LETTER

Hue-Preserving Unsharp-Masking for Color Image Enhancement

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SUMMARY We propose an unsharp-masking technique which preserves the hue of colors in images. This method magnifies the contrast of colors and spatially sharpens textures in images. The contrast magnification ratio is adaptively controlled. We show by experiments that this method enhances the color tone of photographs while keeping their perceptual scene depth.

key words: *hue-preserving unsharp-masking, image enhancement, contrast magnification, image sharpening, color tone, scene depth*

1. Introduction

The histogram equalization (HE) or tone mapping (TM) techniques are used for enhancing the contrast in images. These techniques do not preserve the hue of colors, and they have been improved to maintain the hue of colors of every pixel [1], [2]. Unsharp masking (UM) is a technique widely used for sharpening textures in photographs. Various methods of UM for image enhancement are reviewed and compared [3]. The halo artifact of UM in artistic effects has been examined [4]. HE and TM are pixel-wise procedures processing each pixel individually, while UM is a spatial processing. These contrast magnifying and spatially sharpening techniques are often used in combination for enhancing images [5]. UM, however, does not preserve the hue of colors as the same as HE and TM.

The hue of colors is desired to be preserved in the color management of photographs. In this letter, we propose a modified UM which preserves the hue of colors. This proposed UM sharpens textures in images and magnifies the contrast of colors in images. We show by experiments that this method exactly preserves the hue of colors and improves color contrasts in images. In this letter, vectors are denoted with capital letters and scalars are represented by lower-case letters.

2. Unsharp Masking

We denote the color of pixel (i, j) in an input image by $C_{ij} = [r_{ij}, g_{ij}, b_{ij}]$. These stays in the color cube: $C_{ij} \in [0, 255]^3$. The output of the unsharp masking (UM) is expressed by

$$D_{ij} = C_{ij} + \delta(C_{ij} - \tilde{C}_{ij}) \tag{1}$$

Manuscript received August 5, 2014.
Manuscript revised September 9, 2014.
Manuscript publicized September 22, 2014.

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DOI: 10.1587/transinf.2014EDL8159

where $\delta > 0$ and $\tilde{C}_{ij}$ is smoothed C_{ij}:

$$\tilde{C}_{ij} = \sum_{l=-p}^{p} \sum_{m=-p}^{p} w_{ijlm} C_{i+l,j+m} \Big/ \sum_{l=-p}^{p} \sum_{m=-p}^{p} w_{ijlm} \tag{2}$$

where $w_{ijlm} = e^{-\alpha(l^2+m^2)}$ in the Gaussian filter or $w_{ijlm} = e^{-\alpha(l^2+m^2)-\beta\|C_{ij}-C_{i+l,j+m}\|^2}$ in the bilateral filter [6].

An example of UM is shown in Fig. 1 where (a) is an input color image and (b) is a result of UM with the Gaussian filter of $p = 5, \alpha = 0.01$. Fine textures are sharpened, while halos are produced around edges. Scene depth is flattened by strengthened shade.

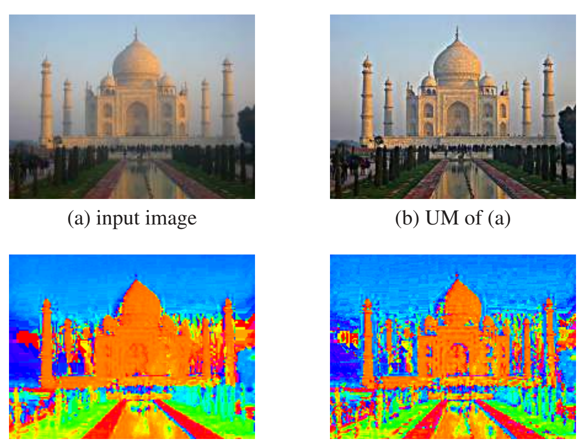
3. Prerequisite for Hue Preservation

This procedure is desired to keep the tone of colors in photographs. For it, the following condition is known:
[hue-preservation condition [1], [2]]
A necessary and sufficient condition for the hue of D_{ij} is equal to that of C_{ij} is that they satisfy the following relation:

$$D_{ij} = x_{ij} C_{ij} + y_{ij} E \tag{3}$$

where E is the unity vector $E = [1, 1, 1]$, x_{ij} is positive while y_{ij} is arbitrary. Note that Eq. (3) is written in a linear form, while coefficients x_{ij} and y_{ij} are possibly functions of C_{ij}, hence Eq. (3) is generally nonlinear with respect to C_{ij}.

