IJIRR

International Journal of Information Research and Review
Vol. 03, Issue, 11, pp. 3103-3113, November, 2016

Research Article

AUTOMATIC CORRECTION OF CHROMATIC ABERRATION USING PHOTOACUTE STUDIO

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ARTICLE INFO

Article History:

Received 18th August, 2016
Received in revised form
22nd September, 2016
Accepted 14th October, 2016
Published online November, 30th 2016

Keywords:

Almalance's PhotoAcute Studio
Automatic Chromatic Aberration
Red Fringing
Green Fringing
Axial Chromatic Aberration (ACA)
Lateral Chromatic Aberration (LCA)
Paraxial Optics
Achromatic
Apochromatic Doublets.

ABSTRACT

In a digital camera, the causes of color artifacts are due to the characteristics of an image sensor or an optical device. Chromatic aberration is one of the color artifacts. Because chromatic aberration is unpleasant to the eye, users are likely to eliminate or correct the color fringed pixels. At present, most users select the regions which contain the color fringed pixels, and correct them using software such as Adobe® PhotoShop. Other applications such as PTLens® use lookup table of precomputed parameters to reduce the artifacts. This study aims to correct the effects of Chromatic Aberration automatically and overcome the limitations of optics manufacturing technology through the use of Almalance's PhotoAcute Studio, which corrects this aberration automatically, minimizing the circle of confusion, with no need of manual adjustments of any parameters. The study thus concluded that, the Almalence PhotoAcute studio was able to achieve high quality images without any annoying chromatic aberration (red and green fringing) and overcame the limitations of the optics manufacturing technology.

INTRODUCTION

In a digital camera, the causes of color artifacts are due to the characteristics of an image sensor or an optical device. Chromatic aberration is one of the color artifacts. Because chromatic aberration is unpleasant to the eye, users are likely to eliminate or correct the color fringed pixels. (Kim & Park, 2008, p. 1). Chromatic aberration is a characteristic of an optical device (i.e., Lens). In the case of Chromatic aberration, which is a problem caused by optical characteristics, users can see color fringing in an image obtained by the digital cameras.
The image quality of digital cameras depends on the type of artifacts. Fortunately, artifacts of digital images are corrected easily by post processing in the digital image device or graphic editor software, because the digital image file format contains color or intensity information at each pixel. At present, most users select the regions which contain the color fringed pixels, and correct them using software such as Adobe® PhotoShop.
Other applications such as PTLens® use lookup table of precomputed parameters to reduce the artifacts.

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Conventional and proposed methods automatically detect and correct the color fringed pixels. Also, they can be used as a post processing in a digital camera, enhancing the image quality. (Kang, 2007, p. 1) Some previous studies have addressed the subject of Automatic Correction of Chromatic Aberration, In 2007, Sing Bing Kang. Presented a study entitled "Automatic Removal of Chromatic Aberration From a Single Image", and he focused on how to undo most of the effects of chromatic aberration from a single image. He started from the basic principles of image formation to characterize CA, and show how its effects can be substantially reduced. He also showed the results of CA correction on a number of high-resolution images taken with different cameras. (Kang, 2007, p. 1). In 2008. Bayek Kyu Kim & Rae Hong Park presented a research entitled "Automatic Detection and Correction of Purple Fringing Using the Gradient Information and Desaturation ". In this study, they proposed a method to automatically detect and correct purple fringing that is one of the color artifacts due to characteristics of charge coupled device sensors in a digital camera. The proposed method consists of two steps. In the first step, they detect purple fringed regions that satisfy specific properties: hue characteristics around highlight regions with large gradient magnitudes.

