Spatial Gamut Mapping based on Guided Filter

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Abstract

A new spatial gamut mapping algorithm is presented in this paper. The guided filter is used to decompose the original image into a low-frequency band (base layer) which contains only large-scale image-edges and a high-frequency band (detail layer) which contains image-details . The base layer image is processed through a pointwise gamut-mapping algorithm. The gamut mapped based layer image is combined with the enhanced detail layer image. The combination operation can cause some pixel colors that lie near the gamut boundary to be moved outside of the gamut, hence a second gamut mapping step is required to move these pixel colors back into the gamut. The algorithm is designed to reduce the halo-artifacts arising from spatial gamut mapping process. The evaluation experiments indicated that the proposed algorithm is better at image reproduction and detail preservation than pointwise techniques, and has a similar performance to other classical spatial gamut mapping techniques. In addition, the proposed algorithm with the proper guidedfilter parameters can not only have a good gamut mapping result but also reduce the halo-artifacts effectively.

Introduction

Gamut mapping is an important problem in color management, and has been one of the most active areas of color research. The gamut-mapping algorithms can be classified into two basic categories. The first category comprises device dependent algorithms. These algorithms are independent of input image content. And the second category consists of image dependent algorithms. These algorithms are generally expected to perform better than image independent algorithms because they can adapt to image content[1,2,3]. The image dependent algorithm can be classified into pointwise algorithm and spatial algorithm more specifically. Unlike the pointwise algorithms, the spatial gamut mapping algorithms which is the focus of this paper, consists of algorithms that take into account the spatial characteristics in addition to color characteristics of the image. So the spatial algorithm is more consistent with human visual characteristics than pointwise algorithm.

We distinguish two families of spatial algorithms which follow different approaches: the first uses iterative optimization method, the second reinserts high-frequency content in clipped images to compensate for the loss of details caused by clipping. The optimization family includes algorithms proposed by Nakauchi et al. [4], McCann [5], and Kimmel et al. [6]. The second family of spatial algorithms proposes solutions that can be divided in two groups. In the first group of spatial algorithms[7], the original image is gamut mapped in a direction of projection that emphasizes preservation of chroma over luminance. The parts of the original image that were clipped are high-pass filtered and added to the gamut mapped image. The resulting sum is again gamut mapped in a direction of projection that emphasizes preservation of luminance over chroma. Previously conducted psycho-physical evaluations showed that algorithm obtains good scores but suffers from the presence of halos [8]. Recently, Zolliker and Simon proposed to improve the algorithm by using bilateral filtering [9]. In the second group, Meyer and Barth in 1989 [10], Kasson in 1995 [11] and recently Morovic and Wang [12] proposed to first decompose the original image into different frequency bands. The low-pass band is gamut mapped then successive clippings are performed during the reconstruction.

In gamut mapping process, in order to preserve the image detail that maybe lost by image gamut clipping while not reduce the computation efficiency, a new framework for image gamut mapping is proposed based on several classical detail-compensation algorithms. Edge-preservation smooth and halo-artifact elimination are big advantages for guided filter technology. So the guided filter is used to decompose image into different frequency bands by the proposed algorithms. The low-pass band(corresponds to base layer image) is gamut mapped then successive clippings are performed during the combination with the detail layer image .

Description for the algorithm

The principle of guided filter

The guided filtering output at a pixel i of an image is expressed as a weighted average as shown in Eq.(1), where I is guidance image, p and q are input image and output image respectively, i and j are pixel indexes[13]. The filter kernel W_{ij} is a function of the guidance image I and independent of p. Both I and p are given beforehand according to the application, and they can be identical. This filter is linear with respect to p.

$$q_i = \sum_j W_{ij}(I) p_j \tag{1}$$

The key assumption of the guided filter is a local linear model between the guidance I and the filter output q. We assume that q is a linear transform of I in a square window ω_K centered at the pixel k as shown in Eq.(2), where (a_k, b_k) are some linear coefficients assumed to be constant in ω_K. The radius of square window is r. This local linear model ensures that q has an edge only if I has an edge, because $\nabla q = a \nabla I$.

