. *Luma extraction:* a color transform from the RGB to the YUV domain is performed: the luminance is the only feature of the image that is modified in order to achieve sharpening.
2. *Image Activity Analysis:* A 5x5 high-pass filter (Fig. 3) is applied in order to discern homogeneous and textured regions of the image.
3. *Sharpness Gain computation:* a further test is performed by applying a 5x1 filter bank (Fig. 4) in order to compute the sharpness gain to be added to the original pixel value and evaluate the directional information.
4. *Ring Control:* the sharpness gain is corrected evaluating the local dynamic of the image in order to avoid under/overshoot effects.

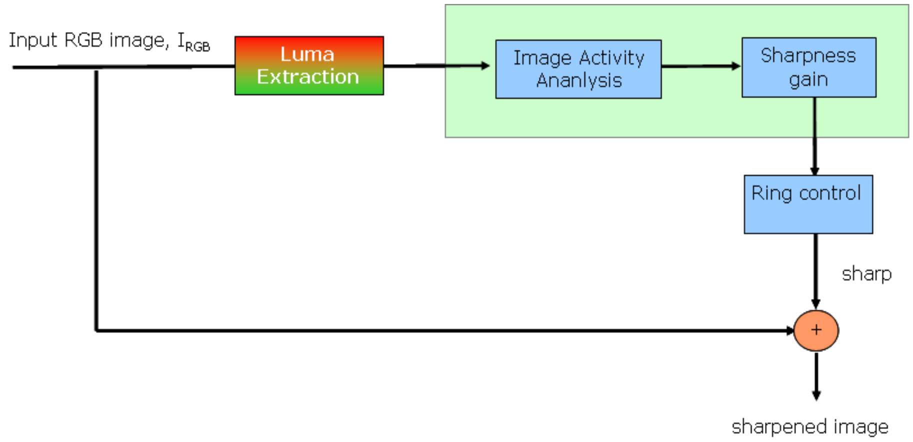

Fig. 2: ADSOC basic scheme.

The first step is performed using the well known standard transformation formula:

- $Y = 0.299 \cdot R + 0.587 \cdot G + 0.114 \cdot B$
- $U' = (B-Y) \cdot 0.565$
- $V' = (R-Y) \cdot 0.713$

but any color transform could be used in order to extract the luminance information from he input image. Then, the "Image Activity Analysis" step is done: it is a coarse edge detection step performed by applying the 5x5 high-pass filter in Fig. 3 to each pixel of the image. If the response of the filter is greater than a threshold th_1 chosen by the user, the pixel P_{in} under study is assumed falling in a textured region of the image and the step 3 of the algorithm is performed, otherwise the intensity value of P_{in} remains unchanged.

-1	0	-1	0	-1
0	-2	-1	-2	0
-1	-1	20	-1	-1
0	-2	-1	-2	0
-1	0	-1	0	-1

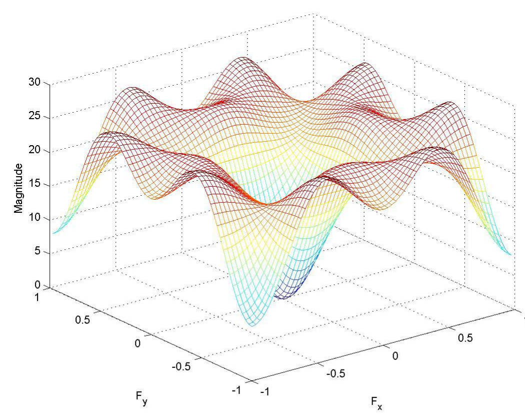

Fig. 3: The 5x5 high-pass filter used in the second step of the ADSOC algorithm.