The above UM does not satisfy this condition because $\tilde{C}_{ij}$ in Eq. (1) contains the color of neighboring pixels. The hue of Fig. 1 (a) and that of Fig. 1 (b) are shown in Fig. 1 (c)



(a) input image (b) UM of (a)
(c) hue of (a) (d) hue of (b)

Fig. 1 Image sharpening by unsharp masking.

and (d) which is different from (c). In Fig. 1 (c), (d), hue is expressed by color images in HSV model of which saturation is set to its maximum 255, lightness to its half 127.5, and hue is those of Fig. 1 (a), (b).

4. Hue Preserving Unsharp Masking

Equation (3) requires that $\tilde{C}_{ij}$ in Eq. (1) should be achromatic, i.e. monochromatic. Instead of $\tilde{C}_{ij}$, we use $\tilde{L}_{ij} = \tilde{l}_{ij}E$ which is a smoothed image of $L_{ij} = l_{ij}E$ where $l_{ij} = (r_{ij} + g_{ij} + b_{ij})/3$ and E is the unity vector. Our proposed hue-preserving UM (HPUM) is written by

$$D_{ij} = C_{ij} + \delta(C_{ij} - \tilde{L}_{ij}) \tag{4}$$

which is in the form of Eq. (3) with $x_{ij} = 1 + \delta > 0, y_{ij} = -\delta\tilde{l}_{ij}$, hence this HPUM preserves the hue of colors. We use the bilateral filter for smoothing L_{ij} in order to prevent halos around edges.

The value of D_{ij}, however, exceeds the range $[0, 255]^3$ in some cases because the UM enlarge the range of pixel colors. Hence, an additional condition is required as:
[gamut-preservation condition]:
D_{ij} should satisfy $D_{ij} \in [0, 255]^3$.

This condition requires normalization of the range of D_{ij} given by Eq. (4) to $[0, 255]^3$. This normalization should satisfy the above hue-preservation condition and maintain the range of D_{ij} given by Eq. (4) as large as possible. These two requirements lead to the normalization:

$$D'_{ij} = s_{ij}D_{ij} + t_{ij}E \tag{5}$$

where s_{ij} and t_{ij} are
if $u_{ij} - v_{ij} > 255, s_{ij} = 255, t_{ij} = -255v_{ij}/(u_{ij} - v_{ij})$,
if $u_{ij} - v_{ij} \le 255$ and $u_{ij} > 255, s_{ij} = 1, t_{ij} = 255 - u_{ij}$,
if $u_{ij} - v_{ij} \le 255$ and $v_{ij} < 0, s_{ij} = 1, t_{ij} = -v_{ij}$,
otherwise $s_{ij} = 1, t_{ij} = 0$
where u_{ij} is the maximum of RGB components of D_{ij} and v_{ij} is their minimum.

D'_{ij} is the final output of our HPUM. Equation (5) also preserves the hue of D_{ij}, so the hue of colors are preserved throughout the proposed HPUM.

5. Adaptive Control of δ

The coefficient δ manages the magnification ratio of the range of colors. Hence δ should be large at pixels where the color range is small in an input image, while small δ is desirable at pixels of already high contrasts. We vary its value as

$$\delta_{ij} = \max\{f - f(m_{ij} - n_{ij})/e, 0\} \tag{6}$$

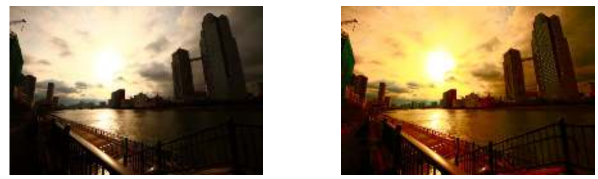
where m_{ij} is the maximum of RGB components of C_{ij} and n_{ij} is their minimum. In the experiments below, we set $e = 100, f = 2$.

6. Experiments

A result of our proposed HPUM for Fig. 1 (a) is shown in Fig. 2 (a). The color tone in Fig. 1 (a) is enhanced while its scene depth is maintained. The hue of colors in Fig. 2 (a) is shown in Fig. 2 (b) which is completely unaltered from Fig. 1 (c). Some applications to image enhancement are shown in Fig. 3 where (a)~(d) are examples of exposure compensation, i.e. brightening of under-exposed photographs and darkening of over-exposed ones, (e)~(h)

(a) HPUM of Fig. 1 (a) (b) hue of (a)

Fig. 2 HPUM of Fig. 1 (a).

