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# INTELLIGENT SHARPNESS ENHANCEMENT FOR VIDEO POST-PROCESSING

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## ABSTRACT

*Sharpness enhancement is one of the post-processing stages in the consumer electronics video chain that operates in an open-loop mode. Although adaptive behavior is possible, in general there is no feedback system aimed at maximizing perceived quality. In this paper we introduce a control system and metric for sharpness enhancement algorithms. We also discuss the options of implementing an internal or local control loop, i.e., to control the basic sharpness enhancement engine at the pixel or region level, and an external or global control loop for sharpness enhancement module.*
***Keywords****: sharpness metric, auto-sharpness, sharpness control.*

## 1. INTRODUCTION

Video post-processing includes modules dedicated to correct artifacts and noise, to modify the spatial-temporal format of the image, and to enhance attributes such as sharpness, color and contrast (see Figure 1). Although the objective is to maximize perceived quality, the objective function and control signals are not yet known. Quality is improved in certain instances by using content adaptive processing according to well accepted principles such as filtering out noise by a low amount so it will not introduce blur, and enhancing sharpness only up to the best known threshold below the appearance of artifacts.

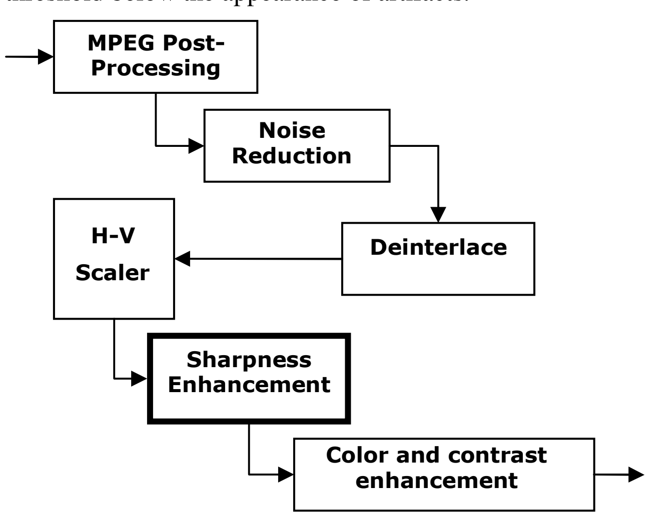


Figure 1 - Video processing chain.

Limited-scope control loops can be found in imaging systems such as STM and consumer and professional video cameras. Those systems include for example auto-focus, automatic image stabilization, and white balance.

Based on our work on no-reference quality metrics [1,3,5], in particular sharpness metrics [2,4], we have started researching control systems for sharpness enhancement in video post-processing. In the case of sharpness, local control, i.e. control of a single module in the video chain, is the best solution given that this module interacts with other subsequent processing and its actual effect cannot be always directly measured at the end of the video chain.

In this paper we present two options for local sharpness control in post-processing. In the first option, an external control system uses a single gain parameter and a global no-reference sharpness metric. In the second option, the external control uses a local gain parameter and a local no-reference sharpness metric.

In the remainder of this paper we discuss in Section 2 the sharpness metric that works both at local and global levels, in Section 3 the control principles used to deal with sharpness, in Section 4 the global control option, in Section 5 the local control option, and in Section 6 we discuss the results.

## 2. GLOBAL AND LOCAL SHARPNESS METRIC

There is a known dependency between perceived sharpness and the gradient at edge pixels in an image. However, the gradient by itself is not a good practical metric as it may be noise sensitive, and there is no accepted approach to translate gradient directly into a perceptual sharpness metric; particularly the gradient magnitude computed from its horizontal and vertical components is not a good perceptual sharpness estimator.

Our new sharpness metric uses a low complexity gradient estimate based on gradient runs or piecewise linear approximations of the horizontal and vertical gradients. Steepness of gradient runs is used to estimate local sharpness as follows:

1. For purely vertical and horizontal edges use the steepness of the local gradient run.
2. For diagonal edges use elliptical calculation (instead of the mathematical gradient magnitude), which gives a total value larger

than the smallest component but smaller than the largest component.

