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Color image sharpening by moment-preserving technique☆

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Abstract

A new approach to sharpening color images using the moment-preserving technique is proposed. An input image is processed pixel by pixel. By preserving some color moments of the $n \times n$ neighborhood of each pixel, analytic formulas are derived to compute two sets of (R, G, B) tristimulus values, and one of them is assigned to the pixel as the sharpening result. Cases with one or more uniform color components in the neighborhood are also treated. The proposed method preserves spatial details, and requires little memory and small computational load. The proposed sharpening operation can also be applied iteratively to the input image to get better sharpening effect. Experimental results show that the proposed approach is effective for color image sharpening.

Zusammenfassung

Es wird ein neuer Ansatz zur Erhöhung der Schärfe von Farbbildern mit einem momentenerhaltenden Verfahren vorgestellt. Aus der Erhaltung gewisser Farbmomente einer $n \times n$ Umgebung jedes Pixels lassen sich analytische Formeln für zwei Mengen von (R, G, B) Wertetripeln herleiten, von denen eines dem Pixel zur Erhöhung der Schärfe zugewiesen wird. Fälle, bei denen eine oder mehrere Farbkomponenten in der Umgebung gleichförmig verteilt sind, werden ebenfalls behandelt. Die vorgestellte Methode erhält räumliche Details und benötigt wenig Speicher und geringe Rechenleistung. Die vorgestellte Bearbeitung zur Erhöhung der Schärfe kann auch iterativ auf das gegebene Bild angewendet werden, um eine bessere Wirkung auf die Schärfe zu erzielen. Experimentelle Ergebnisse zeigen, daß der vorgestellte Ansatz zur Erhöhung der Schärfe von Farbbildern wirkungsvoll eingesetzt werden kann.

Résumé

Une nouvelle approche pour améliorer la netteté des images couleur utilisant la technique de la préservation des moments est proposée. Une image est traitée pixel par pixel. En préservant certains moments de couleur du voisinage $n \times n$ de chaque pixel, des formules analytiques sont developpées pour calculer deux ensembles de valeurs (R, G, B), et l'un d'entre eux est assigné au pixel comme étant le resultat d'augmentation de la netteté. Les cas avec un ou plusieurs composants de couleur uniforme dans le voisinage sont également traités. La méthode proposée préserve les details spatiaux, et réclame peu de memoire et une charge de calcul faible. L'opération d'augmentation de netteté proposée peut

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aussi être appliquée de manière itérative à l'image afin d'obtenir un meilleur contraste. Les résultats expérimentaux montrent que l'approche proposée est efficace pour augmenter la netteté des images couleur.

Keywords: Color image; Image sharpening; Color moment; Moment preserving

1. Introduction

Image sharpening is useful in many image processing applications. Many operators for image sharpening can be found in the literature [7, 8]. The differencing operator and the highpass spatial filter are two common examples [7, 8]. Rowe [9] proposed some nonlinear operators which sharpen image details better than the differencing operator. Chen and Tsai [1] developed another method to sharpen images using the moment-preserving principle. However, these existing methods were proposed for sharpening gray-scale images.

On the other hand, many color image enhancement techniques can be found in literature [7, 10, 11] although they were not proposed directly for the purpose of color image sharpening. Typically, color images are processed in the RGB color space. Several color image enhancement algorithms actually were applied only to the luminance or lightness component. But this approach needs additional time to transform the RGB color values into a desired color space and convert the processing result back to RGB color space again for display.

In this paper, we propose a new approach to sharpening color images based on the moment-preserving principle that has also been applied to some other image processing tasks [5, 6]. The proposed method is directly applied to an observed image in the RGB color space without transforming the image into the luminance-chroma space or the lightness-chroma space. Its effectiveness is verified by experimental results.

In the proposed method, an input image is processed pixel by pixel. Some color moments of the $n \times n$ neighborhood of each pixel are preserved. A set of analytic formulas are obtained accordingly to compute two sets of (R, G, B) tristimulus values. One of the two sets of (R, G, B) tristimulus values is assigned to the pixel to form the desired image. Different techniques are applied to different color conditions in the $n \times n$ neighborhood. Four types of color conditions are identified: 3-spectral, 2-spectral, 1-spectral and uniform (0-spectral). The $n \times n$ neighborhood of a pixel is said to be k-spectral (with $0 \leqslant k \leqslant 3$) if $3 - k$ of the three color components (R, G, B) of the neighborhood pixels are uniform (i.e., if the variations of the values of $3 - k$ color components are very small). For example, the 2-spectral condition means the case of there existing one uniform color component among the R, G and B components in the neighborhood. The minimum Euclidean distance [3] is employed to select the desired set of (R, G, B) tristimulus values for the 3-spectral condition.

