# CORRECTION OF CHROMATICS ABERRATION IN DIGITAL CAMERA IMAGES FOR IMAGE MEASUREMENT

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**KEY WORDS:** chromatic aberration, camera calibration, digital camera, least-squares method

**ABSTRACT:** The paper reports an experiment conducted to investigate three methods to correct chromatic aberrations which are displacements between different color channels (red (R), green (G), blue (B)). One is to correct image coordinates by using three sets of camera calibration results of color-separated images (R, G, B), and the others are methods based on the assumption that the magnitude of lateral chromatic aberrations can be expressed by a linear function and a cubic function of a radial distance from the center of the image frame. The experiment results show that displacements between the three color channels (R, G, B) produced in the investigated camera were unable to be neglected for image measurement. The results show that the camera calibration results by using color-separated images would be unable to correct chromatic aberrations. The results show that the chromatic aberration model based on linear lateral chromatic aberration would be insufficient for correction of chromatic aberrations as well. On the contrary, the results demonstrate that the correction method based on the assumption that the displacement between the color channels can be expressed in a cubic polynomial of the radial distance from the center of the image frame would be able to correct chromatic aberrations satisfactorily. The root mean squares of the differences of image coordinates between R and G, B and G after the correction by the third method was smaller than 1/3 (between B and G) and 1/5 (between R and G) of those before correction.

## 1. INTRODUCTION

As performance of a digital camera becomes better and its price becomes lower in recent years, digital camera images are becoming more popular in diverse fields. The recent increase in number of pixels of images acquired by a non-metric digital camera encourages a nonprofessional to utilize it for image measurement. A non-metric digital camera is required to be geometrically calibrated when it is used for image measurement. Camera calibration to estimate a calibrated principal distance, offsets from the principal point to the center of the image frame, a radial lens distortion component, and a decentering lens distortion component becomes essential for precise image measurement by using a non-metric digital camera.

On the other hand, displacements between different color channels (red (R), green (G), blue (B)) caused by chromatic aberrations are smaller than 1 / 10 of radial lens distortions in almost all the non-metric digital cameras. However, as a unit cell size on the focal plane of a non-metric digital camera becomes smaller, the influence of chromatic aberrations becomes greater. Currently, correction of chromatic aberrations would be indispensable for precise image measurement by using a non-metric digital camera.

Kaufmann *et al.* (2005) reported an experiment to correct chromatic aberrations by using a lateral chromatic aberration model expressed by a linear function of a radial distance. They estimated the model by means of least-squares adjustment. The correction method proposed by them is easy for a nonprofessional, but their results indicated that the effect of the correction would be limited. Luhmann *et al.* (2006) reported an experiment to correct chromatic aberrations by using a chromatic aberration model expressed by a series of odd powered terms of a radial distance added to the ordinary radial lens distortion model. They estimated the model by means of self-calibrating bundle adjustment. The report showed the results on the accuracy of close-range photogrammetry, but the effect of the correction was not shown in the report. The implementation of the function to estimate the model would not be easy for a nonprofessional as well.

The aim of our study is to devise a method to correct chromatic aberrations easily for a nonprofessional. The paper reports an experiment conducted to investigate three methods to correct chromatic aberrations.

## 2. CHROMATIC ABERRATIONS

Chromatic aberrations are caused by the variation of refractive index with wavelength, and produce lateral (oblique) distortions and axial (longitudinal) distortions (McGlone *et al.*, 2004). As for image measurement, the lateral chromatic aberrations that bring geometric errors are more influential than the axial chromatic aberrations that bring image blur. Figure 1 shows the example of the chromatic aberrations. Figure 2 shows the lateral chromatic aberration generating the displacement between different color channels. Displacements between different color channels caused by the lateral chromatic aberrations are point symmetric and the magnitude of the displacements is proportional to a radial distance from the principal point of a camera. Accordingly, the lateral chromatic aberration is often referred to as a chromatic difference in magnification.

