A Vector Median Filter for Color Image Interpolation

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Abstract

This paper presents a new vector median filter in accordance with the characteristic of CIELAB colorspace. This filter fully utilizes the inherent spectral correlations which exist between color planes of CIELAB colorspace to preserve both luminance and chromaticity characteristics of the processed color image. Experimental results show that the method applying the new filter outperforms the traditional interpolation method in the MAE, PSNR and NCD criteria.

1．Introduction

Spatial interpolation of a color image is required for tasks such as zooming, printing and displaying on high resolution display device. Spatial interpolation algorithm affects the final output result directly. Scalar techniques performed on the individual color channels are insufficient since the correlation between the channels of image is not considered producing various spectral artifacts and color shifts [1][2] . Conventional methods such as bilinear interpolation and spline techniques often cause excessive blurring or geometric artifacts [3]. Therefore, the development of the more sophisticated vector based, nonlinear approaches is of paramount importance.

Lang Wen-hui[4] proposed the area-directed interpolation of color image; Hu min[5] presented the method of image zooming based on bivariate vector valued rational interpolation; Lukac[6] proposed the method of image interpolation based on vector median filter, the key is that all of these methods process vector in RGB color space. Since the RGB color space is uneven in vision, the result of interpolate is uneven too. Aiming at these problems, this paper proposes a vector median filter based on in CIELAB color space. This filter utilizes the uniform characteristics of the CIELAB color space and the inherent spectral correlations that exist between channels of the color images fully. Therefore, the interpolation method based on the improved filter can preserve both luminance and chromaticity characteristics of the processed color image, and further increase the interpolation quality.

2. Vector interpolation of color image

Consider a $K1 \times K2$ color image x (RGB or CIELAB colorspace) represent a two-dimensional matrix of three-component samples $x_{(p,q)} = [x_{(p,q)1}, x_{(p,q)2}, x_{(p,q)3}]$. $x_{(p,q)}$ denotes the color vector occupying the spatial location *(p, q)* with the coordinates $p = 1,2,\dots,K1$ and $q = 1,2,\dots,K2$. For $k = 1,2,3$, $x_{(p,q)k}$ represent the k-th elements of $x_{(p,q)}$ with $k = 1$ indicating the first color component, $k = 2$ indicating the second component, and $k = 3$ denoting the third component.

The most popular vector image processing technique operates on some type of sliding window $W_{(p,q)} = \{x_{(i,j)}; i, j \in \varsigma\}$ [1][6], ς is the coordinates set of the pixels in the window W, as shown in figure 1.

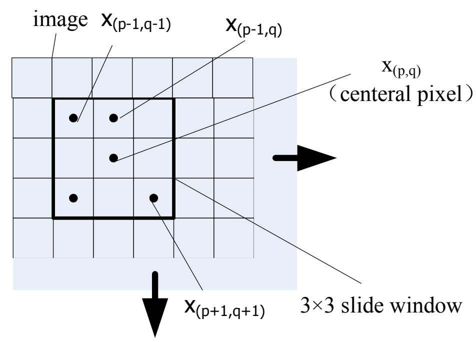


Fig. 1. *supporting window W sliding over the image domain.*

This window operator slides over the image to calculate individually all the new image pixels in the interpolated color image. Consider a 3 × 3 processing window, using function $f(W_{(p,q)})$ representing interpolation on the sliding window, the central pixel of the window can be calculated according the 4 neighbor pixels. The 4 neighbor pixels have two different spatial arrangements, as shown in figure 2.

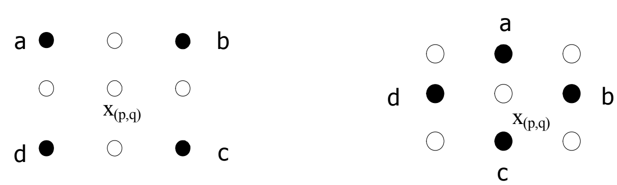


Fig. 2 *Spatial arrangements of available color vectors during the zooming procedure.*

It is not difficult to see that by replacing the interpolation function $f(W_{(p,q)})$, we can get the vector interpolation methods which differ in the design philosophy, characteristics, computational complexity and performance.

Because the interpolation function $f(W_{(p,q)})$ gets output vector according the 4 input vectors, it is called vector filter. Vector median filter is the popular one in image processing [1].