3. Total sharpness can be computed as the average for all non-zero gradient runs.

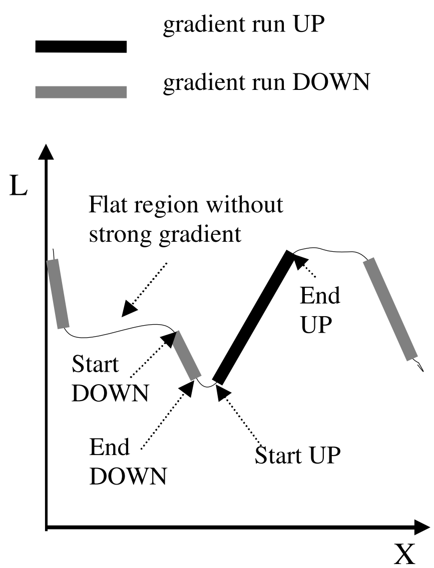


Figure 1 - Gradient runs: piece-wise linear interpolation

If we take a row or a column of pixels in an image, the luminance values will probably show an irregular profile as shown in Figure 1. Regions where the value is changing by more than a certain threshold (in the up or down direction) are represented by a straight segment called a gradient run. The steepness of the run is an indicator of sharpness (in the x or y direction).

The sharpness calculation consists of:

1. Calculate gradient runs for all rows and columns (i.e. horizontal and vertical runs).
2. Compute the sharpness at every pixel as follows:
    a. if there is only one run at that location (only horizontal, or only vertical) use is as the sharpness value
    b. if the two runs exist, then use 0.707 times the total gradient magnitude $(Gx^2 + Gy^2)^{1/2}$ – elliptical formula
3. Total sharpness is a function of the non-zero gradients found on the image. This function can be the average, median, or mode of the distribution plus (optionally) a perceptual factor that is function of contrast sensitivity and/or visual channel model.

The method has been shown to be noise robust, and works consistently for any image orientation (fully isotropic), and robust to non-isotropic sharpening/blurring.

## 3. SHARPNESS CONTROL PRINCIPLES

The perception of sharpness is related to edge definition, contrast, and image resolution. In this study we focus on edge definition, namely the steepness (in the spatial domain), or the richness in high spatial frequencies (in the transformed domain). Most edge enhancement methods work according to the open-loop method shown in Figure 2. Although the filter may be adaptive, usually there is no control loop, and a fixed gain parameter.

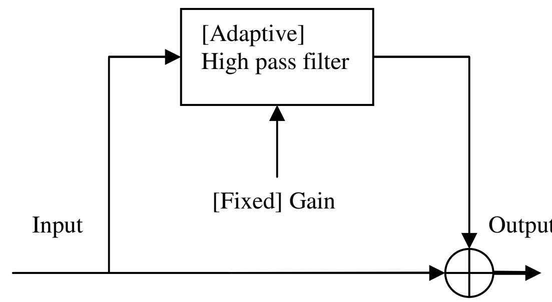


Figure 2 - Generic sharpness enhancement method

In order to control sharpness, it is necessary to have a no-reference sharpness metric to indicate whether sharpness is being modified. We also need to know what the optimum sharpness target is. Sharpness cannot be increased indefinitely, but the acceptable ceiling is not the maximum sharpness attainable, instead, it is the maximum value without side effects (appearance of artifacts such as clipping, halos and posterization or increase in strength of existing noise). Thus, to control sharpness we may also need an artifact metric.

We also need to choose the control strategy (e.g. hill-climbing); and identify the constraints (e.g. no artifacts).

For global or external control, a global sharpness metric is sufficient, while for internal control we must have a sharpness metric that works at the local level as well.

## 4. GLOBAL SHARPNES CONTROL LOOP

Global sharpness control is the best option if the sharpness enhancement module must be treated as a simple black box with one or very few control signals. In this case, the global or external control is based on one control cycle per output frame. This means sharpness and artifacts are measured after one full cycle and feed back to the gain controller as shown in Figure 3.