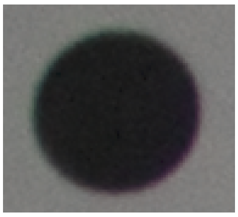


Figure 1. Chromatic aberration

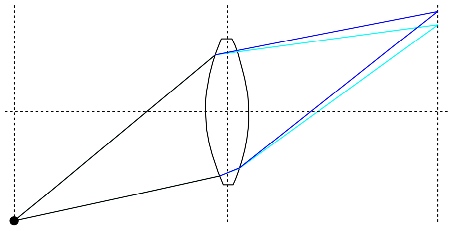


Figure 2. Lateral chromatic aberrations

A compound lens assembled from lens elements made of substances with different refractiveness can be utilized to reduce chromatic aberrations. The most common type is an achromatic doublet composed of two elements made of crown glass and flint glass. By combining more than two lenses of different composition, the degree of correction can be further increased. However, it is impossible to correct chromatic aberrations perfectly.

## 3. OUTLINE OF EXPERIMENT

### 3.1 Investigated Cameras

Two non-metric lens-interchangeable digital SLR (single lens reflex) cameras: Olympus E-P2 with Olympus M.ZUIKO DIGITAL 17 mm F 2.8 lens, which is called E-P2 for short from now on, and Canon EOS 50D with Tamron 18 - 270 mm F / 3.5 - 6.3 lens, which is called EOS 50D for short from now on, were investigated in the experiment. Table 1 shows the specifications of the investigated cameras.

Table 1. Specifications of the investigated cameras

| | | |
|---|---|---|
| Model | Olympus PEN E-P2 | Canon EOS 50D |
| Image sensor | Live MOS sensor | CMOS sensor |
| Image size | 17.3 mm × 13.0 mm | 22.3 mm × 14.9 mm |
| Unit cell size on the focal plane | 4.29 μm ×4.29 μm | 4.70 μm ×4.70 μm |
| Number of recording pixels | 4032 × 3024 | 4752 × 3168 |
| Lens | Olympus<br>M.ZUIKO DIGITAL 17 mm F 2.8 | Tamron<br>18 - 270 mm F / 3.5 - 6.3 Di II VC |
| Focal length<br>35 mm film equivalent | 17 mm<br>34 mm | 18 ~ 270 mm<br>28 ~ 419 mm |
| Lens construction | 6 elements in 4 groups | 18 elements in 13 groups |

### 3.2 Investigated Images

We prepared a white sheet with 14 by 10 black solid points placed at regular intervals as shown in Figure 3. Images photographed the target sheet were utilized for the evaluation of the chromatic aberration correction methods in the experiment. Image coordinates of each color channel (red (R), green (G), blue (B)) of the center of a point were measured by least squares matching.

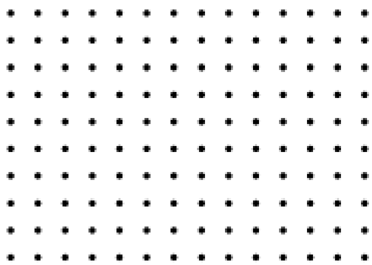


Figure 3. target sheet

### 3.3 Correction Methods

We treated the green channel (G) as the reference channel. We examined three methods to correct displacements (R $\rightarrow$ G) between red channel (R) and the green channel (G) and displacements (G $\rightarrow$ B) between the blue channel (B) and the green channel (G).

($u_R$, $v_R$), ($u_G$, $v_G$), ($u_B$, $v_B$) are uncorrected image coordinates of R, G, B respectively and ($u_C$, $v_C$) are uncorrected image coordinates of the target channel (C), that is, C = R or C = B from now on. ($u_{0R}$, $v_{0R}$), ($u_{0G}$, $v_{0G}$), ($u_{0B}$, $v_{0B}$) and ($u_{0C}$, $v_{0C}$) are uncorrected image coordinates of the center of the image frame of R, G, B and the target color (C = R

/ B) respectively as well. Moreover, $(u'_R, v'_R)$, $(u'_G, v'_G)$, $(u'_B, v'_B)$ and $(u'_C, v'_C)$ are corrected image coordinates of R, G, B and the target color (C = R / B) respectively.