$$q_i = a_k I_i + b_k, \forall i \in \omega_k \tag{2}$$

It can be proven that the kernel weights can be explicitly expressed as shown in Eq.(3), where $|\omega|$ is the number of pixels in window ω_K, μ_K and σ^2_K are the mean and variance of I in ω_K. The criterion of a "flat patch"area or a "high variance" area in an image is given by the parameter ε. The "high variance" corresponds to the edges of image. The patches with variance much than ε smaller are smoothed, whereas those with variance much larger than ε are preserved. The effect of paramet ε in the guided filter is similar as the range variance σ^2_r in the bilateral filter. It determines "what is an edge/a high variance patch that should be preserved." This is the edge-preserving filtering property of the guided filter.

$$W_{ij}(I) = \frac{1}{|\omega|^2} \sum_{k:(i,j)\in\omega_k} \left(1 + \frac{(I_i - \mu_k)(I_j - \mu_k)}{\sigma_k^2 + \varepsilon}\right) \quad (3)$$

He K, Sun J and Tang X[13] empirically set up a “correspondence” between the guided filter and the bilateral filter: r-σ_S and ε-σ^2_r. In this example, the guidance I is identical to the input p.

Framework for the gamut mapping algorithm

The general flowchart of the spatial gamut mapping algorithm is shown in Fig.1. Firstly, the luminance channel(L channel) of the original image in CIELab color space is used as input signal p. Its edge-preserving smoothed output is used as a base layer q (corresponds to image-edges) . And the difference between the input signal and the base layer is the detail layer d = p - q. So the L channel image for the original image can be decomposed into based layer gray image and detail layer gray image by the guided filter. Through a large number of gamut mapping test, the parameters for guided filter are set as shown in Eq.(4), the proposed algorithm do not only have a good image gamut mapping performance, but also can reduce the halo artifact.

$$r = 2, \varepsilon = 0.1\hat{\ }2 \quad (4)$$

After image layering, the detail layer image is enhanced in order to improve the mapped image quality, as shown in Eq.(5). L_detail and L_detail_enchanced are relatively luminance alue before and after enhancement.According to a large number of gamut mapping tests, when the coefficient “n=1.5”, the proposed algorithm can have a good performance. Then the based layer image is obtained by combining the based layer image(L channel) with a,b channels. And it is gamut mapped by HpMinDE(Hue-Preserving Minimum ΔE clipping) pointwise algorithm for the first time. After the first mapping process, the L channel values of the enhanced detail layer image are added to the L channel of based layer image to complete details compensation. Finally, the details compensated image is gamut mapped by the CUSP(a gamut clipping toward the point on lightness axis with the luminance of the cusp) algorithm for the second time.

$$L\_detail\_enhanced = L\_detail \times n, \ n = 1.5; \quad (5)$$

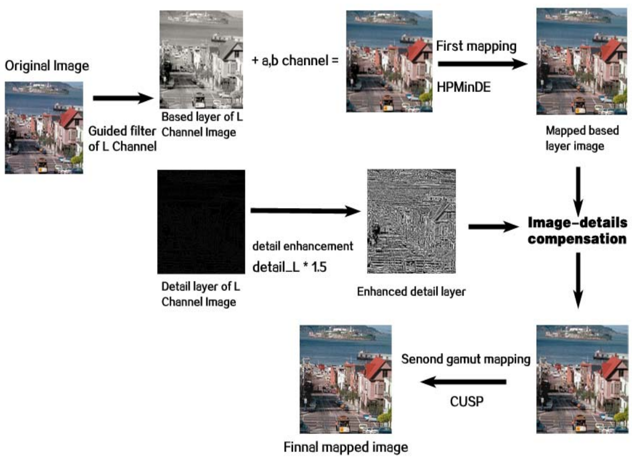

Figure .2. The general flowchart of the algorithm

Assessment for the new algorithm

The proposed spatial gamut mapping algorithm was compared with two standard pointwise gamut clipping algorithms, a pointwise gamut compression algorithm and a classic spatial algorithm, which were: HPMinDE, CUSP_CULP, CUSP_MAP(a gamut compression toward the point on lightness axis with the luminance of the cusp) and Bala’s algorithm[7]. 10 images with different characteristics of color and tone from TID2008 image database(I02, I03, I04, I18, I19, I23) and CSIQ (cactus, sunset_sparrow, trolley, sunsetcolor) database are chosen as test images(Fig.2). The ICC Profile of NEC monitor is used to convert these test images to CIELab color space from RGB color space. All the images were then gamut mapped using 5 different algorithms mentioned above. The destination gamut was the gamut of an HP z3200 printer using HP Standard paper. Segment Maxima Gamut Boundary Descriptor with the parameter “segment number=10” is applied to these gamut mapping algorithms[14].

