# Highlight-Detection-Based Color Correction Method for Multiview Images

Feng Shao, Gangyi Jiang, Mei Yu, and Yo-Sung Ho

*ABSTRACT—In multiview imaging systems, color correction is adopted to eliminate color inconsistency between views. However, the influence of highlights on color correction has not been considered before. In this letter, a new color correction method based on highlight detection is proposed. The method is designed to treat highlight and highlight-removal regions independently when calculating correction parameters. Finial correction is implemented with a fusion mechanism. Experimental results show that the proposed method can improve objective and subjective correction performance, while achieving better coding performance than other correction methods.*

*Keywords—Color correction, highlight detection, multiview image.*

## I. Introduction

Multiview video is a new type of natural video media which can provide interactive free viewpoint experience [1]. In a multiview imaging system, color inconsistency may occur among views due to various imaging factors, such as geometric inaccuracy, non-Lambertian reflection, and sensor noise. These inconsistency problems degrade the performance of subsequent multiview video coding or virtual view rendering. Therefore, color correction is necessary for multiview imaging systems as a pre-processing step.

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An important issue in color correction is how to acquire accurate correspondence between views. In [2], color correspondence mapping is obtained by detecting scale invariant feature points. In [3], dominant colors are extracted, and correspondence mapping is established between dominant colors. However, the influence of highlights on color correction is neglected in the existing methods. In this letter, we propose a new color correction method based on highlight detection which is capable of suppressing the influence of highlights.

## II. Color Correction Method Based on Highlight Detection

In multiview imaging systems, absolute Lambertian scenes are rare in practice. Specular highlights due to non-Lambertian surfaces make the intensities and the colors of corresponding pixels different among views. In particular, the human visual system is more sensitive to highlights than surface color [4]. Therefore, a significant issue for color correction is how to remove those non-Lambertian features, that is, highlights, and this indicates the necessity of highlight detection.

For a Lambertian model, color image $I_k$ is described as

$$I_k = \int_\lambda E(\lambda)S(\lambda)R_k(\lambda)d\lambda, \quad (1)$$

where $E(\lambda)$ denotes the spectral power distribution of the illumination, $S(\lambda)$ denotes the surface spectral reflectance of the object, and $R_k(\lambda)$ is the spectral sensitivity of the $k$-th camera sensors.

The dichromatic reflection model [5] describes surface reflected light color $I_k$ as a linear combination of diffuse and specular colors:

$$I_k = \rho_{\mathrm{d}}\int_\lambda E(\lambda)S(\lambda)R_k(\lambda)d\lambda + \rho_{\mathrm{s}}\int_\lambda E(\lambda)R_k(\lambda)d\lambda, \quad (2)$$

  

where $\rho_d$ and $\rho_s$ represent coefficients that govern the magnitudes of diffuse and specular reflection, respectively.

Specular reflection forms highlights, and these highlights appear as additional features in a scene which undermine the Lambertian surface assumption in color correction algorithms. Therefore, it is generally beneficial to remove them in calculating the correction parameters. The proposed color correction method includes the following steps.

**Step 1.** Highlight detection is first performed for source and reference views.

**Step 2.** A linear regression operation is used to estimate correction parameters for highlight and highlight-removal regions, respectively.

**Step 3.** Color correction is performed for the source view by fusing the correction parameters from highlight and highlight-removal regions.

A fast highlight detection method is proposed. The highlights of an image are the regions with the highest value of luminance. For the $Y$ component, a mean $\mu_1$ is first calculated, then for all pixels with luminance values larger than $\mu_1$, the corresponding mean $\mu_2$ is calculated. Similarly, for all pixels whose luminance value is larger than $\mu_2$, the mean $\mu_3$ is calculated again. Finally, the pixels with luminance values larger than $\mu_3$ are regarded as highlights; otherwise, they are classified as highlight-removal regions.

A finite dimensional linear model is used to describe the spectral function of illumination and surface reflectance as a linear combination of several basis functions:

$$S(\lambda)=\sum_{j=1}^{n}\sigma_j s_j(\lambda),\quad E(\lambda)=\sum_{j=1}^{m}\varepsilon_j e_j(\lambda), \tag{3}$$

where $m$ and $n$ denote the numbers of basis functions, and $m=n=3$ in this paper. Here, $s_j(\lambda)$ is the $j$-th reflectance basis function, $\sigma_j$ is its weighted coefficient, $e_j(\lambda)$ is the $j$-th basis function for the illuminant, and $\varepsilon_j$ is its weighted coefficient.

Then, under the finite dimensional linear model assumption, a linear regression operation can be used to find a linear relationship for highlight or highlight-removal regions in two views. Let $I_k^S(x, y)$ and $I_k^R(x, y)$ be the $k$-th color components of the source and reference views, and $\mathbf{\Psi}=[I_1^S, I_2^S, I_3^S, 1]^T$, then the linear regression model is described as

$$\{\mathbf{a}_i \mid i=1,2,3\}=\arg\min_{\mathbf{a}_k}\sum_{k=1}^{3}\sum_{(x,y)\in\Omega}\left(I_k^R(x+d_x, y+d_y)-\mathbf{a}_k\mathbf{\Psi}\right)^2, \tag{4}$$

where $\mathbf{a}_k$ denotes the correction vector for the $k$-th color component, $\Omega$ denotes highlight or highlight-removal regions in the source view, and $d_x$ and $d_y$ are the horizontal and vertical disparity vectors from the source view to the reference view, respectively.