**Method-1**: A method is based on the assumption that differences of image coordinates between different color channels can be corrected by using interior orientation parameters of each color channel estimated by ordinary camera calibration executed by using color-separated images.

**Method-2**: A method is based on the assumption that differences of image coordinates between different color channels are produced by lateral chromatic aberrations, and those can be corrected by using the following equations:

$$\begin{cases} u'_C = u_C - (u_{0C} - u_{0G}) - a_{1C}(u_G - u_{0G}) \\ v'_C = v_C - (v_{0C} - v_{0G}) - a_{1C}(v_G - v_{0G}) \end{cases} \tag{1}$$

where $a_{1C}$ is the coefficient expressing the difference of the focal lengths between the target channel (C) and the reference channel (G), $(u_{0C} - u_{0G}, v_{0C} - v_{0G})$ expresses the displacement of the center of the image frame. $a_{1C}$ and $(u_{0C} - u_{0G}, v_{0C} - v_{0G})$ in Equation (1) are estimated by least-squares method.

**Method-3**: A method is based on the assumption that differences of image coordinates between different color channels are produced by lateral chromatic aberrations and radial distortions which are expressed by cubic polynomials and those can be corrected by using the following equations:

$$\begin{cases} u'_C = u_C - (u_{0C} - u_{0G}) - \dfrac{(u_G - u_{0G})}{r_G}(a_{1C}r_G + a_{2C}r_G^2 + a_{3C}r_G^3) \\ v'_C = v_C - (v_{0C} - v_{0G}) - \dfrac{(v_G - v_{0G})}{r_G}(a_{1C}r_G + a_{2C}r_G^2 + a_{3C}r_G^3) \end{cases} \tag{2}$$

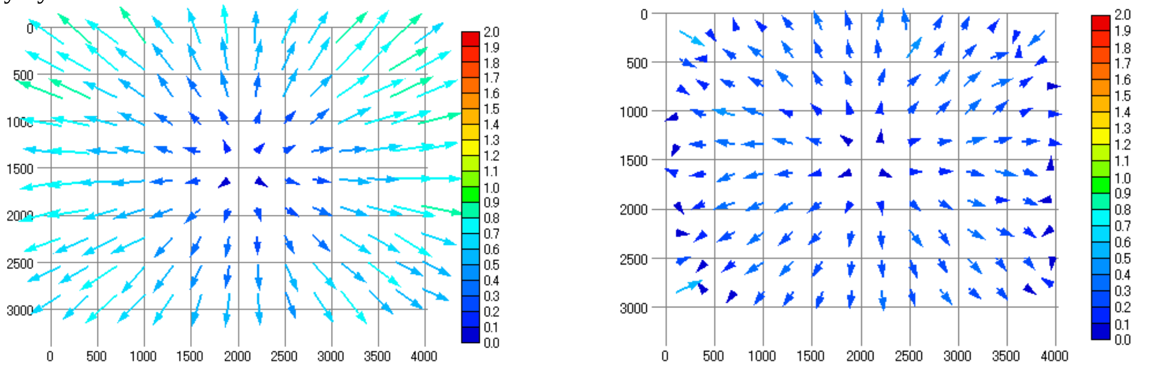
$$r_G = \sqrt{(u_G - u_{0G})^2 + (v_G - v_{0G})^2} \tag{3}$$

where $a_{1C}$ is the coefficient expressing the difference of the focal lengths and $a_{2C}$, $a_{3C}$ expressing the difference of the radial distortions between the target channel (C) and the reference channel (G), $(u_{0C} - u_{0G}, v_{0C} - v_{0G})$ expresses the displacement of the center of the image frame. $a_{1C}$, $a_{2C}$, $a_{3C}$ and $(u_{0C} - u_{0G}, v_{0C} - v_{0G})$ in Equation (2) are estimated by least-squares method.

