VECTOR MEDIAN FILTERS FOR PROCESSING OF COLOR IMAGES IN VARIOUS COLOR SPACES

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Abstract

The paper presents a comparative study of performance of 2D vector median filters which calculate in various color coordinates the distances between the vectors corresponding to pixels of color images. The paper deals with the problem of the best choice of the color space for vector median calculations. The problem is considered for the task of restoration of color images corrupted with impulse noise. The comparison has been made experimentally, using 4 test images and 3 types of impulse noise. The results have been evaluated by consideration of quadratic errors in the Munsell space as well as by comparing their subjective quality.

INTRODUCTION

Growing interest in vector approach to color image processing in last years is based on the common conviction that inter-component correlation can be exploited in this way. On the other hand, good performance of median filters in presence of impulse noise and the growing number of their applications in image enhancement, reconstruction and restoration have stimulated intensive studies on vector median filters, Öistämö and Neuvo (1), Astola et al (7). Even some extensions of two-dimensional median filters have been already examined for applications in color image processing.

The vector image processing of color images consists in simultaneous processing of all the three signal components, i.e., a pixel value is considered as a triple of the values of the color components related to a given pixel. There exists a variety of distance measures for calculation of vector medians. First of all various norms in the 3-D vector spaces can be used. The Euclidean and taxi cab norms are of the greatest interest here. The first gives better results in vector processing while the latter is easier to calculate. Nevertheless the expense of calculation of the Euclidean norm is not crucial for the overall computational cost of the implementation of a vector median filter. Therefore this norm is used throughout this paper.

The paper deals with restoration of color images corrupted with impulse noise.

Considered is the problem of the best choice of the color space for vector median calculations. The choice of the color coordinate system should be considered to take the maximum advantage of the vector approach. On the other hand, in order to obtain minimum visible distortion, the color distance measured should well agree with human perception rules.

RESEARCH OBJECTIVES

In order to find out the differences between various color systems applied to vector median filtering a series of experiments are carried out, Bartkowiak (8). Simulations are done for some test images corrupted with impulse noise of various types. Then the images are restored using the vector median filters, Öistämö and Neuvo (1), Astola et al (7).

$$VMED(\underline{x}) = \left[\underline{x}_{MED}: \quad \sum_i \left\| \underline{x}_{MED} - \underline{x}_i \right\| \le \sum_i \left\| \underline{y} - \underline{x}_i \right\| \quad \forall \underline{y} \right] \tag{1}$$

where "$\|\cdot\|$" denotes the Euclidean norm in a given color space, $\underline{x}_i$ and $\underline{y}$ are the pixel values (three-element vectors) and $\underline{x}_{MED}$ is the median (output) value. .

The norm in the VM definition is computed in different color spaces producing various output images. The resulting images are compared one to the others using the objective performance measure (SNR gain) as well as the subjective opinion score.

The color spaces examined are the standard CIE: linear (RGB and XYZ) and nonlinear (L*a*b*) systems, Wyszecki and Stiles (2), Nibblack (3). The relations between CIE RGB, XYZ and L*a*b* color coordinates are as follows:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.18 & 0.81 & 0.09 \\ 0.00 & 0.01 & 0.99 \end{bmatrix} \begin{bmatrix} r \\ g \\ b \end{bmatrix} \tag{2a}$$

$$\begin{aligned} L^* &= 116\sqrt[3]{y/y_0} \\ a^* &= 500\left[\sqrt[3]{x/x_0} - \sqrt[3]{y/y_0}\right], \\ b^* &= 200\left[\sqrt[3]{y/y_0} - \sqrt[3]{z/z_0}\right] \end{aligned} \tag{2b}$$

where x_0, y_0, z_0 are the coordinates of the white (C illuminant)

NOISE MODELS

Three types of impulse noise are generated to simulate different classes of distortions which may happen to color image:

- Type A noise: Random disturbance of all R,G,B components (independently) with probability p_A= 0.5 and 0.1 and depth L_A= 0.5 and 1.0 :

$$P\left\{\begin{matrix} R' = R(1- L_A) + x_r L_A \\ G' = G(1- L_A) + x_g L_A \\ B' = B(1- L_A) + x_b L_A \end{matrix}\right\} = p_A, \quad P\left\{\begin{matrix} R' = R \\ G' = G \\ B' = B \end{matrix}\right\} = 1 - p_A \quad (3)$$

where P{ · } denotes the probability that the pixel values in the brackets substitute the original values according to the given terms,
and x_r, x_g, x_b are stochastic variables with an uniform distribution over the range (0,1)

