A HUE-PRESERVING CONTRAST ENHANCEMENT METHOD USING HISTOGRAM SPECIFICATION FOR EACH RGB COMPONENT

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Introduction

Contrast enhancement is commonly applied to low-visibility photographs captured under certain conditions. Generally, for natural images, enhancement processing is applied to the lightness component, and RGB values (RGBs) are adjusted.

Related Methods

Problems

- Histogram equalization (HE) and contrast limited adaptive histogram equalization (CLAHE) tend to cause over-enhancement.
- Contrast enhancement methods that guarantee processing within a specific color space [1, 2] may reduce the vividness and require adjustment of the smoothing parameters for the image being processed.
- Learning-based contrast enhancement methods [3, 4] may fail in hue-preservation and the overall contrast of the processed image may be lost.

Purposes

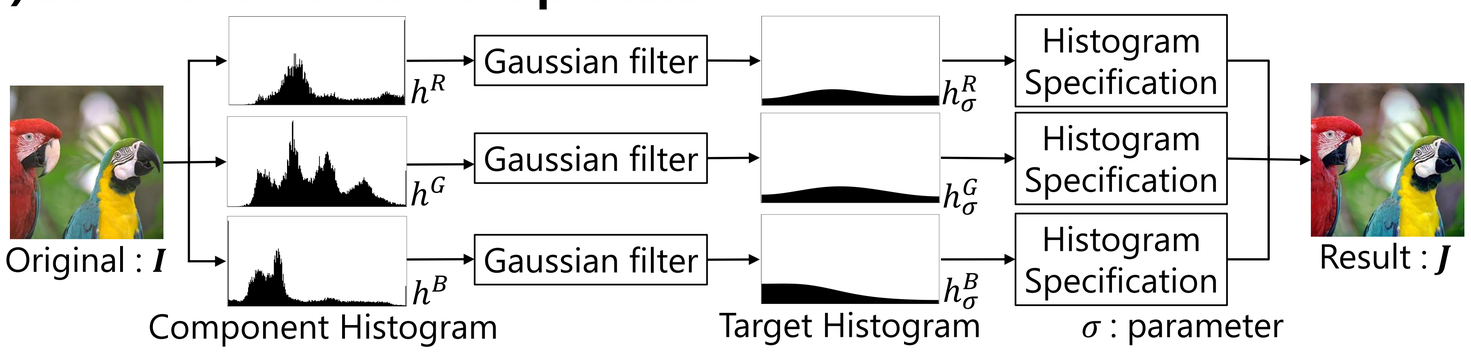
Purposes of our research are (1) to enhance contrast while preserving the hue of the input image, (2) to guarantee the color gamut and (3) to realize chroma adjustment.

Proposed Method

Processing Flow

$\boldsymbol{I}$
↓
(1) Contrast enhancement process
↓
(2) Hue preservation and chroma adjustment
↓
(3) Correction of out-of-gamut pixels on equi-hue plane in RGB color space
↓
$\boldsymbol{O}'$

(1) Contrast enhancement process



(2) Hue preservation and chroma adjustment

$\boldsymbol{J}(i,j)$ is approximated to adjust the chroma while preserving the input image hue as follows:

$$\boldsymbol{O}(i,j) = A(i,j)\boldsymbol{I}(i,j) + B(i,j).$$

$A(i,j)$: scaling parameter
$B(i,j)$: shifting parameter

$A(i,j)$ and $B(i,j)$ are determined by minimizing the following cost function:

$$E(i,j) = \sum_{c\in\{R,G,B\}} \left\{J^c(i,j) - \left(A(i,j)I^c(i,j) + B(i,j)\right)\right\}^2 + \lambda \sum_{(c',c'')\in\Omega} \left\{A(i,j)\left(I^{c'}(i,j) - I^{c''}(i,j)\right)\right\}^2.$$

$\Omega = \{(R,G),(R,B),(G,B)\}$

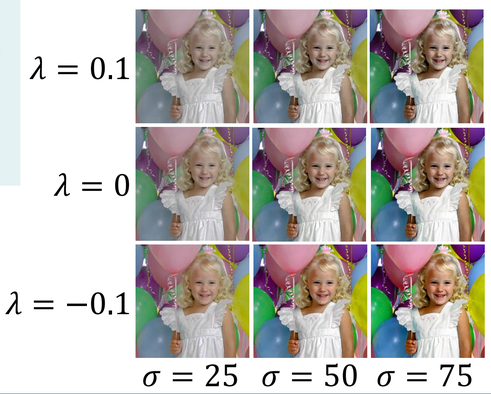
$A(i,j)$ and $B(i,j)$ are obtained using the least-squares method as follows:

$$A(i,j) = \frac{s_{\boldsymbol{IJ}}(i,j)}{\sigma_{\boldsymbol{I}}^2(i,j) + \frac{\lambda}{3}\sum_{(c',c'')\in\Omega}\left(I^{c'}(i,j)I^{c''}(i,j)\right)^2},$$

$$B(i,j) = \bar{J}(i,j) - A(i,j)\bar{I}(i,j).$$

$s_{\boldsymbol{IJ}}(i,j)$: covariance of RGBs of $\boldsymbol{I}(i,j)$ and $\boldsymbol{J}(i,j)$
$\sigma_{\boldsymbol{I}}^2(i,j)$: variance of RGBs of $\boldsymbol{I}(i,j)$
$\bar{I}(i,j), \bar{J}(i,j)$: averages of RGBs of $\boldsymbol{I}(i,j)$ and $\boldsymbol{J}(i,j)$

$\boldsymbol{O}(i,j)$ may be out of gamut.



