Restoration of color appearance by combining local adaptations for HDR images

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ABSTRACT

Image colors are often degraded due to saturation or fade-out for the scenes illuminated by colored lightings. This research improves such degradation for high dynamic range (HDR) images that can fully capture the brightness and chroma at high bit-depth. The dynamic range should be compressed to fit that of ordinary color monitors, and color appearance model (CAM) is widely used for authentically reproducing colors in compressions. This model can take the feature of human visual system that can adaptively perceive colors according to the brightness within a local area. This adaptation model, however, is inapplicable to an image including both brightly- and dimly-lit areas. We propose a method of combining such local adaptations for different brightness on a single image. Our method enables unified color restoration for HDR images while retaining the global consistency of brightness variations, and its effectiveness is experimentally demonstrated for the indoor scene illuminated by a color LED.

1. INTRODUCTION

With popularization of color LED lightings, accurately restoring the chromaticness of captured images become important for demonstrating their effectiveness, which may be utilized for lighting design, advertisement, etc. Most of ordinary digital cameras, however, lack the capability in color restoration, owing to the insufficient dynamic ranges of their image sensors.

HDR images can fully capture the scene radiance at high bit-depth, and displaying them on ordinary monitors of lower bit-depth requires compressing their dynamic range. The range compression based on iCAM06 (Kuang 2007) can reproduce the color appearance. Since the scenes including glaring colored light source have very wide dynamic range, iCAM06 cannot sufficiently restore the colorfulness owing to its limited compression rate.

Our previous study (Kubo 2014) divides an input HDR image into the areas of lights and surroundings, for separately compressing their dynamic ranges. It can reproduce the color appearance for each image region whose dynamic range is lower enough for accurate restoration. This approach, however, often causes a contrast inversion along the boundary of areas to which different adaptation parameters are set. This paper therefore proposes the dynamic range compression by introducing a local adaptation of white point with a bilateral filter. This can reproduce the local color appearance of an HDR image on an ordinary low dynamic range (LDR) image, without causing any contrast inversion.

2. DYNAMIC RANGE COMPRESSION

Methods of dynamic range compression are roughly categorized as the following types:

(a) Non-linear function whose global parameter is changed for a whole image, which can retain brightness gradients without causing any contrast inversion

(b) Non-linear function whose parameters are changed for each pixel, which can preserve the details of the scene

(c) Non-linear function based on the color appearance model (Kuang 2007) (Reinhard 2010)

where the last category is most suitable for our target, especially, those based on the iCAM06 model.

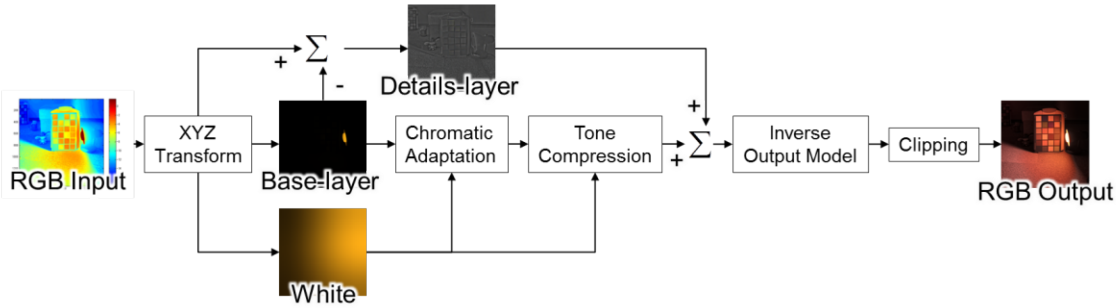


Figure 1: Flowchart of iCAM06.

2.1 iCAM06

Human visual system consists of many non-linear response functions and adaptations for maximizing sensing performance against real world of very wide dynamic range, and many range compression algorithm for HDR image is developed by imitating this functionalities.

The iCAM06 was developed for HDR image rendering by extending iCAM framework (Johnson 2003) that can reproduce the color appearance based on CIECAM02 (Moroney 2002). The CIECAM02 predicts the color appearance attributes from the tristimulus values; this process, however, cannot be suited to compress the dynamic range of the HDR image into LDR one. The iCAM06 introduces an empirical range clipping mechanism by rounding off the values outside the 1th and 99th percentile. Although this clipping is suitable for most of the HDR scenes, color degradation is inevitable for the scenes including very wide dynamic range, e.g. the scene including both dim regions and colored lights, as shown in Figure 2.