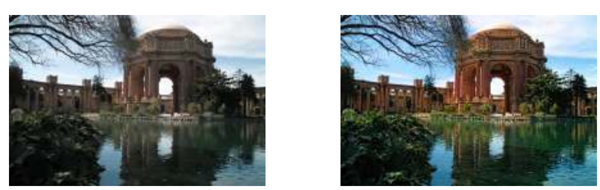


(a) river (b) HPUM of (a)

(c) street (d) HPUM of (c)

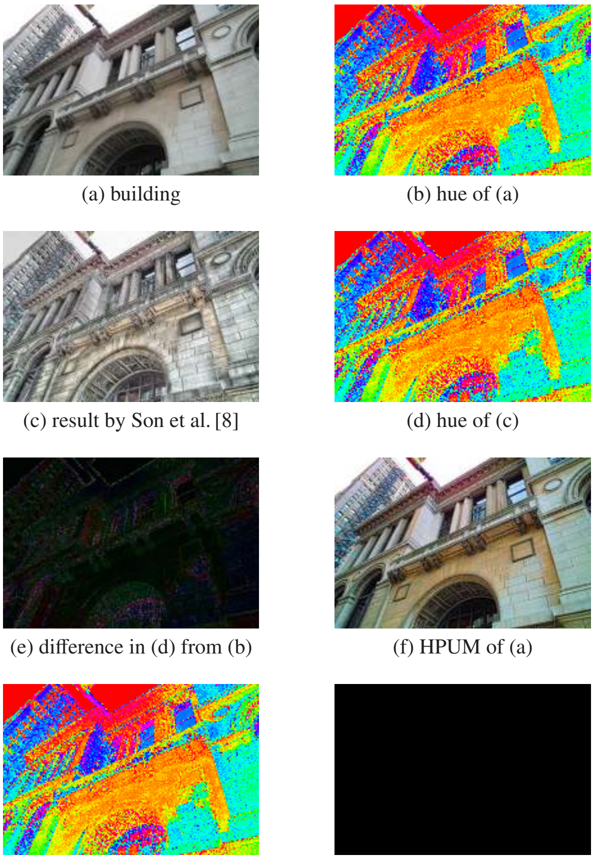
(e) garden (f) HPUM of (e)

(g) palace (h) HPUM of (g)



(i) pond (j) HPUM of (i)

Fig. 3 Exposure compensation, dehazing and artistic tone.



(a) building (b) hue of (a)
(c) result by Son et al. [8] (d) hue of (c)
(e) difference in (d) from (b) (f) HPUM of (a)
(g) hue of (f) (h) difference in (g) from (f)

Fig. 4 Comparison with Son et al.'s method [8].

are examples of dehazing and (i), (j) show transformation of a photograph to artistic color tone. Note that our method cannot create artistic color tone but only boost it potentially existing in the original image. Hence, aesthetic pleasing photographs satisfying composition rules are desirable to be selected as an input photograph for transforming it to artistic images, e.g. by using a photograph ranking system [7].

Finally, comparison with the technique by Son et al. [8] which is a detail enhancing method similar to our HPUM. Example input image in [8] is shown in Fig. 4 (a) of which hue is shown in (b). A result by their method is shown in Fig. 4 (c) of which hue is shown in Fig. 4 (d) which differs from Fig. 4 (b). Difference between Fig. 4 (b) and (d) is shown in Fig. 4 (e). A result by our HPUM is shown in Fig. 4 (f) of which hue is shown in Fig. 4 (g) which is exactly identical with Fig. 4 (b) as is known from Fig. 4 (h). Figure 4(c) seems slightly noisy and the color tone and the scene depth degrades from Fig. 4 (a). Against it, Fig. 4 (f) is more colorful and well keeps 3D depth of buildings.

In our method, colors become too bright in some parts as the bridge in Fig. 3 (b) and the canopy top in Fig. 4 (f). This is due to that δ_{ij} in Eq. (6) depends only on the range $m_{ij} - n_{ij}$. For preventing too bright parts, δ_{ij} should be suppressed at pixels of large m_{ij}.

7. Conclusion

We have presented a hue-preserving unsharp-masking method for magnifying color contrast and sharpening textures in images. The strength of these magnification and sharpening effects is adjusted by parameters e and f. Adaptive control of these parameters and more elaborated control rule are under study.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number 24500208.

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