- Type B noise: Random simultaneous change of all the R,G,B components with the probability p_B=0.5 and 1.0 and the depth L_B=0.5 and 1.0

$$P\left\{\begin{matrix} R' = RL_B \\ G' = GL_B \\ B' = BL_B \end{matrix}\right\} = p_B, \quad P\left\{\begin{matrix} R' = R \\ G' = G \\ B' = B \end{matrix}\right\} = 1 - p_B \quad (4)$$

- Type C noise: Random change of the saturation (R,G,B crosstalk) with the probability p_C= 0.1, 0.2 and the depth L_C=0.5 and 1.0

$$I = \frac{R+G+B}{3}$$
$$P\left\{\begin{matrix} R' = R(1- L_C) + I \cdot L_C \\ G' = G(1- L_C) + I \cdot L_C \\ B' = B(1- L_C) + I \cdot L_C \end{matrix}\right\} = p_C, \quad P\left\{\begin{matrix} R' = R \\ G' = G \\ B' = B \end{matrix}\right\} = 1 - p_C \quad (5)$$

OBJECTIVE DISTORTION MEASURE

Choice of a good comparison technique is one of the major problems in that kind of experiments which have to find out subtle differences of the method performance. Unfortunately, there is still no standardised method which would be well suitable for the color image quality comparison, i.e., which would well agree with the sensation of the distortion observed by the human beings. In order to avoid the usage of simple pixel-oriented difference measures based directly on the mean-square of the Euclidean distance, we use a more efficient but still pixel-oriented measure based on color differences computed in a perceptually uniform color space.

Our aim is to estimate the performance of the vector median filters applied to images corrupted by a noise, i.e., to determine the attenuation of the noise introduced by the VM. In order to avoid influences due to some distortions introduced by the median operation itself, we compare the corrupted and restored images with filtered original images. The resulting noise attenuation factor is a log ratio of the mean-square differences between original and disturbed image, before and after the filtering:

$$\alpha = 20\log\frac{\sqrt{\sum_n \left|VMED(x_n), VMED(\tilde{x}_n)\right|^2}}{\sqrt{\sum_n \left|x_n, \tilde{x}_n\right|^2}}, \qquad \tilde{x} = x + noise \quad (6)$$

There still exists a problem of the choice of color space in which the difference had to be computed. One should expect that the closer the investigated color space (in which the VM is performed) to the reference (the space, in which the error is computed) is, the better results it gives. That is why the space used for comparison should to be as uniform in the perceptual sense as possible. In opposite to the complicated McAdam space (Wyszecki and Stiles (2)) we decided to use the well known Munsell coordinate system (Munsell (4)) which, while based on human perception tests, gives a very good color difference measure according to the Godlove formula, Godlove (5).

$$\left|x_1, x_2\right| \overset{def}{=} \sqrt{2C_1C_2\left[1-\cos\left|H_1 - H_2\right|\right] + \left|C_1 - C_2\right|^2 + 16\left|V_1 - V_2\right|^2} \quad (7)$$

We used the improved Mathematical Transform of RGB coordinates to the Munsell Color System described recently in Gan et al (6):

$$\begin{bmatrix} x_c \\ y \\ z_c \end{bmatrix} = \begin{bmatrix} 0.620 & 0.178 & 0.204 \\ 0.299 & 0.587 & 0.114 \\ 0.000 & 0.056 & 0.942 \end{bmatrix} \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

$$H_1 = f(x_c) - f(y) \qquad (8a)$$
$$H_2 = f(z_c) - f(y)$$
$$H_3 = f(y)$$
$$\text{where} \quad f(u) = \frac{18.51u}{u + 17.58\left(1 + \frac{5.146u}{u + 30.07}\right)}$$

$$M_1 = H_1$$
$$M_2 = 0.4\,H_2$$
$$S_1 = (8.880 + 0.966\cos\theta)\,M_1$$
$$S_2 = (8.025 + 2.558\cos\theta)\,M_2 \qquad (8b)$$
where $\theta = \arctan\dfrac{M_2}{M_1}$

finally:

$$H = \arctan\frac{S_2}{S_1}$$
$$V = H_3$$
$$C = \sqrt{S_1^2 + S_2^2}$$

SIMULATIONS

Our experiments are undertaken with maximum care about additional errors which could deform the results. Compared are three standard color images ("Lena", "Clown", "Boats"), and a medical microscopic picture of human tissue ("Medic").

