DETECTING AND ELIMINATING CHROMATIC ABERRATION IN DIGITAL IMAGES

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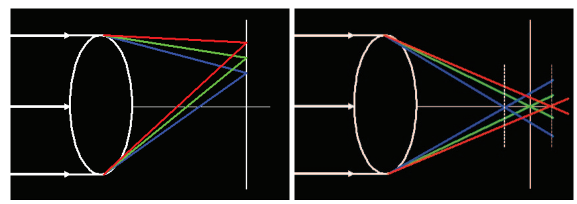
ABSTRACT

Chromatic aberration is a form of distortion in color optical devices that produces undesirable color fringes along borders within images. In this paper, we propose a novel method for detecting and eliminating chromatic aberration using image processing. We first analyze the color difference behavior around edges that do not show chromatic aberration and propose a range limitation property for edges. After searching for the pixels that violate the above property, the corrected pixel values are generated to eliminate the color fringes. The proposed algorithm corrects both lateral and longitudinal aberration on a single distorted image, and experimental results demonstrate the performance of the proposed method is effective.

***Index Terms*—** Chromatic Aberration, Color Fringe, Digital Camera, Image Enhancement

Fig. 1. Chromatic aberration with red color fringes



(a) Lateral aberration (b) Longitudinal aberration

Fig. 2. Two kinds of chromatic aberration

1. INTRODUCTION

Every optical system that uses lenses suffers from distortions that occur due to the refractive characteristics of the lenses. Chromatic aberration is one type of distortion in color optical devices. In this phenomenon, color fringes usually occur along edges of an image(Fig. 1). It is well known that different colors refract through the lens at different angles. There exists two forms of chromatic aberration : the lateral aberration, in which aberration causes geometric shifts between different color channels, and the longitudinal aberration, which causes color blur(Fig. 2).

Optimal lens design techniques [1], [2] have been proposed to reduce chromatic aberration, but this hardware solution can only be used in large cameras and increases their cost. Alternatives to these approaches, active lens control systems [3], [4], in which separately adjusting the three RGB filter lenses, and algorithms using image processing, image warping or other realignment algorithms [5]-[8], are suggested. Also most of these methods require *a priori* information, such as the pre-calibrated test pattern information or the camera setting information like the focal length at the time the image was acquired.

In this paper, we propose an image processing method that corrects both the lateral and the longitudinal aberration simultaneously for a single distorted image. This method exploits our observation that color intensity of the red and the blue channels are distorted due to the fact that cameras are typically focused using the green channel. We first analyze the color difference behavior on edges that do not show chromatic aberration and propose a range limited property for normal edges. After searching for the pixels that violate the defined property, the appropriate compensated image is calculated to eliminate the color fringes. Because the algorithm doesn't require any *a priori* knowledge, it can be applied to any image.

This paper is organized as follows: in Section 2 we suggest a condition for normal edges by analyzing the color difference behaviors in edge areas. In Section 3 we will show that the chromatic aberration areas can be detected and eliminated using the proposed property. In Section 4 we show the experimental results and Section 5 is the conclusion.

2. COLOR DIFFERENCE BEHAVIOR ON EDGES

Every edge areas has a transition region where color variation occurs. The transition region Z can be defined as a set of

This work was supported in part by the IT R&D program of MKE/MCST/IITA (2008-F-031-01, Development of Computational Photography Technologies for Image and Video Contents), in part by the Brain Korea(BK) 21 Program funded by MEST, and in part by the HY-SDR Research Center at Hanyang University under the ITRC Program of MKE, Korea.

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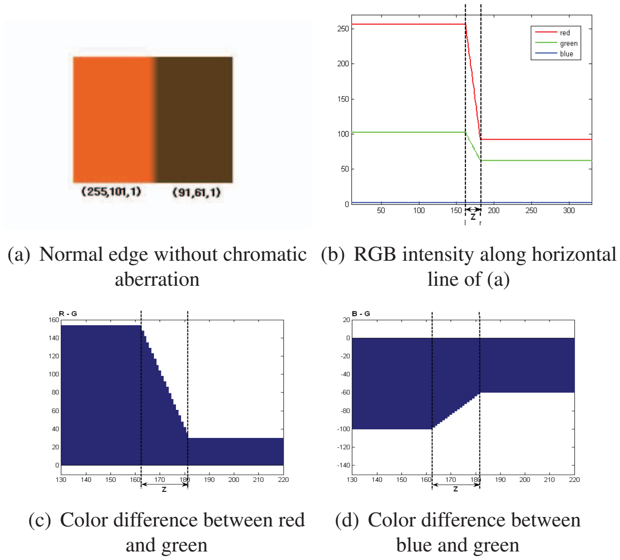
pixels located between l and r. l and r represent the left and the right boundary pixel, respectively, where color variation stops. There exists chromatic correlation [9] on normal edges that do not show chromatic aberration, in which each color channel varies at the same location[Fig. 3(b)]. Color difference signals are calculated as the difference between red(R) and green(G) signals, and as the difference between blue(B) and green(G) signals in RGB color space[Fig. 3(c) and 3(d)]. Color difference signals have a certain property on normal edges. Each color difference signal in Z is higher than the minimum of the values in l and r, and lower than the maximum of the values in l and r. We represent this property as