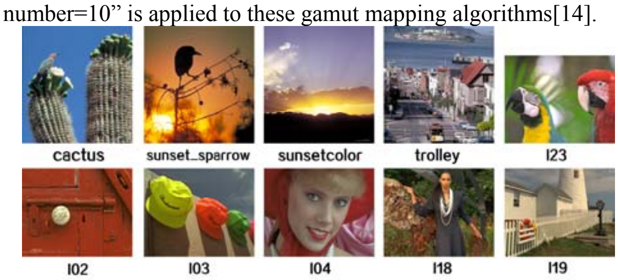

Fig. 2. Thumbnails of experimental images

Psychophysical experiment

The gamut-mapped versions were displayed on the same monitor. 16 observers participated in the paired-comparison experiments. Among these, 10 were experts on color imaging and 6 were nonexperts. All observers reported normal color vision. Two psychophysical experiments were conducted. One used visual preference and the other one used accuracy of reproduction, as the quality criterion. The method of paired-comparison was used in both experiments. In the preference task, the observers were presented with a pair of images corresponding to two gamut-mapping algorithms, and asked to select the most preferred image based on the overall impression on image quality, such as local contrast, colorfulness, image sharpness, and overall natural appearance, etc. In the reproduction task, the original image was presented as a reference, and the observers were asked to select the more accurate reproduction of the reference from a given pair of images.

Fig.3 shows that average preference scores and their 95% confidence intervals of the overall paired comparison evaluations made for the 10 test images. It can be seen that the new algorithm performed significantly better than the three pointwise algorithms and slightly better than Bala’s algorithm. More specifically, the new algorithm and Bala’s algorithm are better at image detail preservation than standard pointwise techniques. It can be seen from the gamut mapping results of local region (marked by red box) of test images “I19” by the four test algorithms and the proposed one, as the Fig.4 shown. Among these three pointwise algorithms, the CUSP_MAP is the best. So it shows that the gamut-compression algorithm is better at image-details preservation than the gamut-clipping algorithm.

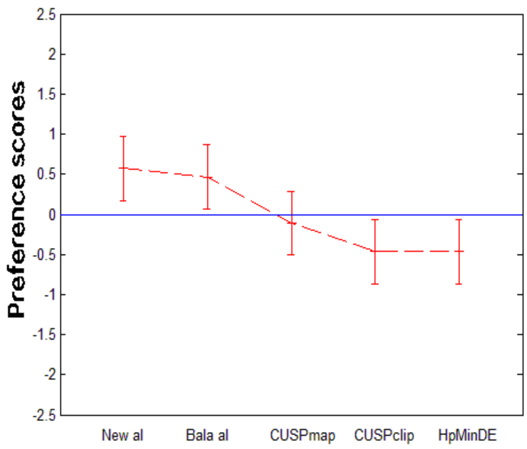

Figure .3. The general flowchart of the algorithm

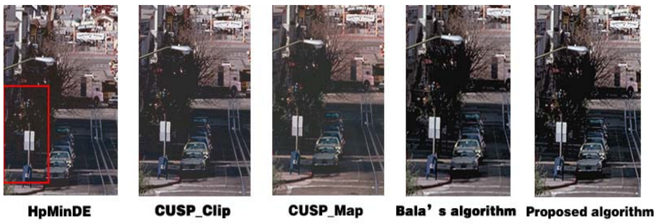

Figure .4. The gamut mapping results of local region of test images "I19"

Fig. 5 shows the average overall accuracy scores for the five algorithms. These results indicate how well the algorithms reproduce the overall appearance of the original image. The overall results show that the proposed algorithm is ranked first, but not better than Bala's algorithm. These two spatial algorithms has significant better performance than the three pointwise algorithms.