Figure 1 shows the flowchart of the iCAM06. The iCAM06 separates the HDR image into the details-layer and the base-layer, and compresses only a wide dynamic range of the base-layer based on the Retinex theory (Rahman 1997) by applying a tone compression. The tone compression consists of cone and rod response functions, which have local adjustments according to an adaptation luminance map. This map is estimated by filtering the input HDR luminance using a Gaussian kernel whose standard deviation is 5 (Kuang 2004).

(a) HDR luminance map (b) iCAM06 (clipped) (c) iCAM06 (normalized)

Figure 2: Range compression for a colored light.

2.2 Effect of iCAM06

Figure 2 shows (a) brightness distribution, (b) the clipped effect of iCAM06, and (c) the normalized effect without clipping, for HDR scene including a colored lighting. Figure 2(b) shows that the colorfulness of the lighting is faded out due to the effect of clipping, whereas it is retained in Figure 2(c). This demonstrates the insufficiency of the range compression rate of iCAM06 for very wide dynamic range scenes.

Figure 3 shows a converted image with iCAM06 and its adaptation luminance, which reveals that the emitted light strongly affects the adaptation white for a whole image. This suggests that restoring the colors of lighting and surrounding areas requires stronger compression of the dynamic range in a separate manner, by using more local adaptation.

3. METHODOLOGY

Our target is to reproduce the color appearance when converting HDR images into LDR ones, which can be attained by more locally changing the adaptation luminance in the iCAM06.

Narrowing the field of view (i.e. decreacing the standard deviation of Gaussian filter) is effective for reducing the chromatic degradation of the lighting area; it, however, causes a halo effect on the boundary against the surrounding and brightens the black colored objects of low reflectance in unnatural ways. For improving these defects, the edge-preserving smoothing operation with a bilateral filter is applied to calculate the local adaptation. This filter is comnputed at the input luminance I of each pixel p as

$$\mathrm{BF}[I_p] = \frac{1}{W_p} \sum_{q \in S} G_{\sigma_s}(\|p-q\|) G_{\sigma_r}(|I_p - I_q|) I_q, \tag{8}$$

$$\mathrm{G}_\sigma(\mathrm{x}) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2}{2\sigma^2}\right), \tag{9}$$

where $\|p-q\|$ denotes the Euclidean distance of pixel coordinates, $|I_p - I_q|$ denotes the luminance difference, and $\mathrm{W_p}$ is the normalization term. Both G_{σ_s} and G_{σ_r} denote the normal distribution function whose standard deviations representing a view field size σ_s and masking effect σ_r are adaptively controlled for avoiding halo effect. We found that a bilateral filter can yield the local adaptation more effectively than that is yielded with a Gaussian filter.

4. EVALUATION

4.1 Experimental setup

We investigated the effects of the dynamic range compression of iCAM06, whose tone compression (Section 2.1) uses our adaptation luminance, for the scenes illuminated by a red LED bulb (CIE xy chromaticity: $x = 0.62$, $y = 0.33$) against various values of σ_s and σ_r.

As a quantitative evaluation, we calculated the differences between reference chromaticity (u_r', v_r') and mean chromaticity (u', v') for each pixel of the output image, where the references are obtained by measuring with a color illuminometer at the following locations:

(A) a white patch of the front chart as shown in Figure 4A.
(B) a white patch of the rear chart as shown in Figure 4B.
(C) the area of the red colored bulb.

The resolution and the range $(\max(\mathrm{I}) - \min(\mathrm{I}))$ of the input image were 2736×1824 and 6.47, and σ_s and σ_r were determined as $\sigma_s = \min(height, width)/s$ and $\sigma_r = (\max(I) - \min(I))/r$, respectively.

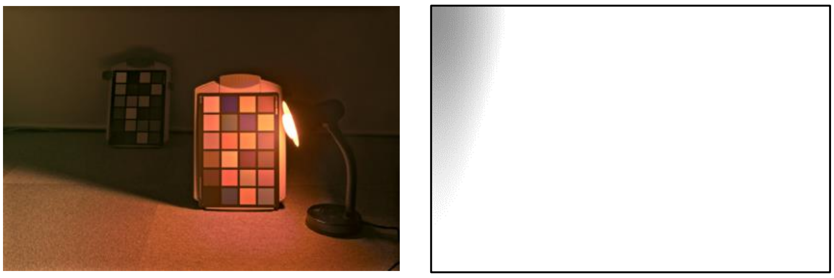


Figure 3: Resulting image with iCAM06 (left) and its clipped adaptation luminance (right).

Figure 4: Experimental environment.