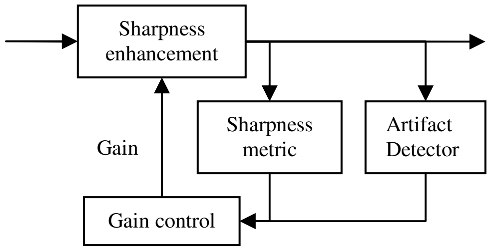


Figure 3 - External sharpness control system

Although gain may be adaptive inside the sharpness enhancement module, and there may be several parameters associated with gain, for simplicity we consider here only one primary gain parameter. The gain control can use any optimization strategy such as hill climbing. The typical control steps are:

1. Initialize gain to an arbitrarily low default value.
2. If sharpness goes up in the next cycle, and no artifacts are present, increase gain by a certain step size.
3. If sharpness does not go up or artifacts are now present, set gain to previous gain and divide the step size by 2 (if not possible, use the smallest possible increment).

To insure convergence without disturbing visual effects, the sensitivity of sharpness to gain (step size) should be below 1JND so that upon convergence, the fluctuation in gain will not be noticeable. It is also possible to lock the gain once the artifact-free maximum is reached, and leave it constant until a change of scene is detected.

To show how the global sharpness control may work, in one experiment we set an upper bound for sharpness increase (knowing that too much sharpness causes distortion), and setting a maximum allowable artifact (e.g. blockiness) increase.

We used an MPEG compressed image as input and applied the following strategy to the sharpness control:

1. Start with a default value for sharpness gain (around the practical maximum)
2. Limit maximum sharpness increase to 10%, and blockiness increase to 3%
3. If sharpness is too high, reduce gain.
4. If criteria are not met (sharpness below target), then increase sharpness gain.

Gain search can be done using a simple *golden section* approach, i.e. gain fraction is halved at each pass. Table 1 shows the results. Notice that a measured increase of 4% in sharpness at the expense of 1.8% increased blockiness gives the best visual quality.

| Image | Blockiness | Sharpness |
|---|---|---|
| Original | 0.567 | 12.452 |
| Option 1 | 0.596 (6%) | 14.5 (17%) |
| Option 2 | 0.587 (3%) | 13.49 (8%) |
| **Option 3** | **0.578 (1.8%)** | **12.99 (4%)** |

Table 1 - Blockiness and sharpness monitor

Figure 4 shows samples of the original and 2 output images for maximum and best enhancement.

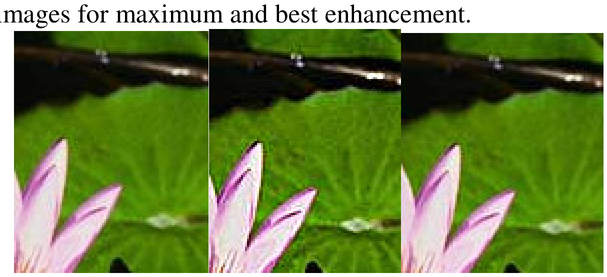

Figure 4 - Original, maximum and best enhancement using bound gain strategy

In a second experiment we used a clean image and the sharpness metric as the only control signal; maximum sharpness gain was 15%. The results are shown in Table 2. The maximum sharpness was attained. Allowing higher sharpness was possible but quality was sub-optimal (as seen in the case of option 3 below).

| Image | Sharpness |
|---|---|
| Original | 9.184 |
| Option 1 | 9.832 (7%) |
| Option 2 | 10.2 (11.9%) |
| Option 3 | 11.461 (24.7%) |
| **Option 4** | **10.5325 (14.6%)** |

Table 2 - Sharpness monitor

Images of original, maximum and best sharpness using a single, bound sharpness control are shown in Figure 4.