3. Vector median filter based on CIELAB colorspace

3.1 Definition of vector median filter

The median of a set of vectors $\{x_i \mid i=1,2,\dots N\}$ is defined as equation (1)

$$x_m \in \{x_i \mid i = 1, 2, ..., N\} \tag{1}$$

and x_m fulfills equation (2)

$$\sum_{i=1}^{N} \phi(x_m, x_i) \le \sum_{j=1}^{N} \phi(x_i, x_j), i = 1, 2, ..., N \tag{2}$$

where $\phi(x_i, x_j)$ is the filter rule of vector median filter. The common rule includes (considering the three-dimension vector)：

(1) L2 norm of vector

$$\phi_L(x_i, x_j) = \|x_j - x_j\|_2 = \sqrt{\sum_{k=1}^{3}(x_{ik} - x_{jk})^2} \tag{3}$$

(2) angle of vector

$$\phi_\theta(x_i, x_j) = \Delta(x_i, x_j) = \cos^{-1}\left(\frac{x_i.x_j}{|x_i||x_j|}\right) \tag{4}$$

3.2 The improved color image vector median filter

Assuming $\{x_i \mid i = 1, 2, \ldots N\}$ is a set of vector in the CIELAB color space, its 1st component (L of CIELAB) indicates luminance, the 2nd component (A of CIELAB) and the 3rd component (B of CIELAB) indicate chromaticity. In order to preserve chromaticity characteristics of color image, the filter rule of the improved vector median filter is defined as equation (5):

$$\phi_m(x_i, x_j) = \sqrt{(x_{i2} - x_{j2})^2 + (x_{i3} - x_{j3})^2} \tag{5}$$

According filter rule ϕ_m, the median of a set of vectors is defined as equation (6)

$$x_m \in \{x_i \mid i = 1, 2, \ldots, N\} \tag{6}$$

and fulfills equation (7)

$$\sum_{i=1}^{N}\phi_m(x_m, x_i) \le \sum_{j=1}^{N}\phi_m(x_i, x_j), i = 1, 2, \ldots, N \tag{7}$$

The filter rule defined in equation (6) and (7) consider chromaticity information only. In order to preserve luminance information, the average of the first component of all vectors served as the luminance component (1st component) of x_m. Namely,

$$x_m = \begin{bmatrix} x_{m1} \\ x_{m2} \\ x_{m3} \end{bmatrix} = \begin{bmatrix} a \\ x_{m2} \\ x_{m3} \end{bmatrix}, \text{where } a = \frac{\sum_{j=1}^{N} x_{j1}}{N} \tag{8}$$

The improved vector median filter introduced in this section can preserve both luminance information and chromaticity information of color image.

4. Interpolation algorithm based on improved vector median filter

In order to verify the performance of the improved vector median filter, a color image interpolation method based on the filter is designed. In this method, color image is translated from RGB colorspace to CIELAB colorspace first. Then spatial interpolation is completed using the improved vector median filter in the CIELAB color space. Finally, the image is translated from CIELAB color space to RGB color space.

4.1. Translation between CIELAB and RGB

The translation between CIELAB and RGB colorspace needs the help of CIEXYZ colorspace which is used to describe the color quantitatively. The translation between RGB and CIELAB colorspace is defined in equation (9) and (10) [7].

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} a_{1,1} & a_{1,2} & a_{1,3} \\ a_{2,1} & a_{2,2} & a_{2,3} \\ a_{3,1} & a_{3,2} & a_{3,3} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{9}$$

$$\begin{cases} L^* = 116\sqrt[3]{\dfrac{Y}{Y_n}} - 16 \\ a^* = 500\left[\sqrt[3]{\dfrac{X}{X_n}} - \sqrt[3]{\dfrac{Y}{Y_n}}\right] \\ b^* = 200\left[\sqrt[3]{\dfrac{Y}{Y_n}} - \sqrt[3]{\dfrac{Z}{Z_n}}\right] \end{cases} \tag{10}$$

where X_n, Y_n and Z_n is the tristimulus values of the reference stimulus.

4.2. Interpolation algorithm

Based on the colorspace translation equations and the improved vector median filter introduced in the previous sections, we proposed the color image interpolation algorithm.

Step 1. We use equation (9) and (10) to translate color image from RGB color space to CIELAB color space..

Step 2. Given the input pixels a，b，c and d shown in Fig. 2a); we use equation (7) and (8) to calculate the central pixel $x'_{(p,q)}$.

Step 3. The arrangement of the unknown pixels in the image got in step 2 is depicted in Fig. 2b); we use equation (7) and (8) to calculate the central pixel $x'_{(p,q)}$.

Step 4. We use equation (9) and (10) to translate interpolated color image from CIELAB colorspace to RGB colorspace..

5. Experimental Results

To assess the performance of our vector median filter, two color images Lena and Peppers shown in figure 3 are employed. In order to facilitate comparisons, both images have been normalized to the standard 256×256, 8-bit per channel RGB representation.

