Appearance Improvement of Color Image by Adaptive Scale-Gain Retinex Model

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Abstract

Human vision can see the very wide range of luminance scenes with keeping the color constancy. This paper is addressed to improve the image appearance based on Multi-Scale Retinex (***MSR***) model. Two linear ***MSR*** models are presented based on the ***adaptive Scale-Gain*** control for Center/Surround field. The proposed models worked well to compress the dynamic range and to dramatically improve the visibility in shadow areas.

Introduction

The electronic camera can't catch the details in the heavy change of highlight and shadow, while human vision can do. ***Retinex*** model proposed by Land and McCann[1] controls the scene dynamic range automatically not by "pixel-to-pixel" but by ***"spatial-to-pixel"*** process like as human vision. Jobson[2], Rahman[3], Funt[4], and others have advanced the single-scale retinex (***SSR***) into multi-scale retinex (***MSR***) based on the center/ surround (***C/S***) model.

In the basic ***MSR***, the retinex output $R_i(x, y)$ is given by

$$R_i(x,y) = \sum_{m=1}^{M} W_m \cdot log \frac{I_i(x,y)}{\langle G_m(x,y) * I_i(x,y) \rangle}, \quad i = R,G,B \quad (1)$$

$$G_m = Kexp\{-\sigma_m{}^2/(x^2+y^2)\}, \iint G_m dxdy = 1 \quad (2)$$

RGB output is calculated by the weighting sum of ***C/S*** ratio for center pixel ***C***=$I_i(x, y)$ vs surround ***S***=$<G_m * I_i>$. G_m denotes Gaussian averaging filter with ***scale*** m of standard deviation σ_m for surround field and the symbol * denotes convolution. However, the conventional ***MSR*** have the following difficulties in practical use.

- Unstable ***Log*** function (for dark noise or offset level)
- Ambiguous weights and gain factors in multi-scales
- Chromatic unbalance in RGB channel process

To keep the color balance in channels with the positive value in log, for example, the following additional formula was introduced to ***MSR***[8].

$$R_i'(x,y) = R_i(x,y) \cdot log\left(1 + C \frac{I_i(x,y)}{\sum_{i=1}^{3} I_i(x,y)} \right), \quad C = 125 \quad (3)$$

The channel ratio to the sum of R, G, B works to preserve the chromaticity. Jobson et al introduced the clipping process for cutting the long tails and heads in the histogram of $R_i'(x, y)$ with wide spread outputs. They reported the modified ***MSR*** worked nice and stable for many natural images. However it still remains the difficulties in setting the many parameters.

System Concept

Here the adaptive ***scale-gain*** control model for ***C/S*** field is presented by introducing,
[1] Linear ***C/S*** ratio without ***Log***
[2] Use of Luminance Y to keep gray balance
[3] Adaptive ***scale-gain*** control for C/***S*** field
Fig.1 shows the overview of proposed system.
First, the RGB linear input image was converted to luminance-chrominance *YIQ* image and Y was used for convolution.