The "Sharpness Gain computation" step uses the response of a 5x1 filter bank (Fig. 4) in order to perform a more reliable edge detection test. If the pixel P_{in} under examination yields at least a filter response d_i greater than a fixed threshold th_2, it belongs to an edge region, thus the intensity of P_{in} is adjusted to achieve sharpening. In particular, the estimated gain to be added to P_{in} is the response of the 5x1 filter corresponding to the direction orthogonal respect to d_i. For each pixel P_{in}, the sharpened value P_{out} is given by:

$$P_{out}=P_{in}+(d_i * gain/16)$$

where "gain" is the sharpness boost and it varies in the range [0,…,128].
The final "Ringing Control" step is performed exploiting the information concerning the local dynamic of the image to correct the P_{out} value in order to avoid undesired effects. For each NxN block (is N=5 due to the size of the filter mask) of the input image, if the sharpened value P_{out} falls out of the range [Min,…,Max], with Min=minimum(N,N) and Max=maximum(N,N), the overshoot/undershoot effects are reduced making smaller the gain between the sharpened value and the maximum (or minimum) intensity value of the block, accordingly with the following formula:

if P_{in}+sharp >Max(n,n) → $P_{out}=Max+\alpha\cdot(P_{in}+sharp-Max)$
if P_{in}+sharp $\in$[Min(n,n),Max(n,n)] → $P_{out}=P_{in}+sharp$
if P_{in}+sharp <Min(n,n) → $P_{out}=Min-\alpha\cdot(Min-P_{in}-sharp)$

where is:

$$\alpha=\begin{cases} 0 & ifstrength=0 \\ \dfrac{strength}{l} & strength\in[1,...l] \end{cases}$$

and l is the number of sharpening levels. The parameters *strength* and α allow choosing the ringing intensity: if $\alpha=0$ P_{out}=Max and overshoot are not allowed, whilst if $\alpha=1$, the ringing control is disabled.

Since an image without any ringing could appear too flat, but a small ring improves the observer perception of depth, a good tuning of the parameters *gain* and *strength* is the key for obtaining a good sharpened image.
Note also that the size and the kind of the filter masks used in the second and in the third step of the algorithm could be changed with no affect the core of the method. For example, memory could be saved by using a 3x3 Laplacian filter in order to find the textured zones of the images and the corresponding 3x1 monodimensional filter bank could replace the 5x1 filters used to detect the "master" direction. Of course, the use of larger filter makes the algorithm more robust to noise and more reliable at the cost of a slight increase of the computational complexity.

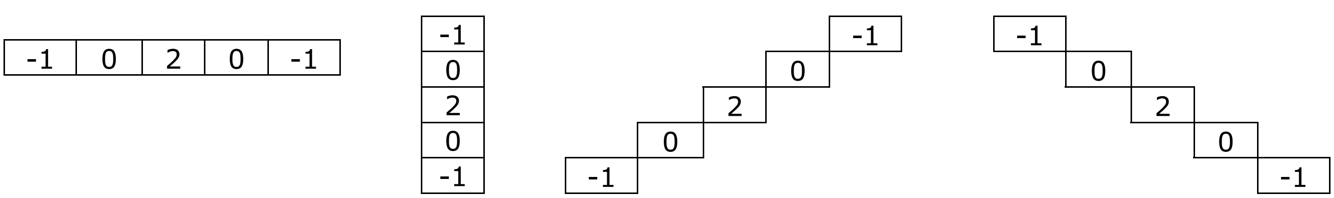

Fig. 4: 5x1 filter bank used in the ADSOC in order to compute the sharpness gain.

3. EXPERIMENTS

Several tests have been performed in order to evaluate the ADSOC performances. A database containing many images acquired at different resolutions and different light conditions has been processed. The results showed that the ADSOC allows to achieve a good visual quality in the output in any condition. In order to find an appropriate tuning of the basic parameters that manage the sharpening intensity, each image has been processed varying the parameters gain and strength.

The best trade-off has been reached fixing *gain*=16 and *strength*=3, but the choice of the ideal values depends on the application and on the input image features. In particular, a high value of *strength*, corresponding to a visible ringing effect along strong edges, may be unpleasant in synthetic images or in scenes with a big amount of text. Fig. 5 shows the output obtained applying the ADSOC with standard parameters. The sharpening effect is evident and the homogeneous regions of the image are not affected by the algorithm. Moreover, since the ADSOC doesn't modify the chrominance components of the image, the original colors are preserved. The strong diagonal edges and the text don't suffer the ringing thanks to the ringing control. Fig. 6 shows another example where the algorithm is applied with the default parameters.

