A color correction algorithm for noisy multi-view images

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A novel color correction algorithm for noisy multi-view images is presented. The key idea is to use the improved Karhunen-Loeve (K-L) transform to obtain correction matrix that can eliminate noise effect to the fullest extent. Noise variance estimation is first performed in the algorithm. In the end, wavelet transform is applied to denoise the corrected image. Experimental results show that, compared with traditional correction method, a well-performed correction result is achieved using the proposed method, and the visual effect of the denoised corrected image is almost consistent with ideal corrected image.

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In multi-view video systems, scenes are captured simultaneously by multiple cameras from different locations and/or different angles, in which color information is very sensitive to ambient condition of varying illumination. Since the same object may display different colors under different lighting conditions, maintaining the consistence of colors on images with varying viewpoint and lighting conditions has become an important issue in the multi-view video systems. Some color correction methods have been proposed[1−3]. Generally, the corrected image provides a well color agreement with the target image. However, since image noise inevitably interferes in imaging or transmission process, the spectral sensitivity function for different color channels will be changed significantly. Therefore the negative impact of noise on color correction should not be ignored. For sensors with typical three color channels (i.e. R, G and B), color correction is typically implemented with a 3×3 matrix multiplication. Barnhoeffer *et al.* explored the trade-off between the mean color deviation and the amplification of noise[4]. However, for typical color correction, the noise variance does not change significantly since color correction is a pixel-wise operation, but image quality is degraded when there are significant off-diagonal negative elements as the signal strength decreases[5].

In this paper, the influences of noise on color correction are first discussed, and then a novel color correction algorithm is proposed, which can farthest eliminate noise influence. The block diagram of the method is given in Fig. 1. The first operation is optional since the noise statistics of the image sensor (e.g. variance) can be obtained from the data specifications of the image sensor. Even in this case, if color correction is performed after image compression, the noise variance must be computed. Then by computing the correction matrix without noise influence, the corrected image can be obtained. Finally wavelet transform is applied to denoise the corrected image.

Assumed ideal (i.e. non-noisy) color correction is represented by

$$\begin{bmatrix} R_{\text{out}} \\ G_{\text{out}} \\ B_{\text{out}} \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \begin{bmatrix} R_{\text{in}} \\ R_{\text{in}} \\ R_{\text{in}} \end{bmatrix} = \mathbf{M} \begin{bmatrix} R_{\text{in}} \\ G_{\text{in}} \\ B_{\text{in}} \end{bmatrix}. \tag{1}$$

Noisy color correction is represented by

$$\begin{bmatrix} R'_{\text{out}} + N'_R \\ G'_{\text{out}} + N'_G \\ B'_{\text{out}} + N'_B \end{bmatrix} = \begin{bmatrix} m'_{11} & m'_{12} & m'_{12} \\ m'_{21} & m'_{22} & m'_{23} \\ m'_{31} & m'_{32} & m'_{33} \end{bmatrix} \begin{bmatrix} R_{\text{in}} + N_R \\ G_{\text{in}} + N_G \\ B_{\text{in}} + N_B \end{bmatrix}$$

$$= \mathbf{M}' \begin{bmatrix} R_{\text{in}} + N_R \\ G_{\text{in}} + N_G \\ B_{\text{in}} + N_B \end{bmatrix}. \tag{2}$$

Generally, the sum of color error between the ideal value and noisy value should not be very large; otherwise, it will result in significant color distortion. The color error function f is defined by

$$f = E[(R_{\text{out}} - R'_{\text{out}})^2 + (G_{\text{out}} - G'_{\text{out}})^2$$
$$+ (B_{\text{out}} - B'_{\text{out}})^2]. \tag{3}$$

Assume that the three color noises N_R, N_G and N_B are Gaussian white noises with zero means and standard deviations of σ_R, σ_G and σ_B. Further assume that N_R, N_G and N_B are independent of the signals (R, G and B) and of each other. If $f = 0$, matrices of color correction will be consistent for ideal and noisy image, then noise amplification or color distortion problem will be easily solved.

Karhunen-Loeve (K-L) transform is a useful analysis tool in color correction based on the statistical

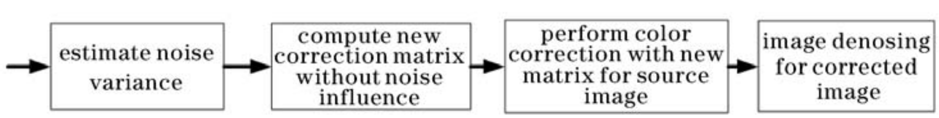

Fig. 1. Block diagram of the new color correction method.