4.2 Observation

Figure 5(a) shows the converted images with our method and Figure 5(b) shows the corresponding adaptation luminances. The results with small σ_s can preserve the color of the red colored bulb but causes the halo effects at the front chart and the bulb and reducing the global contrast. Our method can, however, reduce the halo effects by setting smaller σ_r as shown in the upper row of Figure 5(a). Unfortunately, our mtehod also unnaturally brightens the black colored objects as shown in Figure 5. This negative effect is caused by neglecting the reflectance components for bilateral filtering. We solved this problem by extending the bilateral filter to a cross bilateral filter with a Lighting or Shading map, which is obtained by intrinsic image estimation algorithms.

Figure 6 shows the chromatic differences of our method against the iCAM06, sampled at three areas whose brightness are middle (A), low (B) and high (C). The difference is lower in images restored with our method than those obtained with the iCAM06, where our local adaptation effect is relatively noticeable at the areas (B) and (C). The color reproducibility of the iCAM06 is promoted at the area (A) because the middle brightness area is not affected by clipping or weak range compression.

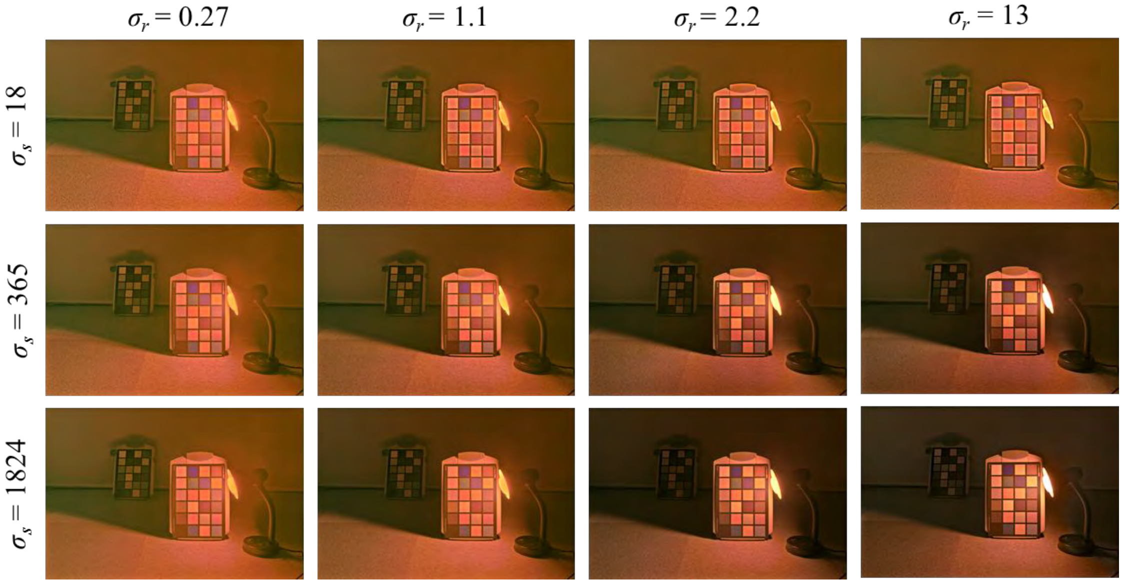
Consequently, we have found that our method can restore local color appearance more accurately by setting σ_s and σ_r by smaller values. These settings, however, decrease a global contrast of the output image, because of the trade-off between the color reproducibility and the global contrast. This paper does not evaluate the chromatic differences for the lower reflectance areas, where (A) and (B) are the higher reflectance areas and (C) is the light bulb area. We should measure the reference chromaticity with a spectral radiance meter at the various reflectance areas for more accurately evaluating the chromatic differences.