The sequence in the Fig. 7 shows a detail that proof how the ringing effect grows with the value of *strength*. The first upper left image obtained fixing *strength*=2 appears yet blurred and the text is not highlighted enough from the background, whilst in the bottom left image, obtained with the ringing control disabled, an overshoot is introduced. The Fig. 8 shows an example where the sharpening strength has been increased varying the *gain*.

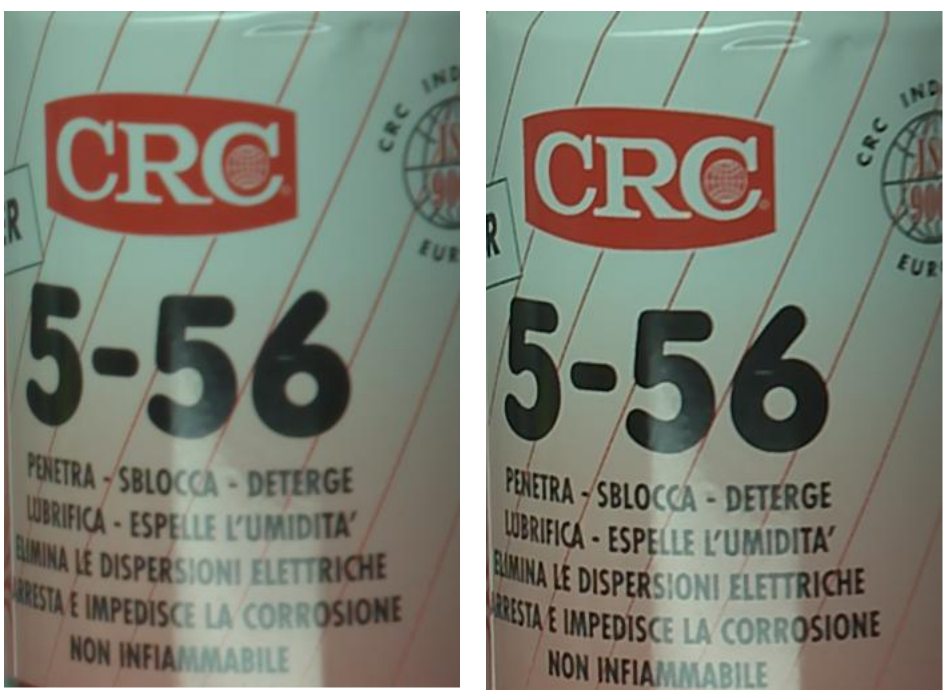

Fig. 5: Example of the sharpening effect obtained applying the ADSOC (ringing *strength*=3 and *gain*=16).

Fig. 6: Sharpening effect obtained applying the ADSOC (ringing *strength*=3 and *gain*=16).

Fig. 7: ringing control effect: the enlarged details show the results obtained with the ringing strength parameter, in clockwise motion, set to 2, 4, 8, 6 respectively.