Three color correction methods are discussed in this letter. In method 1, a correction vector from highlight regions is directly used for correction of the source view. In method 2, a correction vector from highlight-removal regions is directly used for correction of the source view. In the proposed method, color correction is achieved by fusing the correction vectors from highlight and highlight-removal regions.

In order to eliminate errors arising from the difference between correction vectors, especially at the edges of highlight and highlight-removal regions, a fusion mechanism is proposed. Let $\mu_1$ and $\mu_2$ be means of the highlight and highlight-removal regions in luminance component $Y$, and let $\sigma_1$ and $\sigma_2$ be the corresponding standard variances, respectively. The probability $P_{xy}^i$ that pixel $(x, y)$ belongs to highlight or highlight-removal regions is defined as

$$P_{xy}^i=\frac{e^{-(Y(x,y)-\mu_i)^2/2\sigma_i^2}}{e^{-(Y(x,y)-\mu_1)^2/2\sigma_1^2}+e^{-(Y(x,y)-\mu_2)^2/2\sigma_2^2}}. \tag{5}$$

Here, $i$=1 denotes highlight regions, and $i$=2 denotes highlight-removal regions. Finally, a color correction operation is implemented for the source view to obtain the color-corrected view $I_k^C(x,y)$ by

$$I_k^C(x,y)=\sum_i P_{xy}^i\cdot(\mathbf{a}_k^i\mathbf{\Psi}), \tag{6}$$

where $\mathbf{a}_k^i$ denotes the correction vector for highlight regions ($i$=1) or highlight-removal regions ($i$=2). The proposed algorithm is implemented in $YUV$ space.

## III. Experimental Results

The multiview video, "flamenco1," provided by KDDI Corp. was used as a test sequence. Figures 1(a) and (b) show the reference view and source view at the 570th time instant. Figure 1(c) shows the highlight detection results for the source view, in which white regions denote the detected highlights in the view. Figure 1(d) shows the corrected view obtained with method 1, which destroyed the color consistency in highlight-removal regions. Figure 1(e) shows the corrected view obtained with method 2, which shows obvious color distortion in highlight regions. By contrast, the corrected views obtained with the proposed method, as shown in Fig. 1(f), can eliminate these phenomena.

Average root mean square errors (RMSEs) between matching pixels in the reference and source views are calculated for 50 consecutive frames and compared with the RMSEs of the reference and the corrected views. Figure 2 shows the RMSE comparison results of methods 1 and 2, the proposed method, and the method in [3]. The proposed method clearly can achieve the comparatively lowest RMSE if all regions, including highlight regions and highlight-removal


Fig. 1. Color correction results for flamenco1: (a) reference view, (b) source view, (c) highlight detection result of source view, (d) corrected view with method 1, (e) corrected view with method 2, and (f) corrected view with proposed method.

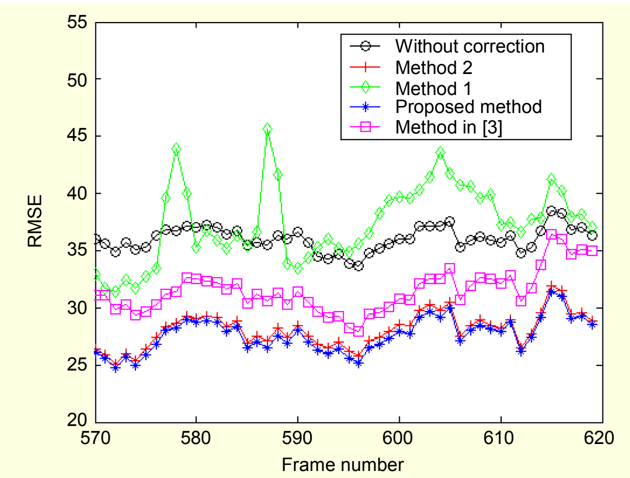


Fig. 2. RMSE comparison results for flamenco1.

regions, are evaluated simultaneously.

We analyzed the average PSNR of the *U* and *V* components to evaluate the coding performance because the coding gains mainly come from these components. Figure 3 gives the rate-distortion curves of the corrected views with 50 consecutive frames encoded by a Joint Multiview Video Model (JMVM). The proposed method can achieve 0.9 dB and 1.5 dB coding gains compared with the method in [3] and method 1,

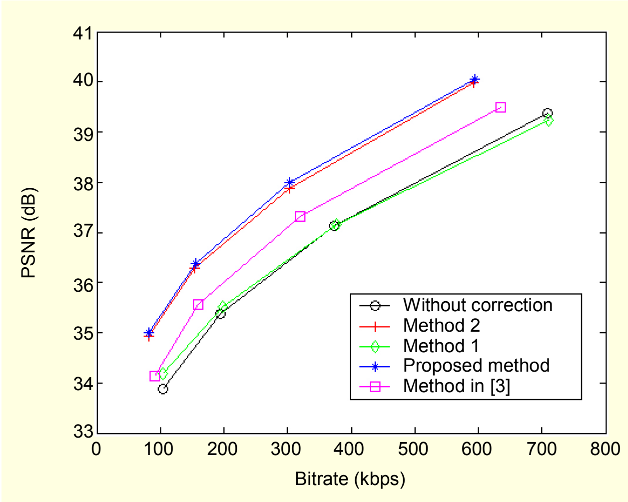


Fig. 3. Comparison results of rate-distortion performance for flamenco1.

respectively, and its performance is almost the same as that of method 2.

## IV. Conclusion

A color correction method based on highlight detection was proposed in this letter. The method treats the highlight and highlight-removal regions independently and implements final color correction by a fusion mechanism. The experimental results confirm that the proposed method offers superior performance compared with that of other methods.

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