

THRESHOLD DECOMPOSITION DRIVEN ADAPTIVE MORPHOLOGICAL FILTER FOR IMAGE SHARPENING

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Abstract: A new method is proposed to sharpen digital images. This sharpening method is based on edge detection and a class of morphological filtering. Motivated by the success of threshold decomposition, gradient-based operators, such as Prewitt operators, are used to detect the locations of the edges. A morphological filter is used to sharpen these detected edges. Experimental results demonstrate that the performance of these detected edge deblurring filters is superior to that of the traditional sharpening filter family.

1 INTRODUCTION

The Chinese proverb “*One picture is worth a thousand words*” underestimates the amount of information contained in a single picture. Most media (e.g. newspapers, TV, cinema) use pictures (still or moving) as information carriers. The tremendous volume of optical information and the need for its processing and transmission paved the way to image processing by digital computers (Pitas, 1993).

The past twenty years in particular were characterized by a massive increase in the speed, power and availability of digital computers. Accordingly, one area of information technology that has grown rapidly is imaging science. This subject has become increasingly important because of the growing demand to obtain information about the structure, composition and behaviour of objects without the need to inspect them visually (Blackledge, 1989).

Image sharpening has played an important role in image processing since the beginning of the digital image revolution (Pratt, 1978). Thus, many well-known techniques for image sharpening exist today and are readily available in most commercial software packages.

Edge detection is a fundamental tool used in most image processing applications to obtain information from the images and frames. This

process detects the boundaries of the objects and separates them from the background of the image.

Digital image enhancement techniques are concerned with the improvement of the quality of the digital image. The principal objective of enhancement techniques is to process an image so that the result is more suitable than the original image for a specific application. Image enhancement is usually done simultaneously with detection of features such as edges and peaks. Tools of linear systems have been used to solve many of the image enhancement applications. Nowadays, a new understanding has emerged that linear approaches are not well suited or even fail to solve problems involving geometrical aspects of the image. Thus, there is a need for nonlinear geometric approaches. A powerful nonlinear methodology that can successfully address the image sharpening problem is mathematical morphology (Maragos, 2005).

In this paper, we propose a novel approach for effectively sharpening blurred images. Our strategy is that if we can detect the edges and locate their position in the image, then we are able to increase the contrast of these edges by applying a morphological filter at these locations only.

Section 2 introduces the threshold decomposition and the method used for edge detection. Morphological filtering for image sharpening is explained in Section 3. Section 4 will present in detail the proposed sharpening filter. Then, this proposed filter is tested on several examples and its performance is compared with that of traditional

sharpening-type filters. Finally, Section 5 contains some concluding remarks.

2 BACKGROUND

2.1 Threshold Decomposition

Threshold decomposition is a powerful theoretical tool used in image analysis. Introduced by Fitch in (Fitch et al., 1984) and later modified by Arce in (Arce, 1998) and Paredes in (Paredes and Arce, 1999). Consider an integer-valued set of samples X_1, X_2, \dots, X_N forming the vector $\mathbf{X} = [X_1, X_2, \dots, X_N]^T$ where $X_i \in \{-M, \dots, -1, 0, 1, \dots, M\}$. The threshold decomposition of \mathbf{X} amounts to decomposing this vector into $2M$ binary vectors $x^{M+1}, \dots, x^0, \dots, x^M$, where the i th element of x^m is defined by

$$x_i^m = T^m(X_i) = \begin{cases} 1 & \text{if } X_i \geq m \\ -1 & \text{if } X_i < m \end{cases} \quad (1)$$

where $T^m(\cdot)$ is referred to as the threshold operator.

The above threshold decomposition is reversible, such that if a set of threshold signals is given, each of the samples in \mathbf{X} can be exactly reconstructed as

$$X_i = \frac{1}{2} \sum_{m=-M+1}^M x_i^m \quad (2)$$

Thus, an integer-valued discrete-time signal has a unique threshold signal representation, and vice versa.

2.2 Edge Detection

Edge detection is a fundamental tool used in most image processing applications. This process detects outlines of an object and boundaries between objects and the background in the image.