5. CONCLUSION

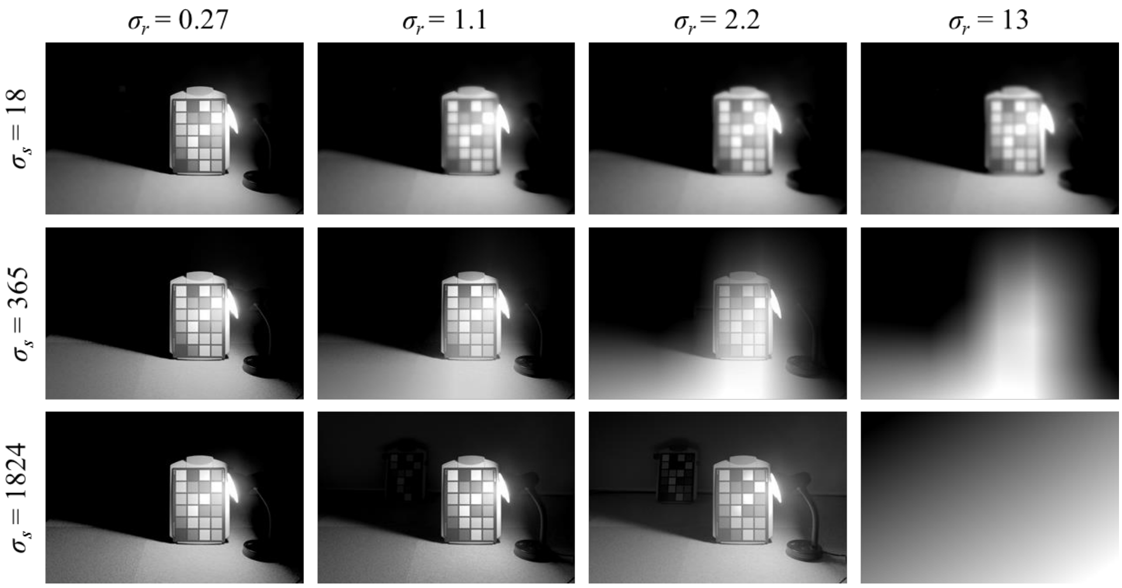
This article has proposed a color restoration scheme for the scenes of very wide dynamic range caused by colored lightings. Our method calculates the local adaptation white more effectively with the bilateral filter, and adaptively utilizes iCAM06 to reproduce the color appearance of HDR images.

We should improve the remapping mechanism for lower reflectance areas by introducing more accurate quantitative evaluation for color reproducibility of various reflectance areas.

It is also challenging task to restore colors for the scenes illuminated by many lightings of different colors. Our future work also includes psychological experiments in actual lighting environments or with various color monitors.



(a) Converted images for various parameters



(b) Adaptation luminance (clipped)

Figure 5: Output images and adaptation luminacnes.

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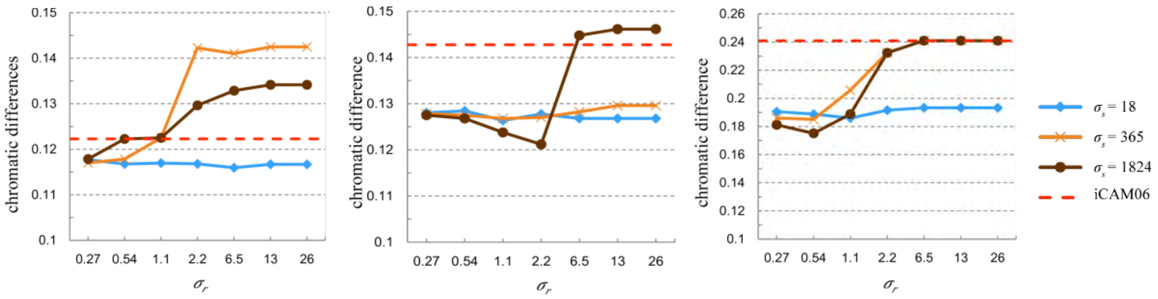
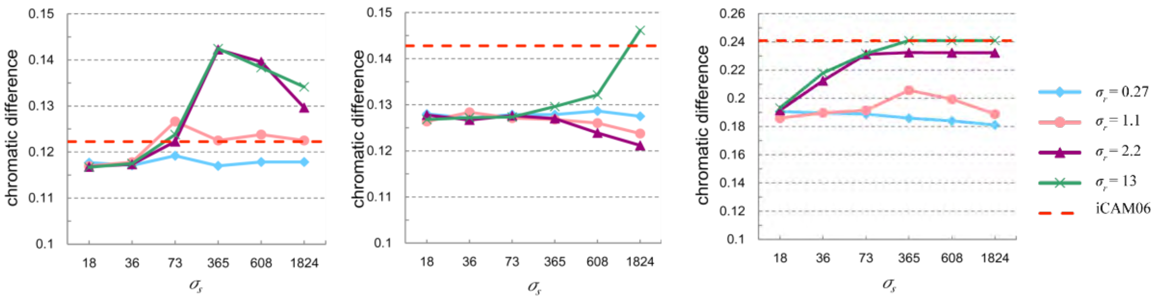


(A) white patch of the front chart

(B) white patch of the rear chart

(C) light bulb

(upper row) chromatic differences when setting the various σ_r against the fixed σ_s



(A) white patch of the front chart

(B) white patch of the rear chart

(C) light bulb

(lower row) chromatic differences when setting the various σ_s against the fixed σ_r

Figure 6: Chromatic difference against measurement.

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