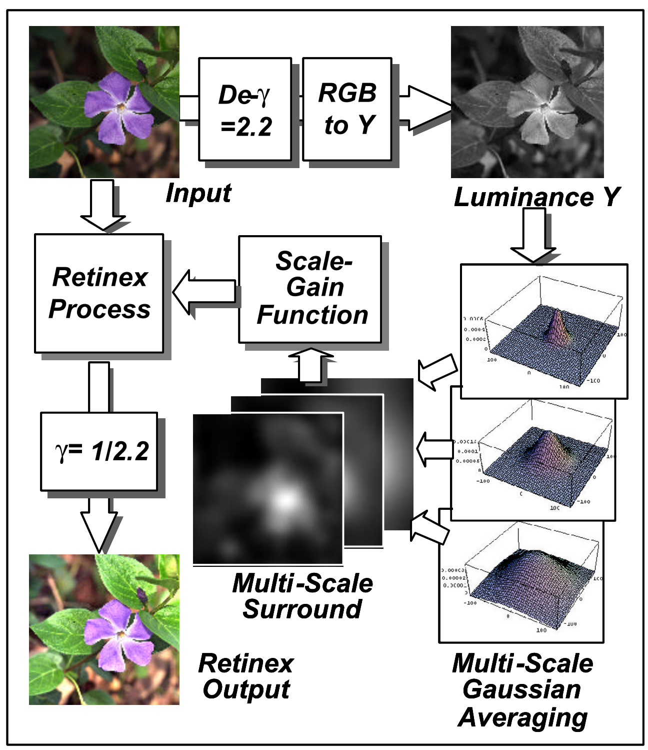

Fig.1 Overview of the proposed adaptive scale-gain ***MSR***

The ***linear SSR*** is simply described by

$$R_i(x,y) = A \cdot \frac{I_i(x,y)}{\langle G_m(x,y) * I_i(x,y) \rangle} \tag{4}$$

Here a gain A should be appropriately determined in relation to the kernel size used for convolution. We approximated the Gaussian field by the $N \times N$ square kernel for the ***scale*** m of standard deviation σ_m by taking $\pm 2\sigma_m$.
As the denominator in Eq. (4) swings larger for the smaller σ_m, the dark areas will be lit up higher. The convolution of Y image with very large kernel gives the mean luminance level of the image and will converge to 0.5, if the Y is random variable. In such case, the maximum **C/*S*** ratio in Eq. (4) is expected to approach to 2. Thus, the gain factor A may be set to ***0.5*** for the largest kernel.
Fig. 2 shows an example of ***linear SSR*** image processed by different σ_m for ***A=0.***5.
As the **C/*S*** ratio in the low luminance surround is amplified, the shadow areas surrounding the daily flower tend to be raised up and become visible. Because the **C/*S*** ratio for the smaller kernel size is estimated to concentrate around unity, the Retinex effect looks to appear near the edges of image. On the contrary, the Retinex output is getting stable for the larger kernel size. Since the image size is small (128 × 128 pixels) in this sample, the maximum kernel size was limited to $N=129$.

(σ=2, M=9) (σ=4, M=17) (σ=8, M=33) (σ=16, M=65)

*Fig.2 **C/S** effect for different kernel size in linear **SSR** model*

Adaptive Scale-Gain MSR Model

In the proposed linear ***MSR*** model, the key point lies in the weighting sum of multi-scale surrounds with variable gain function $A(\sigma_m)$ depending on the image contents.
The proposed model discusses how to compose the linear ***SSR***s in different scales to ***MSR*** in a simple and logical way. The linear adaptive ***scale-gain MSR*** is described by

$$R_i(x,y,\sigma_m) = \sum_{m=1}^{M} 0.5 W_m A(\sigma_m) \left\{ \frac{I_i(x,y)}{S_m(x,y,\sigma_m)} \right\} \tag{5}$$

$$S_m(x,y,\sigma_m) = \langle G_m(x,y) * Y(x,y) \rangle \tag{6}$$

S_m denotes the surround for scale m. The convolution <*> is also taken between $G_m(x, y)$ and common luminance $Y(x, y)$ to keep the color balance. $W_m=1/M$ denotes a constant weight for M different scales and *0.5* means a normal gain.

Type A: Gain Function Based on Surround

Since the swing range of the surround S_m will be related to the maximum and minimum ***C/S*** ratio, we designed the gain function $A(\sigma_m)$ in relation to the min and max surround levels given by

$$S_{min}(m) = \min_{x=1,\,y=1}^{X,Y} \{ S_m(x,y,\sigma_m) \} \tag{7}$$

$$S_{max}(m) = \max_{x=1,\,y=1}^{X,Y} \{ S_m(x,y,\sigma_m) \} \tag{8}$$

Considering these behaviors of the surround, the following types of gain functions were examined.

MinSPG : Min-Surround Proportional Gain

$$A(\sigma_m) = S_{min}(m) / S_{min}(M) \tag{9}$$

MinSPG works to control the gain factor in proportion to the minimum surround level in current scale m normalized by that in maximum scale M.