## 4. RESULTS AND DISCUUSION

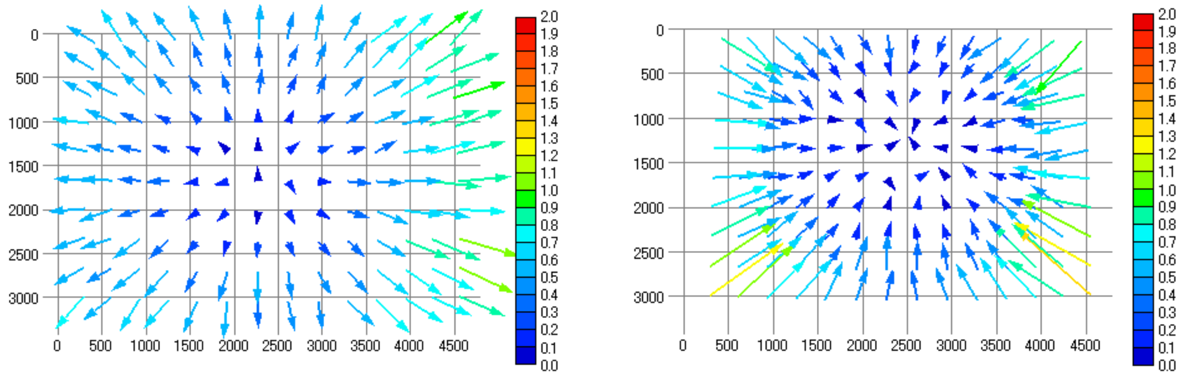
### 4.1 Measurement of Chromatic Aberrations

Figure 4 and Figure 5 show displacements (R → G) between red channel (R) and the green channel (G) and displacements (G → B) between the blue channel (B) and the green channel (G) of the image acquired by E-P2 and EOS 50D respectively. The results indicate that the root mean squares (RMSs) of both the displacements (R→ G) and the displacements (G → B) were larger than the ordinary measurement accuracy of image coordinates. We concluded that both the displacements (R → G) and the displacements (G → B) would be unable to be neglected for image measurement. As the radial distance from the center of the image frame increases, the magnitude of the displacement increases. The fact indicates that the displacement between the color channels would be produced mainly by lateral chromatic aberration.




(R → G) Maximum: 0.885 pixel, RMS: 0.606 pixel (G → B) Maximum: 0.516 pixel, RMS: 0.251 pixel

Figure 4. Displacement vectors of Olympus E-P2 (Unit: pixel)




(R →G) Maximum: 1.073 pixel, RMS: 0.541 pixel (G → B) Maximum: 1.394 pixel, RMS: 0.498 pixel

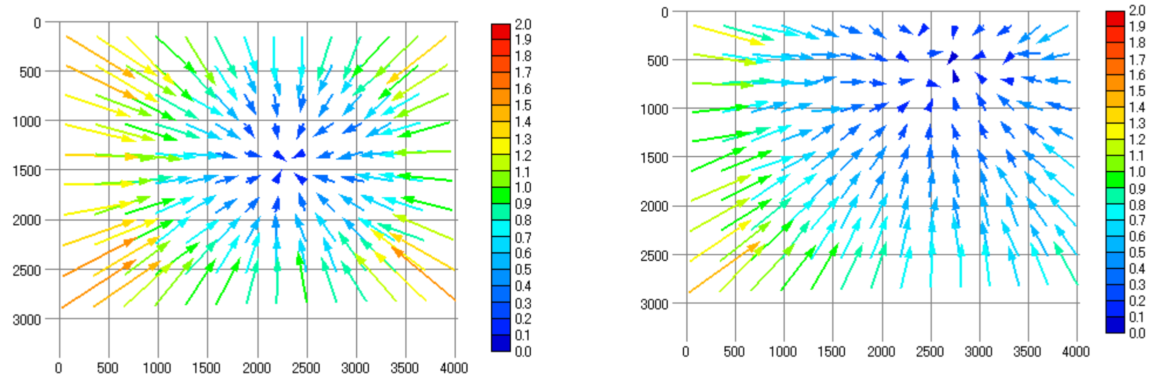
Figure 5. Displacement vectors of Canon EOS 50D (Unit: pixel)