$$\begin{array}{l}\min\{D_R(l), D_R(r)\} \leq D_R(j) \leq \max\{D_R(l), D_R(r)\} \\ \min\{D_B(l), D_B(r)\} \leq D_B(j) \leq \max\{D_B(l), D_B(r)\},\end{array} \quad (1)$$

where $D_R(\cdot) = R(\cdot) - G(\cdot)$, $D_B(\cdot) = B(\cdot) - G(\cdot)$ and j is the pixel location in Z. This means that the color difference signals in the transition region have limited varying range between the values in the adjacent boundary pixels. We call this the Color Difference Condition for Normal Edges.

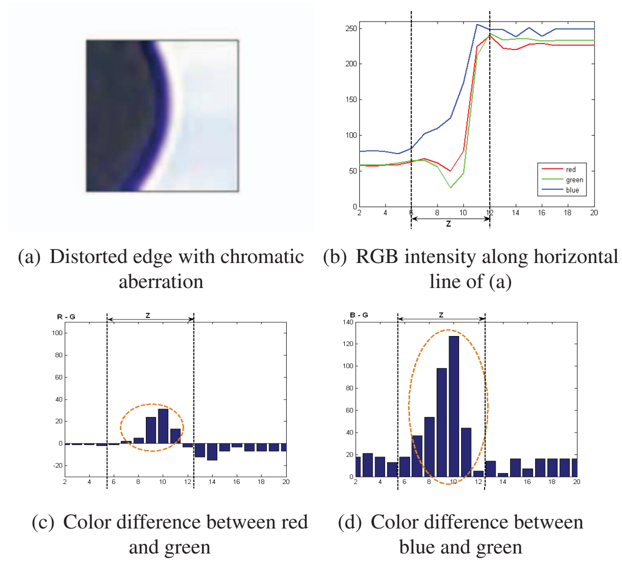


(a) Normal edge without chromatic aberration (b) RGB intensity along horizontal line of (a)

(c) Color difference between red and green (d) Color difference between blue and green

Fig. 3. Color difference behavior on edges

On the contrary, the edges with chromatic aberration violates the proposed condition. Given an image with strong blue color fringes caused by chromatic aberration[Fig. 4(a)], plots of the RGB intensity along the horizontal direction reveal geometrical shifts in the blue signal, and channel blur due to the lateral and the longitudinal aberration[Fig. 4(b)],respectively. These aberration breaks the chromatic correlation, which means that the varying location between each color channel differ. The transition region on these edge can be defined as the pixels where at least one color channel varies. The color difference signals in Fig. 4(c) and 4(d) demonstrate that some pixels, marked with orange dot circle, violate the Color Difference Condition for Normal Edges. We can specify that these pixels make unpleased color fringes around the edges. Strong blue color fringe is emphasized on the edge because the color difference between the blue and the green intensities are much larger than the those difference between the red and the green intensities. We will use this Color Difference Condition for Normal Edges to detect the aberration areas.



(a) Distorted edge with chromatic aberration (b) RGB intensity along horizontal line of (a)

(c) Color difference between red and green (d) Color difference between blue and green

Fig. 4. Color difference for a distorted edge : Pixels violating the proposed condition are marked with orange dot circle