The images are not converted into another space and back, because it would cause numerical distortions. The coordinates are computed in a space different from the original RGB only to measure the distance needed for the vector median. A long floating point numerical representation is used for precise computation. The computations are implemented in C language using a Sun Sparc20 workstation.

EXPERIMENTAL RESULTS

The results prove that the performance of a vector median filters depends on the color space used for the vector norm calculations. Moreover they are very different for different impulse noises.

Fig. 1 shows the improvement (difference in α [dB]) due to application of the L*a*b* space over the RGB space. The averaged over the noise intensity results are presented for the noise of Type A and B. The improvement is higher for the noise of Type B as well as for more smooth images (improvement for the test image "Lena" is much better than for "Boats" which contain a lot of very small details like narrow ropes). Nevertheless the opinion score is almost always higher for the L*a*b* filter outputs (even for the noise of Type A). The outputs of the XYZ filters are very close to the outputs of the RGB filters. Similarly the results for the noise C in all the three color spaces are very close one to each other.

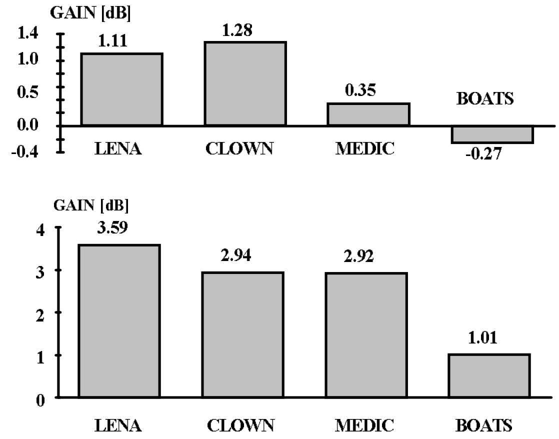

Figure 1: An average improvement resulting from application of the L*a*b* color space instead of the RGB space. The results are averaged over various intensities of the noise of Type A (the upper plot) and Type B (the difference in he lower plot). Gain [dB] is the difference in α as defined above in Eq. 6

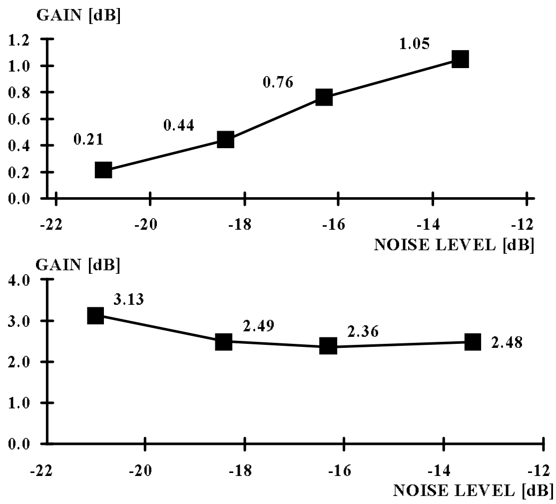

Figure 2: An average improvement resulting from application of the L*a*b* color space instead of the RGB space. The results are averaged over test images and are plotted as a function of SNR in the input degraded image. Gain [dB] is the difference in α as defined above in Eq. 6

The experiments suggest that the differences in performance of vector median filters are relatively small. Nevertheless in some cases proper choice of the color space can bring a substantial improvement. First of all, computations of median filters in the L*a*b* color space lead to reduction degradation which in the case of Type B noise is higher of order of few decibels than in other spaces. Some more detailed report from the experimental results can be found in Bartkowiak (8). It is also noticeable that distortions caused by vector median filters are less perceivable when working in the L*a*b* space than for RGB and XYZ spaces.

CONCLUSIONS

One would expect that like in other noise removing operations, the efficiency of vector median filtering falls down as the noise intensity grows. However, when the noise amplitude is too small, the distortion introduced by VM filtering is greater than disturbance attenuation. Unfortunately, no pixel-oriented error measure can say the truth about the visible noise attenuation, because some kind of "pixel scrambling" performed by vector median, which leads to perceptual indistinguishable local changes, introduces a significant bias to the mean-square. In fact, a sparse, but intensive impulse disturbance is worse in human perception than subtle median blending, while giving better mean-square based SNR.

A small (single dB's), but considerable gain can be seen after introducing a distance measure in the L*a*b* color space within vector median operation. It is easy to notice the difference perceptually. The most spectacular gain in objective measure appears in removing the disturbance which is added to all the RGB components simultaneously.

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