An edge-detection filter can be used to improve the appearance of blurred images or video streams. The Prewitt operator (Prewitt, 1970), similar to the Sobel, Robinson and some other operators approximates the first derivatives of the image. They are sometimes called compass operators because of the ability to determine gradient direction. The gradient is estimated in 4 (for a 3×3 mask) possible directions with a difference of 90° between each direction and the other. These 4 operators will be

represented by 4 (3×3 mask) respectively.

$$h_1 = \begin{bmatrix} 1 & 1 & 1 \\ D_0 & D_1 & D_2 \\ -1 & -1 & -1 \end{bmatrix} \quad h_2 = \begin{bmatrix} -1 & D_0 & 1 \\ -1 & D_1 & 1 \\ -1 & D_2 & 1 \end{bmatrix}$$

$$h_3 = \begin{bmatrix} -1 & -1 & -1 \\ D_0 & D_1 & D_2 \\ 1 & 1 & 1 \end{bmatrix} \quad h_4 = \begin{bmatrix} 1 & D_0 & -1 \\ 1 & D_1 & -1 \\ 1 & D_2 & -1 \end{bmatrix}$$

where $g = \{D_0, D_1, D_2\}$ is the Structuring element used in the mathematical morphology and will be explained later.

By the aid of the threshold decomposition described above, and for each level, the edges are detected by searching for the 4 masks of the Prewitt operators. Thus the sharpening filter is applied only on these detected edges rather than all the pixels of the image.

3 IMAGE SHARPENING BY MORPHOLOGICAL FILTERING

3.1 Introduction to Mathematical Morphology

Kramer in (Kramer and Bruckner, 1975) defines a non-linear transformation for sharpening digitized gray-scale images. The transformation replaces the gray value at a pixel by either the minimum or the maximum of the gray values in its neighborhood, the choice depending on which one is closer in value to the original gray value.

In mathematical morphology (Serra, 1982), the transformation that replaces the gray value at a pixel by the maximum of the gray values in its neighborhood is known as the gray-scale dilation image operator.

$$(f \oplus g)(x) = \bigvee_{\mu \in R^2} [f(\mu) + g(x - \mu)] \quad (3)$$

in which function $f(x), f: x \in R^2 \rightarrow f(x) \in R$ is the original image, and $g(x), g: x \in R^2 \rightarrow g(x) \in R$ is

the structuring element implicitly defining the weighted neighborhood.

Similarly, the transformation that replaces the gray value at a pixel by the minimum of the gray values in its neighborhood is known as the gray-scale erosion image operator

$$(f \ominus g)(x) = \bigwedge_{\mu \in R^2} [f(\mu) - g(\mu - x)] \quad (4)$$

Note that the dilation operator is extensive: $(f \oplus g)(x) \geq f(x)$ and the erosion operator is anti-extensive: $(f \ominus g)(x) \leq f(x)$.

3.2 Contrast Enhancement

Consider a gray-scale image $f(x)$ and a structuring element g containing the origin. Kramer in (Kramer and Bruckner, 1975), and then redefined by Schavemaker in (Schavemaker et al., 2000), used the following discrete nonlinear filter to enhance the local contrast of f by sharpening its edges:

$$\psi(f)[x] = \begin{cases} (f \oplus g)[x] & \text{if } f[x] > ((f \oplus g)[x] + (f \ominus g)[x])/2 \\ (f \ominus g)[x] & \text{if } f[x] < ((f \oplus g)[x] + (f \ominus g)[x])/2 \\ f[x] & \text{otherwise} \end{cases} \quad (5)$$

At each pixel x , the output value of this filter toggles between the value of the dilation of f by g (i.e., the maximum of f inside the moving window g centred at x) and the value of its erosion by g (i.e., the minimum of f within the same window) according to which closer to the input value $f(x)$. If the value of the dilation of f by g equals the value of its erosion by g , the output value will be the same as the input.

3.3 Structuring Element Selection

In this paper, we will focus on two types of structuring element in order to sharpen a gray-scale image.