(a) Lena (b) Peppers

***Figure 3** Color images used to test algorithms.*

Test method is described as below:

First, the 256×256 test image *O* is down-sampled with factor 1/2 to produce the 128×128 image *X*. Then, the image *X* is transformed into 256×256 image *X'* via bilinear interpolation, bicubic interpolation, traditional vector median filter and our improved vector median filter separately. The difference between *O* and *X'* is the result of the zoomer's inaccuracy. This difference is measured using both objective and subjective criteria.

In this paper, the mean absolute error (*MAE*), the peak signal to noise ratio (*PSNR*) and the normalized color-difference (*NCD*) are served as the standards of assessing the performance of algorithm [6].

The *MAE* and *PSNR* criteria are defined as follows:

$$MAE = \frac{1}{3K_1K_2}\sum_{k=1}^{3}\sum_{p=1}^{K_1}\sum_{q=1}^{K_2}\left|o_{(p,q)k} - x'_{(p,q)k}\right| \quad (11)$$

$$PSNR = 10\cdot\log_{10}\frac{3K_1K_2(2^8-1)}{\sum_{k=1}^{3}\sum_{p=1}^{K_1}\sum_{q=1}^{K_2}(o_{(p,q)k} - x'_{(p,q)k})^2} \quad (12)$$

where $K1=K2=256$, $o_{(p,q)} = [o_{(p,q)1}, o_{(p,q)2}, o_{(p,q)3}]$ is the original pixel, $x'_{(p,q)} = [x'_{(p,q)1}, x'_{(p,q)2}, x'_{(p,q)3}]$ is the restored pixel with *(p, q)* denoting a spatial position in a 256×256 color image and k characterizing the color channel.

The NCD criterion is defined as equation (13):

$$NCD = \frac{\sum_{p=1}^{K_1}\sum_{q=1}^{K_2}\sqrt{\sum_{k=1}^{3}(\bar{o}_{(p,q)k} - \bar{x}'_{(p,q)k})^2}}{\sum_{p=1}^{K_1}\sum_{q=1}^{K_2}\sqrt{\sum_{k=1}^{3}(\bar{o}_{(p,q)k})^2}} \quad (13)$$

Where $K1=K2=256$, $\bar{o}_{(p,q)} = [\bar{o}_{(p,q)1}, \bar{o}_{(p,q)2}, \bar{o}_{(p,q)3}]$ and $\bar{x}'_{(p,q)} = [\bar{x}'_{(p,q)1}, \bar{x}'_{(p,q)2}, \bar{x}'_{(p,q)3}]$ are the vectors representing the RGB vectors *o* and *x'*, respectively, in the CIELUV color space.

Table 1 and Table 2 summarize the objective results produced by different algorithms.

Table 1 Objective results corresponding to Lena image

Table 2 Objective results corresponding to Peppers image

Table 1 and table 2 shows that the performance of our algorithm outperforms all other methods in the *MAE*，*PSNR* and *NCD* criteria.

The interpolation results applying the four algorithms to Lena and Peppers are shown in figure 4. The results illustrate that our VMF has better visual effects than the other three methods.

6. Conclusion

This paper proposed a improved vector median filter aiming at the characteristics of CIELAB colorspace, which utilizes the inherent spectral correlations that exist between channels of the CIELAB colorspace fully. The color image interpolation algorithm based on the improved vector median filter processes the color pixels as the set of color vectors, so it preserves both luminance and chromaticity characteristics of the processed color image. Experimental results show that our algorithm outperforms the bilinear interpolation, bicubic interpolation and conventional vector median filter in the *MAE*, *PSNR* and *NCD* criteria, and the visual effect is better than the other three algorithms.

References

[1] R.Lukac, B.Smolka, K.Martin, K.N.Plataniotis, A.N.Venetsanopulos. "Vector filtering for color imaging" [J]. IEEE Signal Processing Magazine; Special Issue on Color Image Processing, January 2005, vol.22:74-86.

[2] R.Lukac, K.N.Plataniotis, D.Hatzinakos. "Color image zooming on the Bayer pattern" [J]. IEEE Transactions on Circuit and Systems for Video Technology, Nov. 2005 , vol.15:1475-1492.

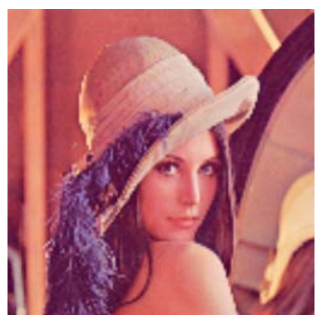
[3] N.Herodotou, A.N.Venetsanopoulos. "Colour image interpolation for high resolution acquisitions and display devices" [J]. IEEE Transaction on Consumer Electronics, November 1995, vol. 41:1118–1126.