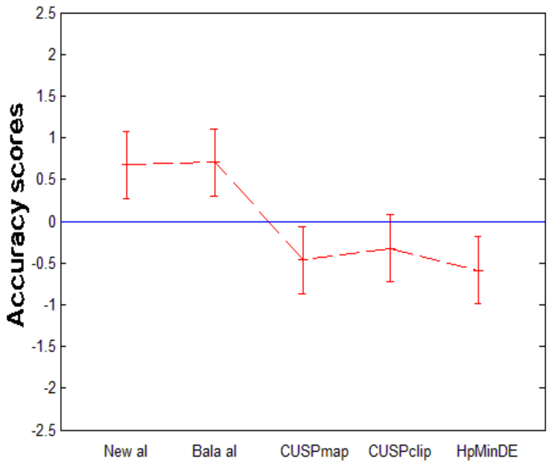

Figure .5. Average overall accuracy scores

Halo-artifact reduction

On the other hand, Bala's algorithm may produce a little bit intensive halo-artifact at sharp edge of two different color patches. In guided filter, the effect of parameter r is similar as the parameter σ_S in the bilateral filter. It is set based on the desired amount of low-pass filtering. So the parameter r controls the width of the halo-artifact. The effect of paramet ε is similar as the range variance σ_S^2 in the bilateral filter. It is set to achieve the desired amount of combination of pixel values. So the parameter ε controls the intensity of the halo-artifact. Fig.6 shows the halo-artifact at sharp edge of two different color patches produced by the proposed algorithm with different guided filter parameters. The lower right corner of the figure is the original test image. The region marked by black cycle is a local area where the halo-artifact is produced. According to Fig.6, we can find that a large r produces a wider halo-artifact, and a large ε produces a much more intensive halo-artifact. So the halo-artifact is the weakest when the r=1 and ε=0.1. But too small r and ε can result in a weak detail layer image. It will affect the final spatial gamut mapping result. So consider the trade-off between the gamut mapping effect and the introduction of halo-artifact, we set r=2 and ε=0.1 in the proposed algorithm. Fig.7 shows the halo-artifacts produced by the two spatial gamut mapping algorithms: Bala's algorithm and the proposed algorithm.

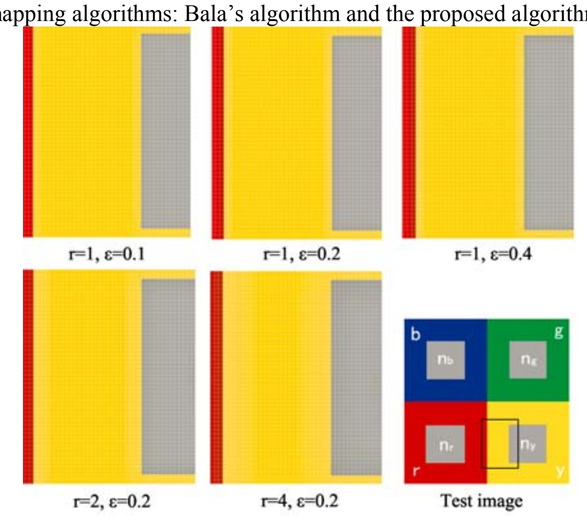

Figure .6. The halo-artifacts at sharp edge of two different color patches

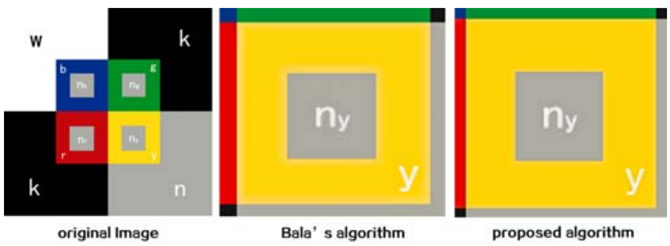

Figure. 7. The halo-artifacts produced by the two spatial algorithms

Computational complexity

We test the running time of three algorithms(HPMinDE, Bala's algorithm, the proposed algorithm) by MATLAB in the same PC. The running time of the three algorithms are shown in Tab.1. Because the pointwise mapping algorithm only do gamut mapping once, so it spends the least running time. Bala's algorithm and the proposed algorithm need to do gamut mapping twice. So the spatial gamut mapping spends more running time than pointwise algorithm. Compared with Bala's algorithm, the proposed algorithm spends only 8-10s more than Bala's algorithm on processing one image on average. So both of them have similar computational complexity.