Firstly, Kramer in (Kramer and Bruckner, 1975) uses flat structuring elements for sharpening digitized gray-scale images.

Secondly, Van den Boomgaard in (Van den Boomgaard et al., 1996) and Schavemaker in (Schavemaker et al., 2000) have shown that all image operators using concave structuring elements have sharpening properties.

In this paper, it will be shown that these two structuring elements have near sharpening behaviour, and that the flat structuring elements are slightly preferable to that of the parabolic concave structuring ones.

4 THE PROPOSED SHARPENING FILTER AND EXPERIMENTAL RESULTS

The sequence of applying the proposed filter will be explained before introducing the experimental results. First, the blurred image is digitized by the threshold decomposition method introduced in section 2.1. On each level, we search for the 4 possible edge directions explained in section 2.2. We have two types of structuring elements: the flat structuring element and the parabolic concave structuring element. After deciding the type of the structuring element, the nonlinear discrete filter introduced in section 3.2 is used to sharpen these detected edges only, rather than the whole images.

This section presents application results for the sharpening operator using flat and parabolic concave structuring elements in the discrete domain. The performance of the proposed filter is compared with a number of sharpener-type filters including high-pass sharpener, modified high-pass sharpener (Fischer et al., 2002), the lower-upper-middle (LUM) filter (Hardie and Boncelet, 1993), the comparison and selection (CS) filter (Lee and Fam, 1987) and the unsharp masking technique.

The normalized mean square error (NMSE) is used to give a quantitative evaluation on the filtering results.

Our proposed filter is tested on some examples. Figures (a) are the Gaussian blurred test images. Figures (b), (c), (d), (e) and (f) show the sharpened images after applying the high-pass sharpener, modified high-pass sharpener, LUM sharpener, CS sharpener and the unsharp masking respectively. As mentioned above, there are two types of structuring elements. Figures (g) show the sharpened images after applying the proposed edge detected, *parabolic concave structuring element morphological filter*, while Figures (h) show the sharpened images after applying the proposed, *flat structuring element morphological filter* on the detected edges.

Table 1 and Table 2 show the NMSE as a quantitative comparison between the above mentioned sharpening techniques. The output of

each filter is evaluated by comparing its estimate to the original image.

Table 1: NMSE for different sharpening-type filters.

Sharpening Filter	Lenna	Peppers
High-pass sharpener	0.0132	0.0149
Modified high-pass sharpener	0.0120	0.0138
LUM sharpener	0.0106	0.0121
CS sharpener	0.0267	0.0317
Unsharp masking	0.0127	0.0144
Proposed edge detected concave structuring element morphological filter	0.0082	0.0070
Proposed edge detected flat structuring element morphological filter	0.0081	0.0069

Table 2: NMSE for different sharpening-type filters.

Sharpening Filter	Walk Bridge	Girl
High-pass sharpener	0.0206	0.0137
Modified high-pass sharpener	0.0187	0.0117
LUM sharpener	0.0168	0.0113
CS sharpener	0.0388	0.0271
Unsharp masking	0.0195	0.0129
Proposed edge detected concave structuring element morphological filter	0.0143	0.0087
Proposed edge detected flat structuring element morphological filter	0.0141	0.0087

5 CONCLUSIONS

In this paper, a new image sharpening filter based on morphological filters was presented. Edges are first detected through threshold decomposition. Then, we choose the type of the structuring element from the flat or the parabolic concave structuring elements. Both give good results, but the flat structuring element was found to perform slightly better. Thus, the threshold decomposition guided adaptive filters

have the ability to sharpen a blurred image. Experimental results and associated statistics have indicated that the proposed algorithm provides a significant improvement over many other well-known sharpener-type filters in the aspects of edge and fine detail preservation, as well as minimal signal distortion.

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Figure 1: (a) Blurred Lenna (b) High-pass sharpened (c) Modified high-pass sharpened (d) LUM sharpened (e) CS sharpened (f) Unsharp mask sharpened.