[4] Lang Wen-hui1 , Jiang Zhao-hui1 , Zhou He-qin , Feng Huan-qing. "Area-directed Interpolation of Color Image" [J]. ACTA ELECTRON ICA SIN ICA. Vol. 34 No. 1 Jan. 2006, pp.35-38

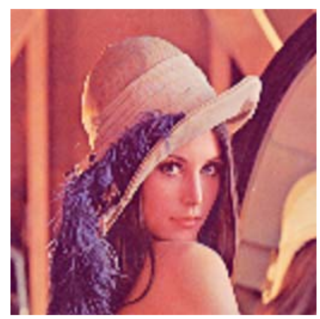
[5] Hu Min Tan J ie-qing Liu Xiao-ping. "Method of Image Zooming Based on Bivariate Vector Valued Rational Interpolation" [J]. JOURNAL OF COMPUTER-AIDED DESIGN & COMPUTER GRAPHICS, Vol.16 , No.11, Nov. , 2004. pp.1496-1500

[6] Lukac, R.Plataniotis, N.Smolka, B.Venetsanopoulos. "Vector Operators for Color Image Zooming" [C]. Industrial Electronics, 2005. ISIE 2005. Proceedings of the IEEE International Symposium, June 2005, vol.3:1273 - 1277

[7] A. Ufuk Agar, Jan P. Allebach,"Model-Based Color Halftoning Using Direct Binary Search" [C]. IEEE TRANSACTIONS ON IMAGE PROCESSING, VOL. 14, NO. 12, DECEMBER 2005, pp. 1945-1959



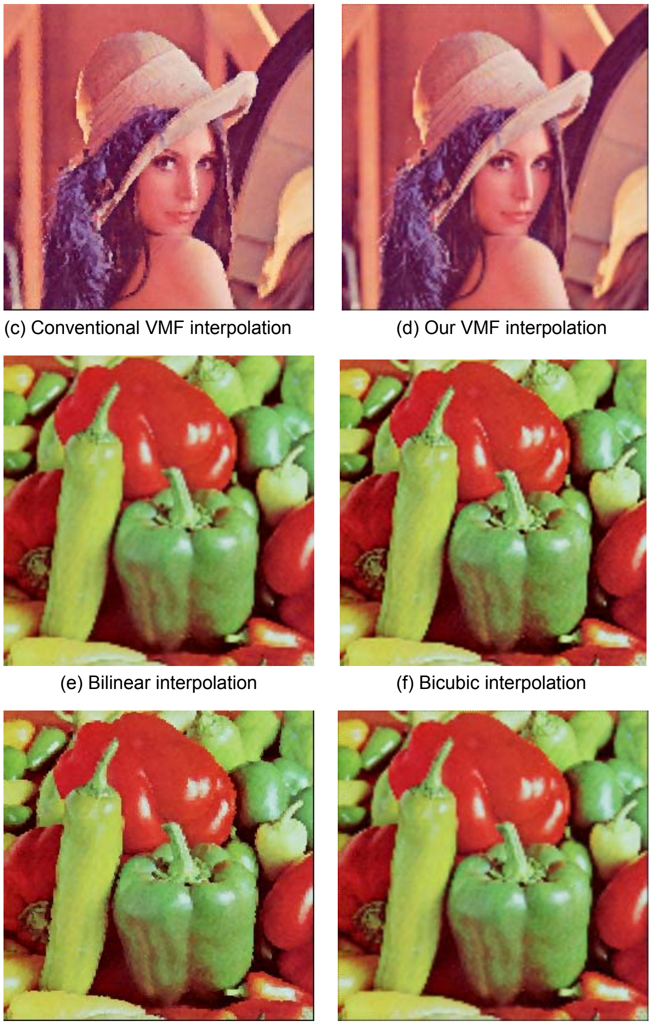
(a) Bilinear interpolation



(b) Bicubic interpolation

	MAE	PSNR	NCD
Our VMF	6.49947	5.93073	0.076641
Conventional VMF	7.09247	5.86484	0.0798664
Bilinear	7.51381	5.89253	0.0875298
Bicubic	7.61785	5.86333	0.0888509

	MAE	PSNR	NCD
Our VMF	6.20188	5.85475	0.0762142
Conventional VMF	7.22694	5.82046	0.0801822
Bilinear	7.4926	5.82224	0.0858006
Bicubic	7.64628	5.79609	0.0882061



(c) Conventional VMF interpolation (d) Our VMF interpolation

(e) Bilinear interpolation (f) Bicubic interpolation

(g) Conventional VMF interpolation (h) Our VMF interpolation

Figure 4. *Interpolation results of color images*

Author Biography

Wan Bo received his BS and MS in Computer Science from Xidian University at 1998 and 2001 respectively .Now he pursues his PhD in Computer Architecture from Xidian University. His work has focused on image process and computer graphics