### 4.2 Correction of Chromatic Aberrations by Method-1

Camera calibration was conducted by PhotoModeler developed by Eos Systems Inc. in the experiment. The image distortion model utilized in the experiment is composed of the calibrated principal distance *c*, the offsets ($\Delta x_P$, $\Delta y_P$) from the principal point to the center of the image frame, the radial lens distortion component with the coefficients $k_1$, $k_2$, and the decentering lens distortion component with the coefficients $p_1$, $p_2$ (Eos Systems Inc., 2003). Table 2 shows the results of the camera calibration of E-P2. Figure 6 shows displacements (R → G) and (G → B) of E-P2 after Method-1 correction by using the obtained interior orientation parameters shown in Table 2. Figure 6 indicates that Method-1 made overcorrections and the camera calibration results by using color-separated images would be unable to correct chromatic aberrations.

Table2. Obtained interior orientation parameters of Olympus E-P2

| | $c$ (mm) | $\Delta x_P$ (pixel) | $\Delta y_P$ (pixel) | $k_1$ ($\times 10^{-04}$) | $k_2$ ($\times 10^{-07}$) | $p_1$ ($\times 10^{-05}$) | $p_2$ ($\times 10^{-05}$) |
|---|---|---|---|---|---|---|---|
| R | 16.863 | −18.690 | 0.282 | 2.244 | −3.250 | −6.142 | 1.663 |
| G | 16.845 | −18.848 | 0.243 | 2.242 | −3.361 | −6.084 | 1.537 |
| B | 16.833 | −19.061 | −0.053 | 2.198 | −3.389 | −6.152 | 1.530 |




(R → G) Maximum: 1.589 pixel, RMS: 0.870 pixel (G → B) Maximum:1.494 pixel, RMS: 0.637 pixel

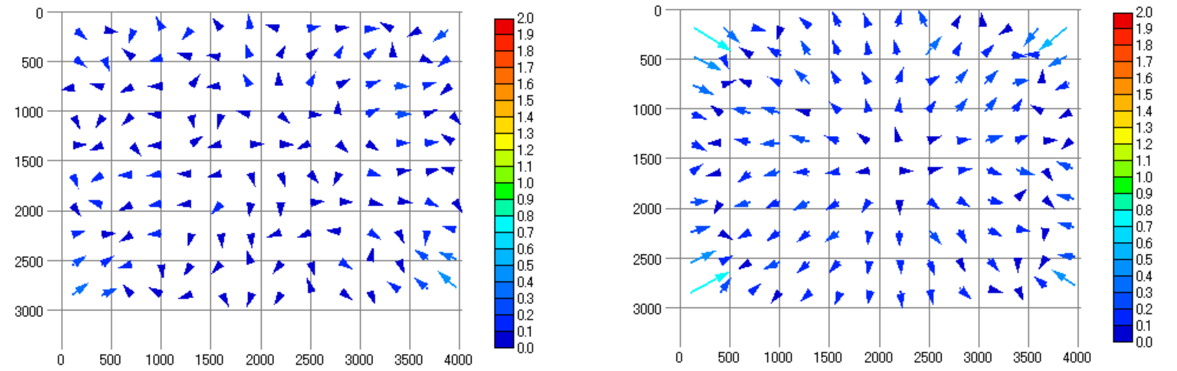
Figure 6. Displacement vectors of Olympus E-P2 after Method-1 correction (Unit: pixel)