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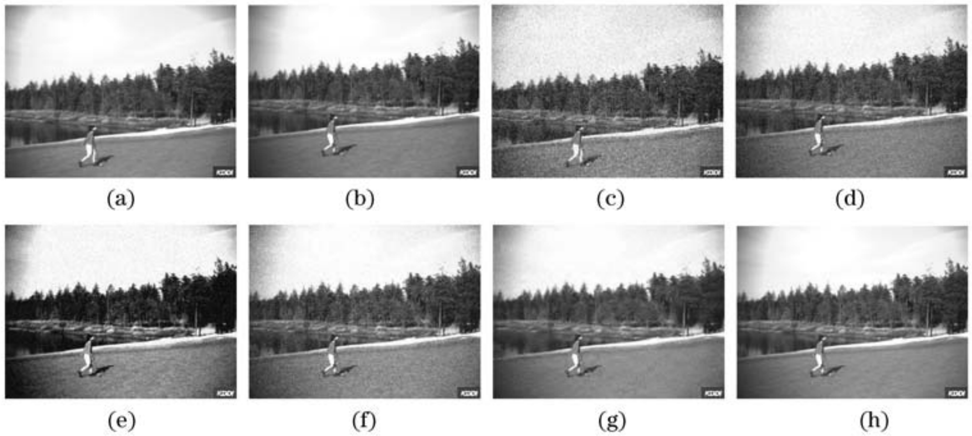

Fig. 2. Correction results for test image golf2. (a) Target image without noise; (b) source image without noise; (c) target image with Gaussian noise; (d) source image with Gaussian noise; (e) noisy corrected image without noise consideration; (f) noisy corrected image with noise consideration; (g) denoised image with the proposed method; (h) ideal corrected image.

Table 1. Comparison of Correction Results

Test Image	golf1		golf2		race1	
	RMSE	Euler	RMSE	Euler	RMSE	Euler
Traditional Correction	41.90	0.049	56.28	0.046	49.04	0.068
The Proposed Method	27.36	0.031	27.93	0.018	25.91	0.038

representation of color vector to reduce cross-correlation between the color channels. Let $\mathbf{X} = [R_{\rm in}, G_{\rm in}, B_{\rm in}]^{\rm T}$ and $\mathbf{X}' = [R_{\rm in}+N_R, G_{\rm in}+N_G, B_{\rm in}+N_B]^{\rm T}$ be ideal and noisy color vectors, respectively, and $\boldsymbol{\mu}$ be the mean vector, then covariance matrices are given by

$$\mathbf{C}_x = E[(\mathbf{X}-\boldsymbol{\mu})(\mathbf{X}-\boldsymbol{\mu})^{\rm T}]$$
$$\text{and} \quad \mathbf{C}'_x = E[(\mathbf{X}'-\boldsymbol{\mu})(\mathbf{X}'-\boldsymbol{\mu})^{\rm T}]. \tag{4}$$

There exists a certain relation between $\mathbf{C}_x$ and $\mathbf{C}'_x$, $\mathbf{C}'_x - \mathbf{C}_x = \mathbf{N}_x$. Here

$$\mathbf{N}_x = \begin{bmatrix} \sigma_R^2 & 0 & 0 \\ 0 & \sigma_G^2 & 0 \\ 0 & 0 & \sigma_B^2 \end{bmatrix}. \tag{5}$$

Therefore, ideal covariance matrix $\mathbf{C}_x$ can be easily obtained by subtracting the noise matrix $\mathbf{N}_x$ from noisy covariance matrix $\mathbf{C}'_x$. Uniform operations are performed for source image and target image, respectively. Then by computing eigenvalue and eigenvector of covariance matrix, correction matrix $\mathbf{M}$ can be easily obtained. Thus, the correction matrix will not be affected by noise.

Because noise variance must be known in advance during correction matrix calculation, noise variance estimation is a pivotal step in the algorithm. The method in Ref. [6] is used in our algorithm. Firstly, the noisy image is filtered by a horizontal and a vertical difference operator to suppress the influence of the original image. Then a histogram of local signal variances is computed. Finally a statistical evaluation of the histogram provides the desired estimation value.

However, for noisy corrected image, denoising is essential for better display or vision impression. Dual tree complex wavelet transform (DT-CWT) is used in our algorithm[7], which is a multilevel transform that has 6 directional subbands per level. The noisy input image is first transformed to compress the image energy into as few coefficients as possible, leaving the noise well distributed. Then suppress lower energy coefficients which are most probably to be noise by thresholding denoising method. In the experiments, hard thresholding is used through experiential selection.

Figure 2 shows the experimental results for multi-view test images 'golf2', provided by KDDI Corp.. Figures 2(a) and (b) show the target image and source image without noise. Figures 2(c) and (d) show the noisy target image and source image with Gaussian noise. Figure 2(e) is the traditional corrected image without noise consideration. Figure 2(f) is the noisy corrected image with the proposed method. Figure 2(g) shows the final denoised image with the proposed method, the vision impression of which is almost consistent with the ideal corrected image shown in Fig. 2(h).

The root mean square error (RMSE) between the corrected image obtained by the proposed method and the ideal corrected image is calculated. And the Euler distance between non-noisy target image and corrected image is also calculated. Table 1 shows the results of the proposed method with respect to golf1, golf2 and race1 test images, compared with traditional correction method in which noise is not considered. From the table it is noted that the proposed correction method achieves smaller RMSE and Euler distance than the traditional correction method.

In conclusion, the proposed method aims at eliminating noise influence in noisy multi-view image color correction. Improved K-L transform is used to obtain correction matrix. This method can effectively extract almost ideal correction matrix from noisy images. Then wavelet transform is applied to denoise the corrected image. Experimental results show that the novel method is effective for noisy multi-view images.

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