3. DETECTING AND ELIMINATING CHROMATIC ABERRATION

3.1. Gradient operation for edge detection

Before detecting the aberration areas we need to search for the transition region Z for each edge. To find the transition region we first perform a gradient operation for each color channel. Our gradient operation is based on the widely-used Sobel operators [10]

$$\begin{aligned} E_{Cx}(i,j) = {} & C(i-1,j-1) + 2C(i,j-1) \\ & + C(i+1,j-1) - C(i-1,j+1) \\ & - 2C(i,j+1) - C(i+1,j+1) \\ E_{Cy}(i,j) = {} & C(i-1,j-1) + 2C(i-1,j) \\ & + C(i-1,j+1) - C(i+1,j-1) \\ & - 2C(i+1,j) - C(i+1,j+1), \end{aligned} \quad (2)$$

where i and j represents the pixel location in row and column, $C \in \{R, G, B\}$, x and y express the horizontal and the vertical directions, respectively. Using these gradient values

$$E_C(i,j) = |E_{Cx}(i,j)| + |E_{Cy}(i,j)|, \quad (3)$$

$$\theta_C(i,j) = \arctan(\frac{E_{Cx}(i,j)}{E_{Cy}(i,j)}) \quad (4)$$

are calculated where $E_C(i,j)$ is the edge magnitude used to find the image edges and $\theta_C(i,j)$ is the gradient direction which is perpendicular to the edge direction. The gradient direction is used to determine whether the appropriate direction for the detection process is horizontal or vertical. Because the color fringes in an image appear parallel to the edge, the detection process proceeds either horizontally or vertically, depending on which of these is close to the gradient direction. The detection proceeds horizontally if the gradient direction range is $-45^o \leq \theta(i,j) \leq 45^o$ and vertically otherwise.

3.2. Detection Method

Our algorithm processes data in the horizontal direction and the vertical direction separately. For simplicity, we present only the process used in the horizontal direction. In the horizontal processing all 2D signals can be considered as 1D cases with a fixed integer i. Starting from initial value $j = 1$, the first step is to find the edge location k by increasing the pixel location j one by one as follows :

EG就是绿色的梯度。3.1节中EC，C属于{RGB}

$$k = j \quad , \quad \text{where } j \text{ is increased until } E_G(j) \geq T_1 \text{ and } |E_{Gx}(j)| \geq |E_{Gy}(j)|. \tag{5}$$

T_1 is the edge threshold. Only the green edge magnitude is used because the widely-used Bayer pattern [11] in an image sensor has twice as many green samples as red or blue samples so the lens in most cameras is focused using this channel. Consequently gradient values for the red and the blue channels includes all blurred and geometrically-shifted information that is caused by chromatic aberration. Magnitude comparison between $|E_{Gx}(j)|$ and $|E_{Gy}(j)|$ is the substitution for arc-tangent calculation where the gradient direction range is $-45^o \leq \theta(i,j) \leq 45^o$. If searching for the other gradient angles, the vertical direction, the sign of inequality in the comparison will be reversed.

The edge location k can be expected to be one of the point located in a transition area, so to find the whole transition region Z_k for edge k, the algorithm searches independently for the nearest homogeneous pixels to the left l_k and the right r_k from k until it reaches a homogeneous region or the next edge as follows :

$$H_x(j) = \max\{|E_{Rx}(j)|, |E_{Gx}(j)|, |E_{Bx}(j)|\}, \tag{6}$$

in which H denotes the maximum gradient value in each pixel among the three color channels and

$$l_k = j \quad , \quad \text{where } j \text{ is reduced from } k \text{ until } H_x(j) < T_2 \text{ or } E_G(j) < T_1 \leq E_G(j-1), \tag{7}$$

$$r_k = j \quad , \quad \text{where } j \text{ is increased from } k \text{ until } H_x(j) < T_2 \text{ or } E_G(j) < T_1 \leq E_G(j+1), \tag{8}$$

where T_2 is a threshold for the homogeneity check. Regions with low gradient values for all color channels are considered as homogeneous regions so the first position where the maximum gradient value H gets lower than a certain threshold T_2 will be the nearest homogeneous pixel. The transition region for edge k can be defined as the region between l_k and r_k.

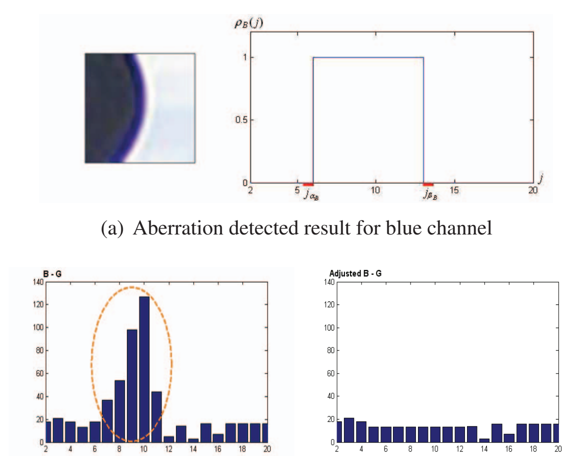
Aberration areas are detected by searching for the pixels which violate the Color Difference Condition for Normal Edges in these transition region.