AveSRG : Average Surround Proportional Reverse Gain

$$A(\sigma_m) = 1 - 0.5\{ S_{min}(m) + S_{max}(m) \} \tag{10}$$

AveSRG works to control the gain in proportion to the reverse of the average of minimum and maximum surround levels in the current scale m.

MaxSRG : Max-Surround Proportional Reverse Gain

$$A(\sigma_m) = 1 - S_{max}(m) \tag{11}$$

MaxSRG works to control the gain in proportion to the reverse of the maximum surround level in current scale m.

The gain factor $A(\sigma_m)$ is limited in the range of 0 to 1 for the ***Type A*** models.

Type B: Gain Function Based on C/S Histogram

Actually, the Retinex outputs are not determined by the min/max surround levels but by ***C/S*** ratio in each pixel. Next we tried to design the gain function based on the ***C/S histogram***. To reduce the computation costs, the C/S histogram was examined only for the luminance Y image. The C/S ratio for Y image is calculated by $Y_{C/S}(x,y,\sigma_m) = Y(x,y)/S_m(x,y,\sigma_m)$ (12)

Fig.3 shows the histogram of for Fig.2. It is shown that the C/S ratio is concentrated around 1.0 for small kernel but tend to spread with the scale m. This means the larger kernel will bring the meaningful Retinex outputs, because the output for C/S=1 doesn't carry any information. Thus, we introduced the standard deviation in the histogram of $Y_{C/S}(x,y,\sigma_m)$ to the weight of Retinex output for each scale m as follows.

$$\Sigma_{C/S}(\sigma_m)=\sqrt{\frac{1}{XY}\sum_{x=1}^{X}\sum_{y}^{Y}\left[Y_{C/S}(x,y,\sigma_m)-Ave\{Y_{C/S}(x,y,\sigma_m)\}\right]^2} \qquad (13)$$

Where, X and Y denote the image size and $Ave\{\}$ means the mean value.

CSHPG: C/S Histogram Proportional Gain

Here we define the ***Type B*** gain function by the normalized weight as follows.

$$A(\sigma_m)=M\left\{\Sigma_{C/S}(\sigma_m)/\sum_{m=1}^{M}\Sigma_{C/S}(\sigma_m)\right\} \qquad (14)$$