Tab.1 the running time of three different algorithms (second)

	I02	I03	I04	I18	I19
HPMinDE	39	37	38	36	38
Bala al	72	72	65	68	64
Proposed al	82	81	72	75	72
	I23	sunset_ sparrow	Sunset color	trolley	cactus
HPMinDE	33	46	44	40	37
Bala al	67	104	97	88	88
Proposed al	77	108	102	96	94

Conclusion

In this paper, a framework for image spatial gamut mapping based on guided filter has been introduced. Within this framework, the guided filter is firstly applied to image layering and detail preservation. This is the innovation of this article. Psychophysical experiments indicated that the proposed algorithm is better at image reproduction and detail preservation than standard pointwise techniques, and has a similar performance as other classical spatial gamut mapping techniques. In addition, the proposed algorithm with the proper guidedfilter parameters(r=2 and ε=0.1) can not only have a good gamut mapping result but also effectively reduce the halo-artifacts produced usually by spatial gamut mapping. Compared with pointwise algorithms, the proposed algorithm and Bala's algorithm both have low computational complexity.

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References

[1] G. Braun, "A paradigm for color gamut mapping of pictorial images", Ph. D. Thesis, Rochester Institute of Technology, 1999.

[2] C. Hung-Shing, M. Omamiuda, H. Kotera, "Adaptive gamut mapping method based on image-to-device", in International Conference on Digital Printing Technologies, IS&T, Springfield, pp. 346-349, 1999.

[3] G. J. Braun and M. D. Fairchild, "General-purpose gamut mapping algorithms: Evaluation of contrast-preserving rescaling functions for color gamut mapping", Journal of Imaging Science & Technology, vol. 24, no. 4, pp. 167-172, 2000.

[4] S. Nakauchi, S. Hatanaka, S. Usui, "Color gamutmapping based on a perceptual image difference measure", Color Research and Application, vol. 24, no. 4, pp. 280-290, 1999.

[5] J. J. McCann, "Color gamut mapping using spatial comparisons", in Proc. SPIE 4300, Color Imaging: Device-Independent Color, Color Hardcopy, and Graphic Arts VI, pp. 126-130, 2001.

[6] R. Kimmel, D. Shaked, M. Elad, I. Sobel, "Space dependent color gamut mapping: A variational approach", Proceedings of IEEE Transactions on image processing, vol. 14, no. 6, pp. 796-803, 2005.

[7] R. Balasubramanian, R. deQueiroz, R. Eschbach, "Gamut mapping to preserve spatial luminance variations, in Eighth Color Imaging Conference: Color Science and Engineering Systems, Technologies, Applications", Scottsdale, Arizona, vol. 1, pp. 122-128, 2000.

[8] N.Bonnier, F.Schmitt, H. Brettel, and S.Berche, "Evaluation of spatial gamut mapping algorithms", in 14th IST/SID Color Imaging Conference, Scottsdale, Arizona, vol. 1, pp. 56-61, 2006.

[9] P. Zolliker, K. Simon, "Adding local contrast to global gamut mapping algorithms", in Third European Conference on Colour in Graphics, Imaging, and Vision (CGIV), vol. 1, pp. 257-261, 2006.

[10] J. Meyer, B. Barth, "Color gamut matching for hard copy", SID 89 Digest, p. 8689, 1989.

[11] J. M. Kasson, "Color Image Gamut-Mapping System with Chroma Enhancement at Human-Insensitive Spatial Frequencies". US Patent 5,450,216, 1995.

[12] J. Morovic, Y. Wang, "A multi-resolution, full-colour spatial gamut mapping algorithm", in 11th IST/SID Color Imaging Conference, pp. 282-287, 2003.

[13] He K, Sun J, Tang X, "Guided image filtering", Pattern Analysis and Machine Intelligence, IEEE Transactions on, vol. 35, no. 6, pp. 1397-1409, 2013.

[14] Ján Morovic, Ming Ronnier Luo, "Calculating Medium and Image Gamut Boundaries for Gamut Mapping", Color research and application, vol. 25, no. 6, pp. 394-401, 2000.

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