$$\rho_S(j|k) = \begin{cases} 1, & \text{where } D_S(j) < \min\{D_S(l_k), D_S(r_k)\} \\ & \text{or } D_S(j) > \max\{D_S(l_k), D_S(r_k)\} \\ 0, & \text{otherwise} \end{cases} \tag{9}$$

where $S \in \{R, B\}$, $j|k$ represent the pixel location j for given edge k, $l_k < j < r_k$ and binary signal ρ_S where aberration regions expressed as value 1. After the detection, j will be substituted to the value r_k+1 and the next edge's transition region will be searched continuously.

3.3. Elimination Method

The elimination method proceeds independently in the red and the blue channels by adjusting color difference values in the detected regions to be similar to the minimum of these differences in adjacent undistorted pixel locations. To find the appropriate value for adjustment the nearest undistorted pixels, where ρ_S is zero, in both left and right direction j_{α_S} and j_{β_S} are calculated. Every color difference value in $j_{\alpha_S} < j < j_{\beta_S}$ is adjusted to the original difference value at j_{α_S} or j_{β_S} which has a minimum absolute difference value. The pixel with minimum absolute difference value is selected, because this maximizes the reduction of the saturation signal. As an example this approach was applied to the blue channel in Fig. 4(a); B-G differences were greatly reduced [Fig. 5(c)].



(a) Aberration detected result for blue channel

(b) Color difference between blue and green

(c) Adjusted color difference signal between blue and green

Fig. 5. Color difference compensation for reducing chromatic aberration

After adjusting the color difference values, the original green input signal is added to compute the output red and blue signals.

$$S_{out}(j) = \begin{cases} D_S(j_{\alpha_S}) + G_{in}(j), & \text{if } |D_S(j_{\alpha_S})| \leq |D_S(j_{\beta_S})| \\ D_S(j_{\beta_S}) + G_{in}(j), & \text{if } |D_S(j_{\beta_S})| < |D_S(j_{\alpha_S})| \end{cases} \quad (10)$$

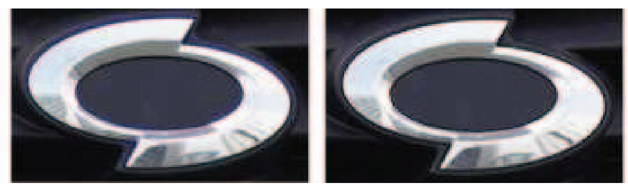
where $S \in \{R, B\}$ and $j_{\alpha_S} < j < j_{\beta_S}$.

4. EXPERIMENTAL RESULTS

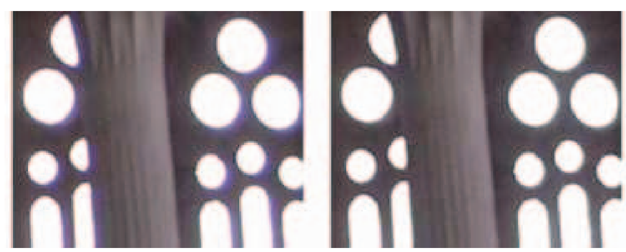
This algorithm was applied to several images acquired from the internet or captures with different digital cameras. Threshold used were $T_1 = 200$ and $T_2 = 40$. Our algorithm significantly reduce both the lateral and the longitudinal aberration without reference to the width of the color fringe or the type of aberration. The red color fringes around windows which mostly occurred due to the lateral aberration in Fig. 6(d) were remarkably reduced after the correction. The longitudinal aberration [Fig. 6(e)] and the purple fringes [Fig. 6(f)] were also corrected properly.

(a) Train (b) Car (c) Church

(d) Left : enlarged image of (a), Right : aberration eliminated image



(e) Left : enlarged image of (b), Right : aberration eliminated image



(f) Left : enlarged image of (c), Right : aberration eliminated image

Fig. 6. Experimental results

5. CONCLUSION

We analyzed the color difference behavior on normal edges and showed that color fringes due to chromatic aberration can be detected using Color Difference Condition for Normal Edges. We introduced an algorithm that corrects chromatic aberration by reducing the intensity difference between the red and the green, and those between the blue and the green in color fringes. This algorithm reduces both the lateral and the longitudinal aberration effectively. It also operates quickly due to the 1D separable process. Methods for the more accurate transition region classification and the selection of appropriate thresholds will be left for future works.

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