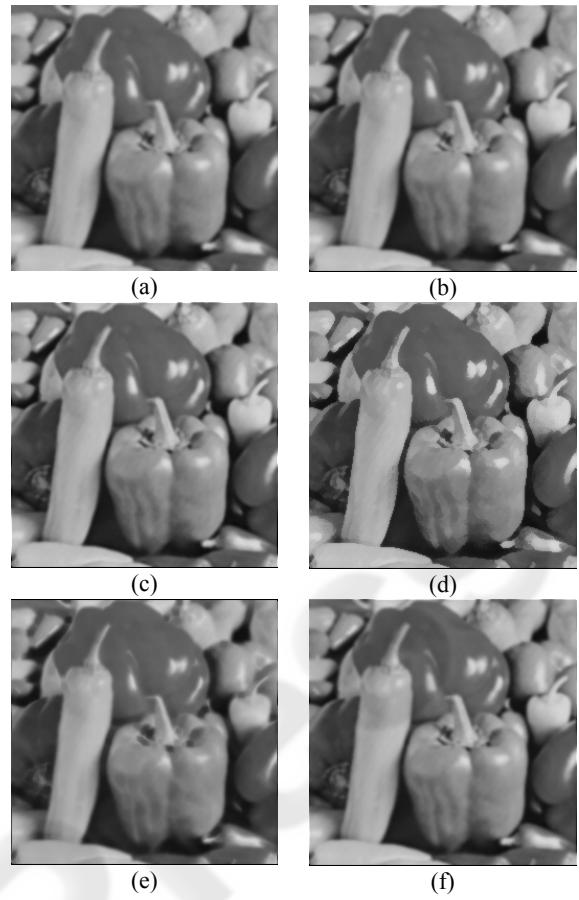


Figure 2: (a) Blurred Peppers (b) High-pass sharpened (c) Modified high-pass sharpened (d) LUM sharpened (e) CS sharpened (f) Unsharp mask sharpened.



Figure 1: (g) Proposed edge detected concave structuring element morphological filter (h) Proposed edge detected flat structuring element morphological filter.

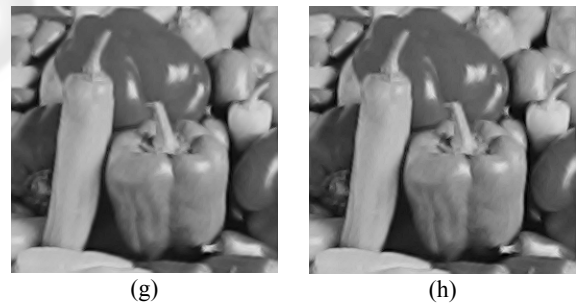


Figure 2: (g) Proposed edge detected concave structuring element morphological filter (h) Proposed edge detected flat structuring element morphological filter.