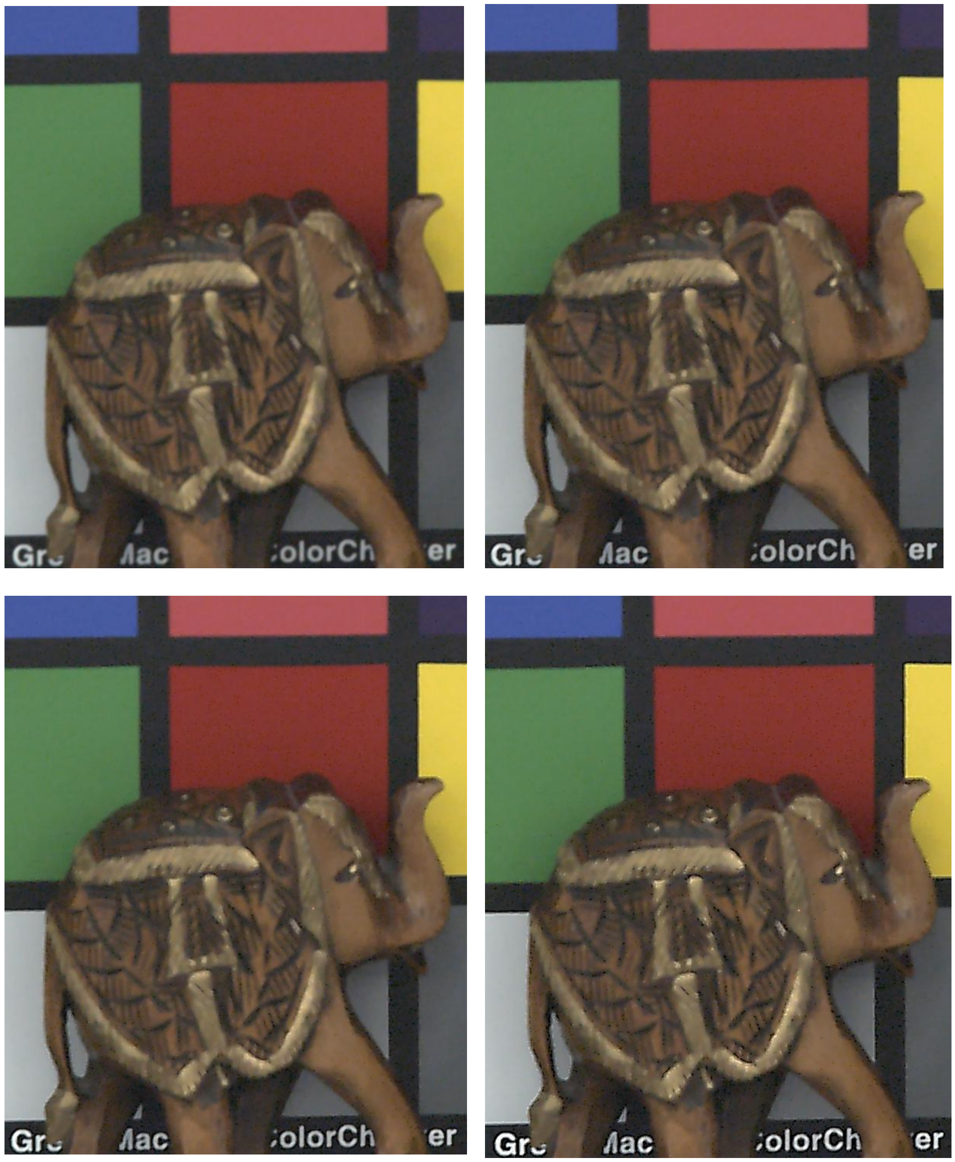

Fig. 8: the sharpening effect could be increased also varying the gain parameter. The input image (upper-left) has been processed by the ADSOC with parameter strength=3 and gain=16 (upper-right), 32 (bottom-left), 64 (bottom-right).

4. CONCLUSION

An adaptive solution for sharpening, the Adaptive Directional Sharpening with Overshot Control (ADSOC) has been presented. The new algorithm allows to perform sharpening with different strength in the input image depending on the local dynamic of the image itself. The algorithm is based on a simple edge-detection method that uses a 5x5 filter mask and a 5x1 filter bank in order to extract and exploit also directional information to improve the final quality of the output. In the regions of the original images where more details and edges are detected, the contrast is increased more than in the other regions, in order to reduce the noise amplification and the overshoot effects, which are the most common defects introduced by the standard sharpening algorithm. Moreover, a ringing control block has been devised in order to allow varying the intensity of the sharpening along the edge and making possible the choice of an appropriate level of oversharp in the output image. The complexity of the algorithm is low both in terms of computational cost and memory requirements, so the ADSOC is suitable for post-processing, but also for real-time applications. Several experiments, performed on a large set of images acquired at different light conditions and using several sensors with different resolutions, showed the ADSOC yields good results in any case.

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