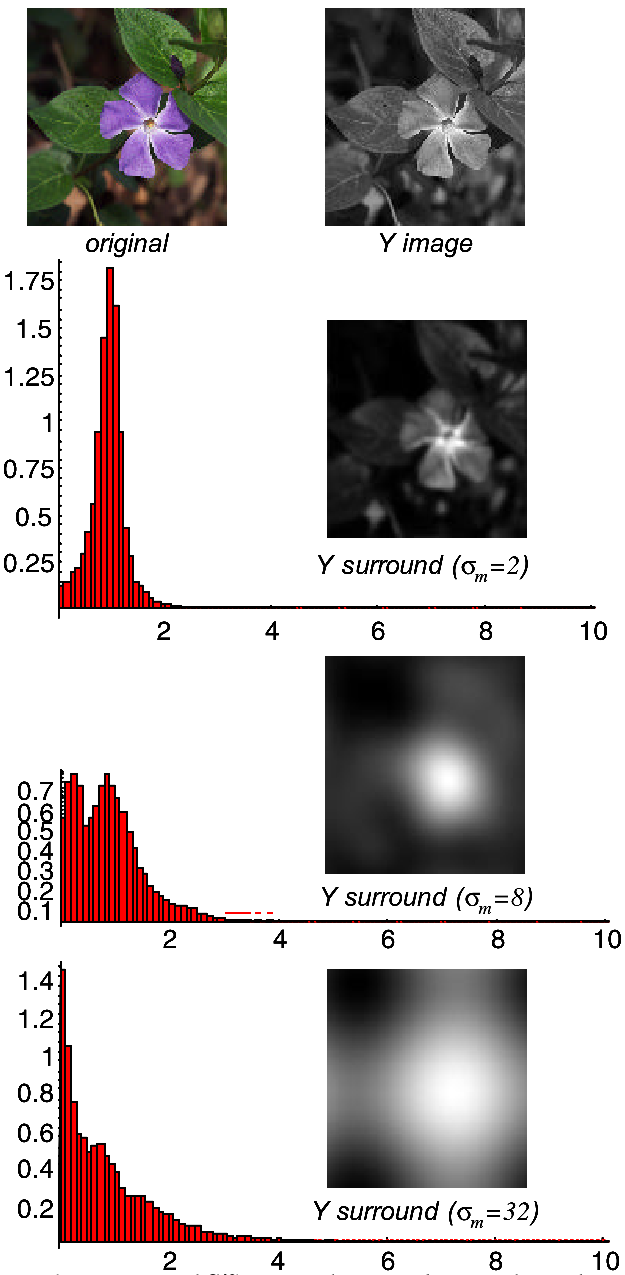

*Fig.3 Histogram of **C/S** ratio and surround images for scale m*

Experimental Results

The proposed ***MSR*** models were compared with the results by Jobson et al opened at the website of ***NASA*** and with the same image processed by ***Frankle and McCann*** model.

Fig.4 shows the changes in ***Type A Gain Function*** $A(\sigma_m)$ adaptive to the scale m for the test ***image22***. These gain curves are ***image-dependent*** but showed monotonously increasing shapes for all the tested images.

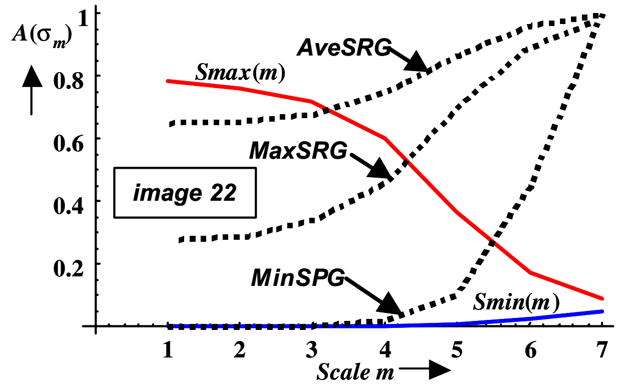

*Fig.4 **Type A** Scale-Gain Function*

Fig.5 shows the changes in ***Type B: CSHPG Gain Function*** given by Eq. (14) for four different test images. All the gain curves were much the same.

Fig.6 arranges a series of surround ***S*** images and ***SSR C/S*** outputs $Y_{C/S}(x,y,\sigma_m)$ in ***CSHPG*** and shows how the ***C/S*** histogram changes with the scale m. Here the seven steps of scale $m=1, 2, \ldots, 7$ were applied to generate ***MSR*** for test ***image 22*** and the data for $\sigma_m=2^m$; *2, 8, 32, 128* (*m=1, 3, 5, 7*) are illustrated in Fig. 6. It is shown that the histogram of ***SSR*** is mostly concentrated around ***C/S***$\cong$*1* for smaller scale m but spans wide range for larger m (take care the graph is limited to ***C/S****=0~2*. As clearly shown in Fig.6 (e), the original Y histogram is distributed in too narrow darker range but automatically expanded in the final ***MSR***. However it includes overflowed highlights as a result for output level to be limited to *1* (see the sharp bar at level *1*).