For other spectral cases, the method of Lin and Tsai [4] is used to compute suitable values for the two non-uniform color components for the 2-spectral condition, and the method of Tsai [12] is used to select a suitable value for the nonuniform color component for the 1-spectral condition. The mean of the original color component values of the $n \times n$ neighborhood of pixels is used as a substitute for each uniform color plane. The proposed sharpening method can also be applied iteratively to obtain better sharpening effect. Good experimental results show the applicability of the method.

The remainder of this paper is organized as follows. The proposed moment-preserving sharpening method for color images is presented in Section 2. Several experimental results shown to support the feasibility of the proposed method are found in Section 3. Finally, some conclusions are made in Section 4.

2. Proposed color image sharpening by moment-preserving technique

Given an image G to be sharpened and a pixel p in G with (r, g, b) tristimulus values, let F be the $n \times n$ neighborhood of p and p_i be a pixel in F with

(r_i, g_i, b_i) tristimulus values. Suppose that H is the desired sharpened version of F and has only two representative colors, or equivalently, two sets of representative tristimulus values (R_1, G_1, B_1) and (R_2, G_2, B_2). Let p_1 be the fraction of pixels with the (R_1, G_1, B_1) tristimulus values in H, and p_2 the fraction of pixels with the (R_2, G_2, B_2) tristimulus values in H.

The proposed algorithm for color image sharpening by the moment-preserving technique (abbreviated as CISMP) is described as follows.

Algorithm CISMP

Step 1: Read in an $M \times N$ color image G which is to be sharpened.

Step 2: For each pixel p in G perform the following steps:

(a) take the $n \times n$ neighborhood F of p;

(b) compute a set of moments of F;

(c) evaluate the number of uniform spectral bands based on the color variance in F;

(d) decide which method to use to compute the two sets of representative tristimulus values:
0-spectral case: use the means;
1-spectral case: use the technique proposed by Tsai [12];
2-spectral case: use the technique proposed by Lin and Tsai [4];
3-spectral case: use the technique proposed in this paper:
(1) preserve the moments and solve the resulting equations;
(2) resolve the sign ambiguities; and
(3) compute the new tristimulus values for p using the Euclidean distance.

Step 3: Do a few iterations of Steps 1 and 2 if necessary.

Based on the moment preserving methods [2, 6] and our color image processing experience, we select the following set of color moments of F mentioned in Step 2(b) to be preserved:

$$m_r = \frac{1}{N}\sum_i r_i, \quad m_g = \frac{1}{N}\sum_i g_i, \quad m_b = \frac{1}{N}\sum_i b_i,$$

$$m_{r^2} = \frac{1}{N}\sum_i r_i^2, \quad m_{g^2} = \frac{1}{N}\sum_i g_i^2, \quad m_{b^2} = \frac{1}{N}\sum_i b_i^2, \quad (1)$$

$$m_{rgb} = \frac{1}{N}\sum_i r_i g_i b_i,$$

where N is the total number of pixels in F, and m_r, m_g and m_b are the means of the (r, g, b) tristimulus values, respectively, m_{r^2}, m_{g^2} and m_{b^2} are related to the variances of the (r, g, b) tristimulus values, respectively, and m_{rgb} is related to the correlation within the (r, g, b) tristimulus values. Note that this set of color moments has not been proposed before for moment preserving by other investigators.

By preserving the above selected moments of F (the input neighborhood) in H (the desired output) and assuming that the means of the color components in F and H are zeros, we get the following equations:

$$p_1R_1 + p_2R_2 = 0, \quad p_1G_1 + p_2G_2 = 0,$$
$$p_1B_1 + p_2B_2 = 0,$$
$$p_1R_1^2 + p_2R_2^2 = om_{r^2}, \quad p_1G_1^2 + p_2G_2^2 = om_{g^2}, \quad (2)$$
$$p_1B_1^2 + p_2B_2^2 = om_{b^2},$$
$$p_1 + p_2 = 1, \quad p_1R_1G_1B_1 + p_2R_2G_2B_2 = om_{rgb},$$

where $om_{r^2} = m_{r^2} - m_r^2$, $om_{g^2} = m_{g^2} - m_g^2$, $om_{b^2} = m_{b^2} - m_b^2$ and $om_{rgb} = (1/N)\sum_i (r_i - m_r)(g_i - m_g) \times (b_i - m_b)$, and all the terms on the left-hand sides of the equalities are the moments of H and all the terms on the right-hand sides are the corresponding ones of F. By simplifying (2), we can get the following equalities:

$$\frac{p_1}{p_2} = -\frac{R_2}{R_1} = -\frac{G_2}{G_1} = -\frac{B_2}{B_1} = k, \quad (3)$$

$$k \times R_1^2 = om_{r^2}, \quad k \times G_1^2 = om_{g^2}, \quad k \times B_1^2 = om_{b^2}, \quad (4)$$

$$k(1-k)R_1G_1B_1 = om_{rgb}, \quad (5)$$

where $k = \frac{1}{2}c + 1 + \frac{1}{2}\sqrt{c^2 + 4c}$ with $c = om_{rgb}^2 / om_{r^2}om_{g^2}om_{b^2}$. Therefore, the desired values of color components for the 3-spectral case can be solved to be

$$R_1 = \pm\sqrt{\frac{om_{r^2}}{k}}, \quad G_1 = \pm\sqrt{\frac{om_{g^2}}{k}}, \quad B_1 = \pm\sqrt{\frac{om_{b^2}}{k}}. \quad (6)$$