### 4.3 Correction of Chromatic Aberrations by Method-2

Table 3 shows the coefficients of Equation (1) of E-P2 obtained by least-squares method, and Figure 7 shows displacements (R → G) and (G → B) of E-P2 after Method-2 correction by using the obtained coefficients of Equation (1) shown in Table 3. Figure 7 indicates that Method-2 made better corrections. However, Figure 7 shows that the displacement vectors should have the dominant radial component and the displacements would not be produced only by linear lateral chromatic aberration.

Table 3. Obtained coefficients of Equation (1) of Olympus E-P2

| | $\Delta u_{0C}$ | $\Delta v_{0C}$ | $a_{1C}$ |
|---|---|---|---|
| R $\rightarrow$ G | 0.000994 | −0.006076 | −0.000101 |
| G $\rightarrow$ B | −0.003884 | −0.020064 | 0.000408 |




(R $\rightarrow$G) Maximum: 0.434 pixel, RMS: 0.115 pixel (G $\rightarrow$ B) Maximum: 0.752 pixel, RMS: 0.203 pixel

Figure 7. Displacement vectors of Olympus E-P2 after Method-2 correction (Unit: pixel)

**4.4 Correction of Chromatic Aberrations by Method-3**

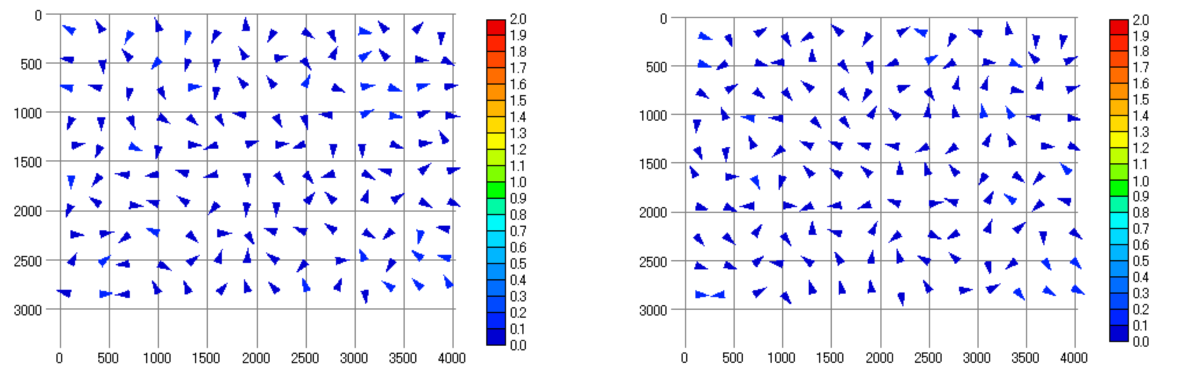
Table 4 and Table 5 show the obtained coefficients of Equation (2) of E-P2 and EOS 50D respectively. Figure 8 shows displacements (R $\rightarrow$ G) and (G $\rightarrow$ B) of E-P2 after Method-3 correction by using the obtained coefficients of Equation (2) shown in Table 4. Figure 9 shows displacements (R $\rightarrow$ G) and (G $\rightarrow$ B) of EOS 50D after Method-3 correction by using the obtained coefficients of Equation (2) shown in Table 5 as well. Both Figure 8 and Figure 9 indicate that Method-3 would be able to make satisfactory corrections of chromatic aberrations. The results that Method-3 made more satisfactory corrections than Method-2 suggests that the fact that the investigated lenses are constructed with several lens elements would produce the nonlinear lateral chromatic aberration.