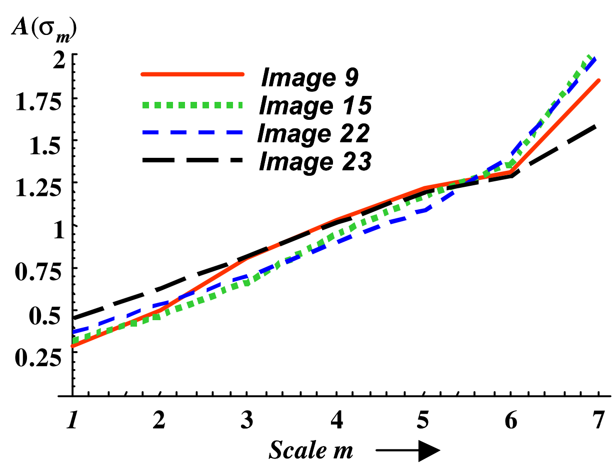

*Fig.5 **Type B:CSHPG** Scale-Gain Function*

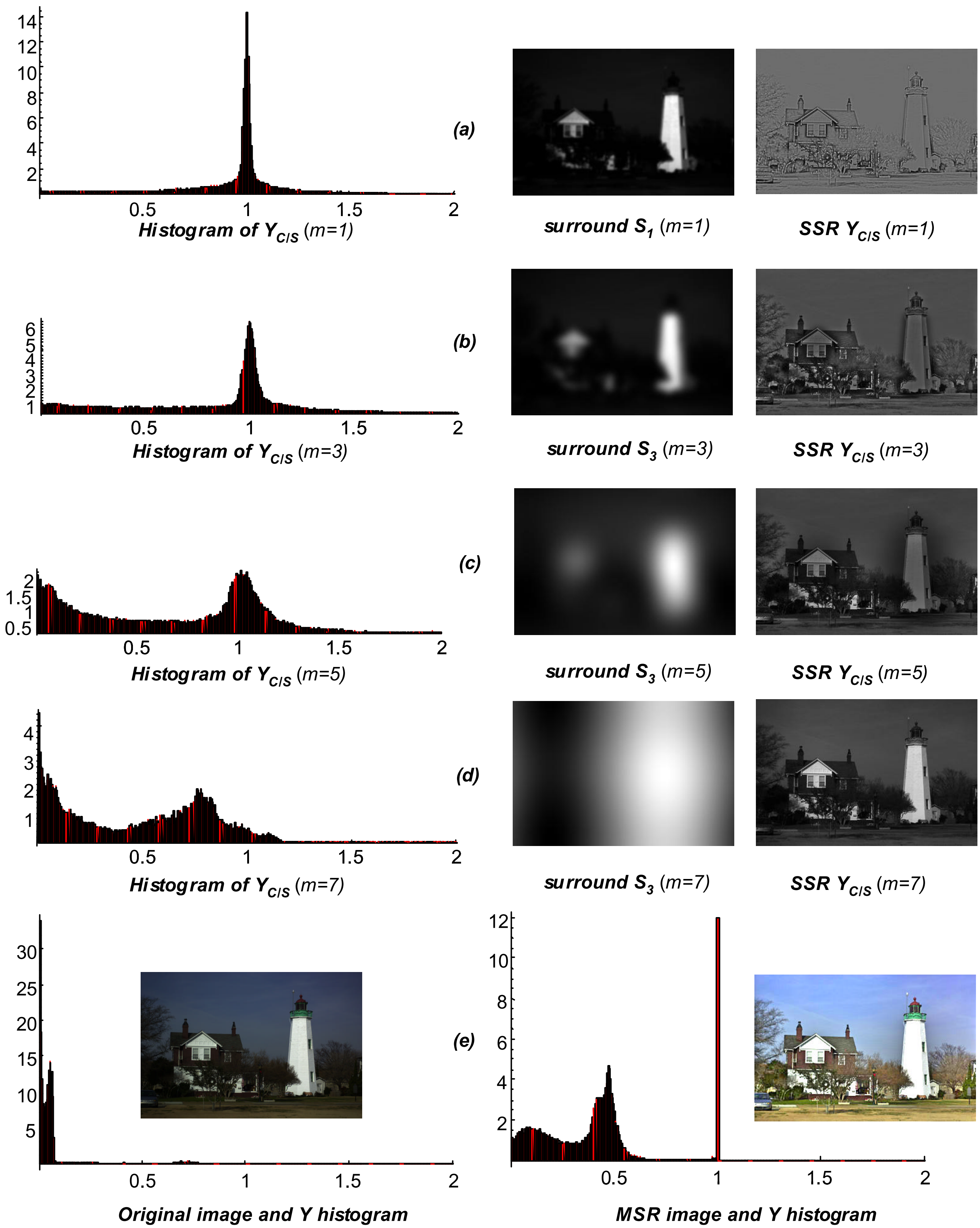

*Fig.6 Multi-scale surround **S** and **C/S** images, and luminance Y histograms in **Type B:CSPG model***