The values of (R_1, G_1, B_1) and (R_2, G_2, B_2) are still undetermined because of the undetermined signs. For example, the formulas do not show whether R_1 is positive or negative. But note that the signs of R_1 and R_2 are opposite, so are the signs of G_1 and G_2, and those of B_1 and B_2. The signs of (R_1, G_1, B_1) and (R_2, G_2, B_2) can be determined by a pixel counting method. The method is described as follows.

Assume $p_1 > p_2$. Then the tristimulus values (R_1, G_1, B_1) must be the representation of the larger group of data. Let

$$r\_count = C_{pr} - C_{nr}, \quad g\_count = C_{pg} - C_{ng},$$

$$b\_count = C_{pb} - C_{nb}, \tag{7}$$

where C_{pr}, C_{pg} and C_{pb} are the number of pixels in F with positive color component values R, G and B, respectively, and C_{nr}, C_{ng} and C_{nb} are the number of pixels in F with negative color component values R, G and B, respectively. Then, the rules for determining the signs are listed as follows:

if $r\_count \geqslant 0$,
  then R_1 is positive and R_2 is negative,
  else R_1 is negative and R_2 is positive;
if $g\_count \geqslant 0$,
  then G_1 is positive and G_2 is negative,
  else G_1 is negative and G_2 is positive; (8)
if $b\_count \geqslant 0$,
  then B_1 is positive and B_2 is negative,
  else B_1 is negative and B_2 is positive.

When one or more than one of r_count, g_count and b_count is close to zero, artificial color will emerge if any of the sign assignments is wrong. In such a case we use three additional counting variables to resolve the ambiguous situations:

$$rg\_count = \begin{cases} rg\_count + 1, & \text{if } r_i * g_i > 0, \\ rg\_count - 1, & \text{if } r_i * g_i < 0, \end{cases}$$

$$gb\_count = \begin{cases} gb\_count + 1, & \text{if } g_i * b_i > 0, \\ gb\_count - 1, & \text{if } g_i * b_i < 0, \end{cases} \tag{9}$$

$$rb\_count = \begin{cases} rb\_count + 1, & \text{if } r_i * b_i > 0, \\ rb\_count - 1, & \text{if } r_i * b_i < 0, \end{cases}$$

where (r_i, g_i, b_i) are the tristimulus values of p_i in F. Initially, rg_count, gb_count and rb_count are set to zero. The final values are found by scanning the pixels in F. These counting variables are related to the information of correlation between the color component values. For example, if rg_count is positive, then R_1 and G_1 should have the same sign; otherwise, they should have opposite signs. The corresponding rules turn out to be:

if $r\_count \geqslant 0$, then R_1 is positive and R_2 is negative,
  else R_1 is negative and R_2 is positive;
if $rg\_count \geqslant 0$, then G_1 is of the same sign as R_1, and
  G_2 is of the same sign as R_2,
  else G_1 is of the opposite sign of R_1,
  and G_2 is of the opposite sign of R_2; (10)
if $rb\_count \geqslant 0$,
  then B_1 is of the same sign as R_1, and
    B_2 is of the same sign as R_2,
  else B_1 is of the opposite sign of R_1, and
    B_2 is of the opposite sign of R_2.

After the signs and values of (R_1, G_1, B_1) and (R_2, G_2, B_2) are computed, the final results of color components are obtained by adding to (R_1, G_1, B_1) and (R_2, G_2, B_2) the original corresponding mean values (recall that we assume previously that the means of the color components in F and H are zeros). That is, the values computed by (6) are modified to be

$$R_1 = \pm\sqrt{\frac{om_{r^2}}{k}} + m_r, \quad G_1 = \pm\sqrt{\frac{om_{g^2}}{k}} + m_g, \tag{11}$$

$$B_1 = \pm\sqrt{\frac{om_{b^2}}{k}} + m_b,$$

where m_r, m_g and m_b are the original mean values defined in (1).

In the previous discussion, nothing is said about the selection of the neighborhood size n. In fact, n determines the sharpening effect. If the blurred objects resemble fine-grained features like thin lines, then n need not be too large. In other words, if a smaller n is chosen, the sharpening result is better. From our experimental experience, we choose the number n to be less than 9.