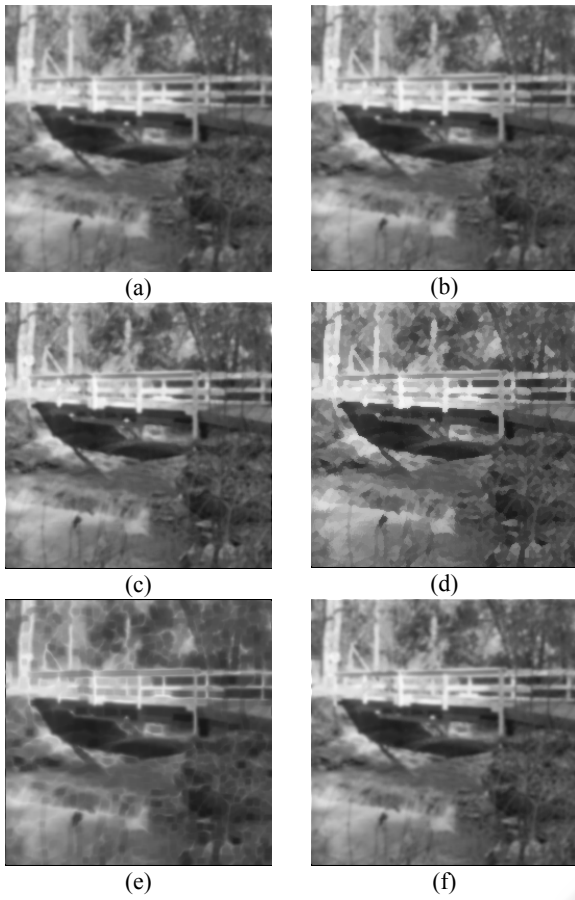


Figure 3: (a) Blurred Rectangle (b) High-pass sharpened (c) Modified high-pass sharpened (d) LUM sharpened (e) CS sharpened (f) Unsharp mask sharpened.

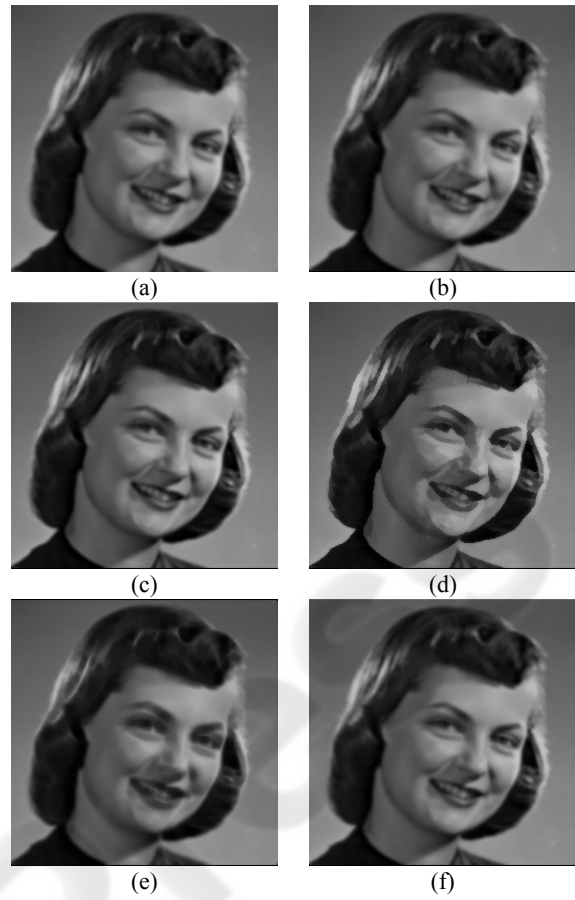


Figure 4: (a) Blurred Girl (b) High-pass sharpened (c) Modified high-pass sharpened (d) LUM sharpened (e) CS sharpened (f) Unsharp mask sharpened.

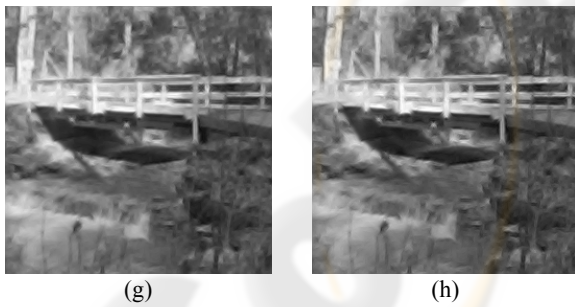


Figure 3: (g) Proposed edge detected concave structuring element morphological filter (h) Proposed edge detected flat structuring element morphological filter.

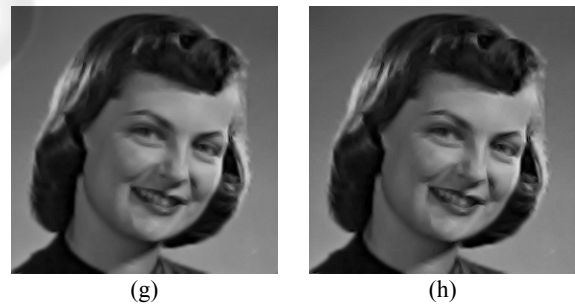


Figure 4: (g) Proposed edge detected concave structuring element morphological filter (h) Proposed edge detected flat structuring element morphological filter.