Fig.7, 8, and 9 show the Retinex images processed by the proposed models in comparison with other results. The visibilities in shadow areas in original are dramatically improved for almost all the models. The scene lightness in the proposed models is well controlled corresponding to the each gain function in Fig. 4 or Fig 5 and makes the final output by summing up. Among the results for test ***image 9***, ***NASA*** was best in the sharpness and the contrast. But for the ***image 15***, ***Frankle -McCann*** model gave the best clear image with color constancy just as seen under the white light. While, ***Frankle -McCann*** didn't work well for the ***image 22*** and ***NASA*** reproduced unclear blue sky. In this sample, the ***proposed models*** resulted in the best color reproduction.
Fig. 10 compares our model ***Type B: CSHPG*** with other results for test ***image 23***. In this sample, ***Frankle-McCann*** was insufficient in the dark range enhancement such as green trees or shadowed area of the building. ***NASA*** also resulted in grayish blue sky and earth colors on the road. While the proposed ***CSHPG*** resulted in the best color reproductions for clear blue sky, greenish trees, and natural earth colors.

Discussions

In general, ***NASA*** model seems to give the sharp and clear images but tend to gray world for the large spatial surround areas such as blue sky because of auto white balances for *RGB* separate channels. On the contrary, our models worked nice in color but the over flows may happen in some scales.
The ***AveSRG*** and ***Type B*** models behaved much the same resulting nice in clear blue sky for ***image 22*** and ***23***, although the highlights may be little bit over amplified. ***MinSPG***. was insufficient to enhance the shadow area's lightness. ***MaxSRG*** has an intermediate gain function between ***AveSRG*** and ***MinSPG*** and worked in stable.

Conclusions

The proposed ***Adaptive Scale-Gain MSR*** worked well to improve the visibility in the shadow areas keeping the good color and the scale-adaptive gain functions in both ***Type A*** and ***Type B*** could be automatically determined without any empirical parameter settings. Future works will be continued to regulate the final histogram range for ***MSR*** to suppress the overflows.

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Biography

Hiroaki Kotera received his B.S degree from Nagoya Institute of Technology and Doctorate from University of Tokyo. He joined Matsushita Electric Industrial Co in 1963. Since 1973, he has been working in digital color image processing at Matsushita Research Institute Tokyo, Inc. In 1996, he moved to Chiba University. He is a professor at Dept of Information and Image Sciences. He received Johann Gutenberg prize from SID in 1995 and journal awards from IS&T in 1993, from IIEEJ in 1990 and 2000