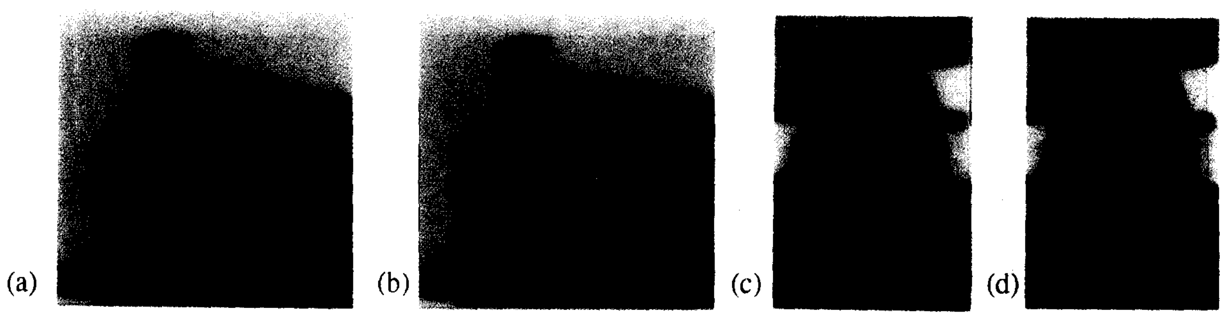
The effectiveness of moment-preserving sharpening for color images is demonstrated with two examples in Fig. 1 with image sizes 256×256 and 340×512, respectively. Fig. 1 includes two test images in (a) and (c), and the corresponding sharpening results in (b) and (d). The above proposed color image sharpening technique is also suitable for any other trichromatic color model. For example, if the YIQ model or the YUV model is preferred, the proposed formulas require no change but only substitutions of variables.

In the above discussions, moment-preserving sharpening for color images is applied to each pixel of an input image for a single time. It is found in this study that if the sharpening operation is applied to the image repetitively, the sharpening effect can be improved. At each iteration step, we use the prior result as the input image. As the number of iterations increases, the sharpening effect is strengthened gradually.

3. Experimental results

The proposed approach has been tested on an IRIS Indigo workstation for several color images. Fig. 2 shows the results of the lady image 'Lena' with neighborhood size $n = 3$. We see that the iterative process indeed can improve the sharpening effect. It is seen that only a few iterations of the proposed method are necessary before the result becomes satisfactory.

Figs. 3–5 show the sharpening results of three images 'house', 'balloon' and 'Lena' with image sizes 256×256, 720×480 and 512×512, respectively. Each figure shown includes a test image in (a) and the sharpening results of iterations 1 and 3 in



1

Fig. 1. Noniterative sharpening results: (a) the input image 'house'; (b) the sharpening result of 'house'; (c) the input image 'lady'; (d) the sharpening result of 'lady' for block size $n = 5$.

2 (a) (b) (c)

Fig. 2. Iterative sharpening results of a lady image 'Lena' with block size $n = 3$: (a) the input image; (b) the result of iteration 1; (c) the result of iteration 3.

3 (a) (b) (c)

Fig. 3. Iterative sharpening results of the house image with block size $n = 3$: (a) the input image; (b) the result of iteration 1; (c) the result of iteration 3.

4 (a) (b) (c)

Fig. 4. Iterative sharpening results of a balloon image with block size $n = 3$: (a) the input image; (b) the result of iteration 1; (c) the result of iteration 3.

5 (a) (b) (c)

Fig. 5. Ineffective iterative sharpening results of the lady image 'Lena' with block size $n = 9$: (a) the input image; (b) the result of iteration 1; (c) the result of iteration 2.

(b) and (c), respectively. Figs. 3 and 4 show the sharpening results of the images 'house' and 'balloon' with neighborhood size $n = 3$, respectively. Fig. 5 depicts the result of the image 'Lena' with neighborhood size $n = 9$. It is seen that for 'Lena' better sharpening results are found in Fig. 2. The reason is that the number $n = 9$ used to produce Fig. 5 is too large.

4. Conclusion

A color image sharpening technique based on the moment-preserving principle has been proposed. The image is processed pixel by pixel. First, the moments of the $n \times n$ neighborhood of each pixel are computed. The number of uniform spectral bands is evaluated according to the color variance of the pixel neighborhood. Different techniques are applied for different spectral cases. Two sets of (R, G, B) tristimulus values are computed accordingly using analytic formulas. One of them is assigned to the pixel as the sharpening result for the 3-spectral case. The proposed method preserves the spatial details in the image content and requires little memory and small computational load. The neighborhood size should not be too large. Better sharpening results can be obtained by applying the proposed method repetitively. The method is applicable not only to the RGB model but also to any other trichromatic model. The experimental results reveal the feasibility and efficiency of the proposed approach.

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