(3) Correction of out-of-gamut pixels on equi-hue plane in RGB color space

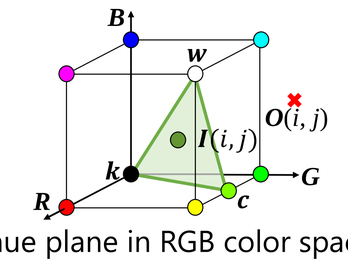
$\boldsymbol{O}(i,j)$ is rearranged to a point on a line on the equi-hue plane, while maintaining the lightness value. Points $\boldsymbol{P}_{\boldsymbol{c},\boldsymbol{w}}$ on $\boldsymbol{c}(i,j)\boldsymbol{w}$ and $\boldsymbol{P}_{\boldsymbol{O},\bar{O}\boldsymbol{e}}$ on $\boldsymbol{O}(i,j)\bar{O}(i,j)\boldsymbol{e}$ are given as follows:

$$\boldsymbol{P}_{\boldsymbol{c},\boldsymbol{w}} = \boldsymbol{c}(i,j) + s\left(\boldsymbol{w} - \boldsymbol{c}(i,j)\right),\ \boldsymbol{P}_{\boldsymbol{O},\bar{O}\boldsymbol{e}} = \boldsymbol{O}(i,j) + t\left(\bar{O}(i,j)\boldsymbol{e} - \boldsymbol{O}(i,j)\right).$$

At intersection $\boldsymbol{P}$, $\boldsymbol{P}_{\boldsymbol{O},\bar{O}\boldsymbol{e}} = \boldsymbol{P}_{\boldsymbol{c},\boldsymbol{w}}$ is satisfied. By calculating the dot(·) and cross(×) products, t and s can be obtained as follows[5]:

$$t = \frac{\left(\left(\boldsymbol{c}(i,j) - \boldsymbol{O}(i,j)\right)\times d_2\right)\cdot(d_1\times d_2)}{(d_1\times d_2)\cdot(d_1\times d_2)},$$

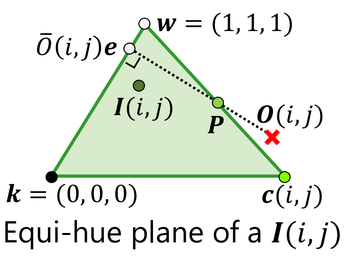
$$s = \frac{\left(\left(\boldsymbol{O}(i,j) - \boldsymbol{c}(i,j)\right)\times d_1\right)\cdot(d_2\times d_1)}{(d_2\times d_1)\cdot(d_2\times d_1)}.$$



Equi-hue plane in RGB color space

The final output value $\boldsymbol{O}'(i,j)$ is calculated as follows:

$$\boldsymbol{O}'(i,j) = \boldsymbol{O}(i,j) + t\left(\bar{O}(i,j)\boldsymbol{e} - \boldsymbol{O}(i,j)\right).$$



Equi-hue plane of a $\boldsymbol{I}(i,j)$

Experimental Results

Parameters(Ours)
$\sigma = 50, \quad \lambda = -0.1$

Quantitative Evaluation (Average of 37 images)

	$L^*(\uparrow)$	$C^*(\uparrow)$	LOE(↓)	Q value(↑)	$\bar{I}(\uparrow)$	$\bar{\sigma}(\uparrow)$
Original	18.61	19.44		3654.41	130.75	28.10
HE(RGB)	28.11	18.62	925.82	6700.59	150.91	44.51
HE(I)	**29.86**	20.36	864.36	7391.30	149.61	49.07
CLAHE(I)	23.81	21.61	2503.09	**7516.91**	148.47	**50.88**
Naik and Murthy	29.59	11.99	868.89	6514.43	141.81	45.85
Ueda et al.	21.70	20.41	**442.53**	4790.37	140.26	34.36
Ni et al.	21.11	24.76	565.30	4457.57	144.19	31.62
Wang et al.	13.19	24.80	1536.45	3095.64	**152.38**	20.41
Ours	23.55	**24.83**	506.03	5417.37	140.42	38.65

Conclusions

We proposed a hue preserving contrast enhancement method that realizes the adjustment of chroma without gamut problem in the RGB color space. Future work is the establishment of a method to determine the values of parameters automatically.

[1]S. K. Naik and C. A. Murthy, "Hue-preserving color image enhancement without gamut problem," *IEEE Trans. Image Process.*, vol. 12, no. 12, p. 1591–1598, Dec. 2003.
[2]Y. Ueda et al., "Hue-preserving color contrast enhancement method without gamut problem by using histogram specification," in *Proc. of 2018 IEEE Int. Conf. Image Process.*, pp. 1123–1127, 2018.
[3]Z. Ni et al., "Towards unsupervised deep image enhancement with generative adversarial network," *IEEE Trans. Image Process.*, vol. 29, pp. 9140–9151, Sept. 2020.
[4]H. Wang, K. Xu, and R. Lau, "Local color distributions prior for image enhancement," in *Proc. Computer Vision-ECCV*, pp.343–359, 2022.
[5]F. Dunn and I. Parberry, *3D Math Primer for Graphics and Game Development*, AK Peters/CRC Press, 2011.

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