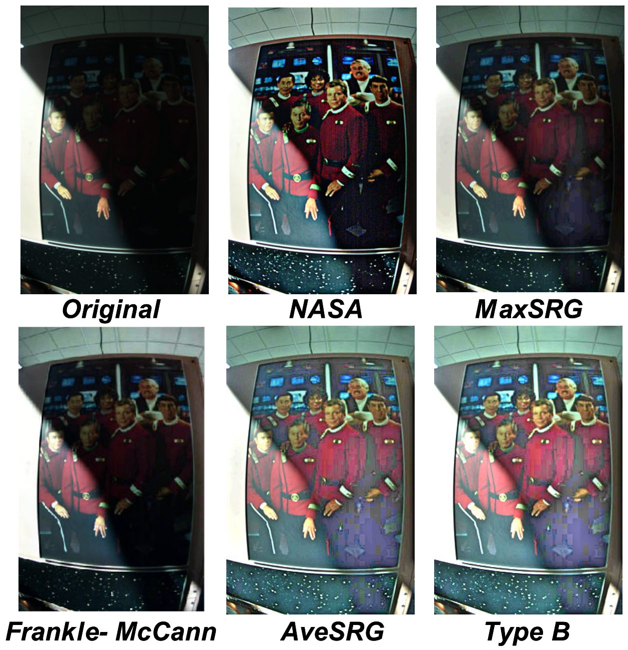

Fig.7 Retinex results for ***image 9***

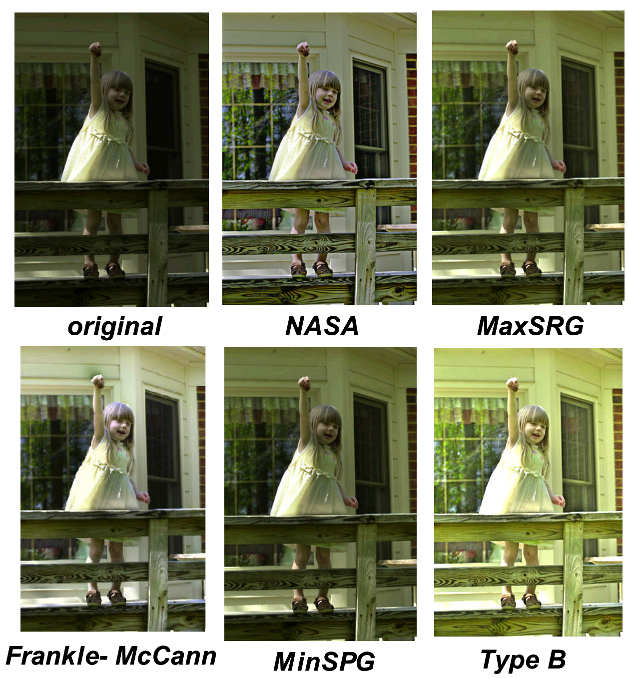

Fig.8 Retinex results for ***image 15***

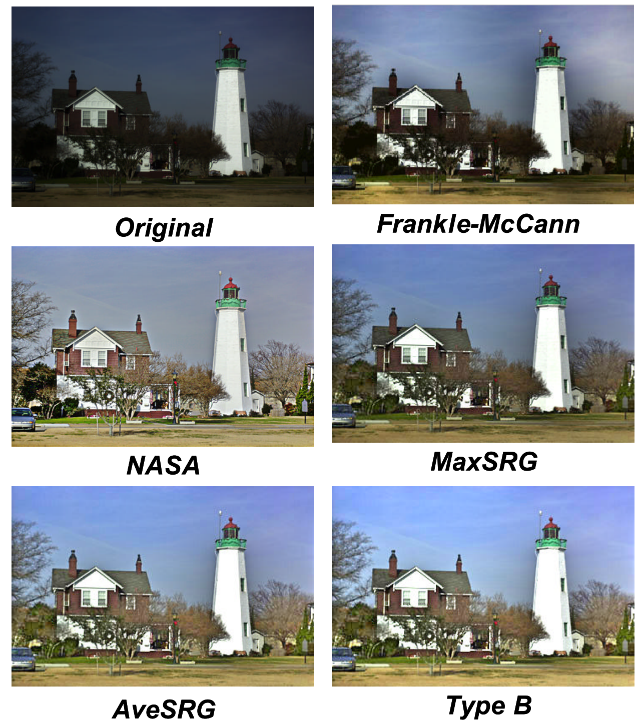

Fig.9 Retinex results for ***image 22***

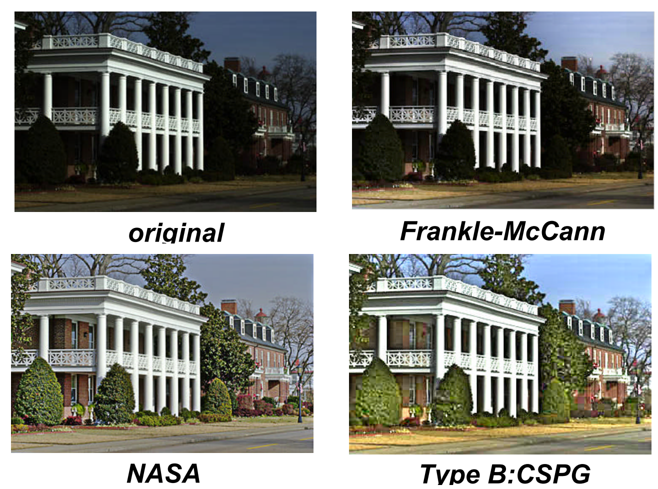

Fig.10 Retinex results for ***image 23***