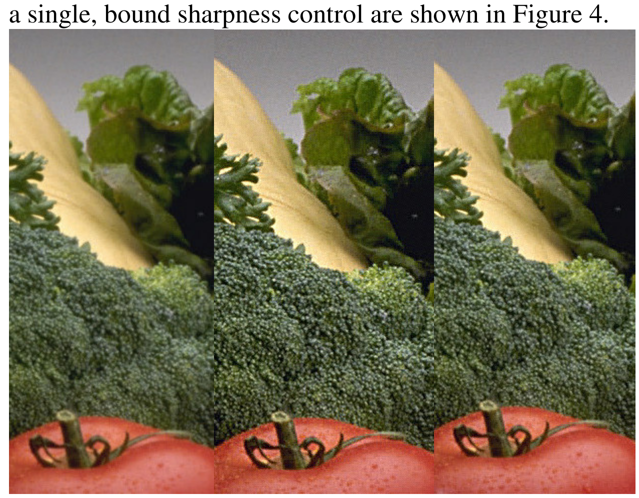

Figure 4 - Original, maximum, and best output

## 5. LOCAL SHARPNESS CONTROL LOOP

The local or internal sharpness control system is based on controlling the core process inside the sharpness enhancement module, e.g. at the pixel or small-region level. The main difference with the external control case is that the sharpness metric and artifact detector must be local values that scale well to become global estimates (i.e. global metric is a function of the local values). The block diagram for internal sharpness control is shown in Figure 4.

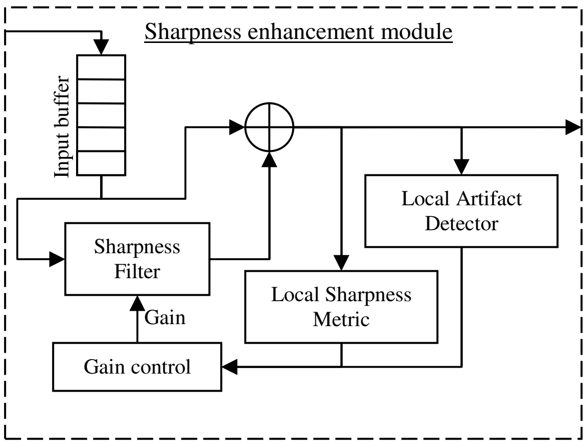


Figure 5 - Internal sharpness control system

The internal control system offers a fine-grain control option. Local maximization of sharpness enables more advanced techniques such as adaptive enhancement of regions and objects of interest, including use of different enhancement methods depending on the content of those objects or regions.

To illustrate the power of a local sharpness control we used the input of the second example of global control explained before, and applied the following strategy (slightly modified from that of Figure 5 such that sharpness is measured at two points):

1. Set the overall sharpness gain to the best known value.
2. At the local level, e.g. pixel, calculate sharpness before and after applying the sharpness filter.
3. If the local sharpness goes up, then keep the enhanced pixel output value.
4. If the local sharpness goes down, then keep the original pixel value.

The image outputs of the global control and the local control are shown in Figure 6. The visual improvement is derived from the fact that the local control avoids any local degradation which may happen with practical filter implementations.

Figure 6 - Output of global and local control loop

## 6. RESULTS AND DISCUSSION

In this paper we presented a new sharpness metric that can be applied to global and local control using a variety of strategies.

The new metric is less complex than others we developed before, and improves over the use of simple gradient by meeting the requirement that total sharpness is larger than the smallest component and smaller than the largest component (and larger than the average). Further refinements can take into account properties of the human visual system, e.g. contrast, sensitivity (e.g. normalizing by local average luminance and applying contrast sensitivity function), and orientation (e.g. angle arctangent of y/x components and steepness can be used to place the estimate on the orientation-frequency channel model of the human visual system). The global metric is naturally bias free as it can be calculated as the most frequent steepness found in the image (median, or mode of the distribution are possible choices).

We have tested the global (or external) and local (or internal) control methods using a simple sharpness enhancement algorithm. We have shown that local control can potentially outperform global control given that it is sensitive to local degradations not visible to global quality metrics. Strategies that maximize sharpness subject to limited increase in artifacts were discussed for the case of compressed images.

Further research will need to address complex scenarios with the presence of other artifacts such as noise and ringing, and whether the limited gain approach is sound for both global and local control strategies. Also, effective combinations of global, local, and multiple control methods are also an area for further exploration.

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