Table 4. Obtained coefficients of Equation (2) of Olympus E-P2

| | $\Delta u_{0C}$ | $\Delta v_{0C}$ | $a_{1C}$ | $a_{2C}$ ($\times 10^{-07}$) | $a_{3C}$ ($\times 10^{-10}$) |
|---|---|---|---|---|---|
| R $\rightarrow$ G | 0.004942 | −0.009175 | 0.000264 | −1.90246 | 1.60182 |
| G $\rightarrow$ B | −0.005880 | −0.018534 | 0.000321 | 2.90469 | −1.33597 |

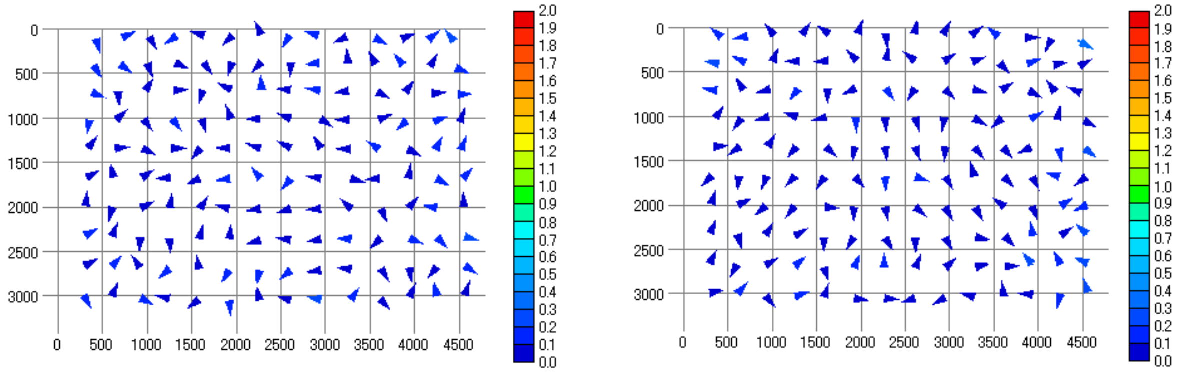
Table 5. Obtained coefficients of Equation (2) of Canon EOS 50D

| | $\Delta u_{0C}$ | $\Delta v_{0C}$ | $a_{1C}$ | $a_{2C}$ ($\times 10^{-07}$) | $a_{3C}$ ($\times 10^{-10}$) |
|---|---|---|---|---|---|
| R $\rightarrow$ G | 0.090937 | −0.018691 | 0.000333 | −1.30701 | 9.99113 |
| G $\rightarrow$ B | −0.057189 | 0.002944 | 0.000647 | 0.50656 | −1.10182 |




(R $\rightarrow$ G) Maximum: 0.180 pixel, RMS: 0.075 pixel (G $\rightarrow$ B) 0.197 pixel, RMS: 0.066 pixel Maximum:

Figure 8. Displacement vectors of Olympus E-P2 after Method-3 correction (Unit: pixel)




(R → G) Maximum: 0.266 pixel, RMS: 0.095 pixel (G → B) Maximum: 0.316 pixel, RMS: 0.093 pixel

Figure 9. Displacement vectors of Canon EOS 50D after Method-3 correction (Unit: pixel)

## 5. CONCLUSION

The experiment results show that displacements between the three (Red, Green, Blue) color channels produced in the investigated camera were unable to be neglected for image measurement. As the radial distance from the center of the image frame increases, the magnitude of the displacement between the color channels increases. The fact indicates that the displacement between the color channels would be produced mainly by lateral chromatic aberration.

The results show that the camera calibration results by using color-separated images would be unable to correct chromatic aberrations. The results show that the chromatic aberration model based on linear lateral chromatic aberration would be insufficient for correction of chromatic aberrations as well. On the contrary, the results demonstrate that the correction method based on the assumption that the displacement between the color channels can be expressed in a cubic polynomial of the radial distance from the center of the image frame would be able to correct chromatic aberrations satisfactorily. We guess that the fact that the investigated lenses are constructed with several lens elements would produce the nonlinear lateral chromatic aberration.

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