In the second step, color correction of the purple fringed regions is made by desaturating the pixels in the detected regions. The proposed method is able to detect purple fringe artifacts more precisely than Kang's method. It can be used as a post processing in a digital camera. (Kim & Park, 2008, p. 1)
Our proposed solution to correct the Chromatic Aberration automatically is Almalance's PhotoAcute Studio which is an easy to use program that can improve our digital image quality. With PhotoAcute Studio, we will be able to achieve photos that have less noise and more details. PhotoAcute Studio can also enhance our photos to increase dynamic range and reduce chromatic aberrations. PhotoAcute Studio is compatible with Windows and Mac operating systems. This study aims to correct the effects of Chromatic Aberration automatically and overcome the limitations of optics manufacturing technology through the use of Almalance's PhotoAcute Studio, which corrects this aberration automatically, minimizing the circle of confusion, with no need of manual adjustments of any parameters. In our study, we'll compare between the images before and after the automatic Chromatic Aberration correction with no need of manual adjustments of any parameters by using Almalance's PhotoAcute Studio and see its impact on the quality of the image.

Research Problem

- How can we overcome the limitations of optics manufacturing technology?
- How can we correct the Chromatic Aberration automatically with no need of manual adjustments of any parameters?
- How can we determine if PhotoAcute Studio is effective to image quality?

Objectives

- Using Almalance's PhotoAcute Studio as an easy to use program that can improve our digital image quality, to overcome the limitations of optics manufacturing technology.
- Using Almalance's PhotoAcute Studio to correct the Chromatic Aberration automatically with no need of manual adjustments of any parameters
- Comparing between the images before and after the Automatic Chromatic Aberration correction to find out the impact of Almalance's PhotoAcute Studio on the quality of the image.

METHODOLOGY

This study is based on experimental researches on how to correct the Chromatic Aberration automatically with no need of manual adjustments of any parameters using Almalance's PhotoAcute Studio and compare between the images before and after the Automatic Chromatic Aberration correction to determine its impact on the quality of the image.

We will use the following tools

- Casio EX-F1 camera with 6 Megapixel CMOS sensor
- Fully open aperture F2.7
- Studio Light
- Adobe Photoshop (info menu & guides)

Then we will analyze the results.

Theoretical Framework

Chromatic Aberration

Chromatic aberration or "color fringing" is caused by the camera lens not focusing different wavelengths of light onto the exact same focal plane (the focal length for different wavelengths is different) and/or by the lens magnifying different wavelengths differently. These types of chromatic aberration are referred to as "Longitudinal Chromatic Aberration" and "Lateral Chromatic Aberration" respectively and can occur concurrently. The amount of chromatic aberration depends on the dispersion of the glass. Chromatic aberration is visible as color fringing around contrasty edges and occurs more frequently around the edges of the image frame in wide angle shots. See figure (1). The lens properties vary with wavelength because the index of refraction is wavelength-dependent. In addition to the monochromatic (Seidel) aberrations, chromatic aberration contains wavelength dependent shifts in focus. These shifts can be decomposed into axial or longitudinal chromatic aberration (ACA) (shifts along the optical axis) and lateral chromatic aberration (shifts perpendicular to the optical axis). Lateral chromatic aberration (LCA), otherwise known as a transverse chromatic aberration, combines with spherical aberration (which is a function of aperture radius) to determine the image height of a colored rays. This combined effect is called spherochromatic aberration (SCA) or Gauss error. (Kang, 2007, p. 2). Figure (2) shows axial or longitudinal chromatic aberration (ACA) and Figure (3) shows Lateral or transverse chromatic aberration (LCA).

Axial or longitudinal chromatic aberration (ACA)

With axial or longitudinal chromatic aberration (ACA), the focal point varies along the optical axis with the light's wavelength. As a consequence, the focal length of an object cannot be exactly coincident in all three image planes, but only approaching this crucial ideal. As light strikes the sensor plane, out of focus rays contribute to a circle of confusion, which manifests as a subtle colored halo around the boundary of an object in more extremal circumstances such as at the lens's widest aperture setting. The resulting introduction of image artifacts is minimized as the lens aperture is stopped down or reduced due to the increase in depth of field bringing the axially-misaligned focal points nearer. Many modern digital cameras when in fully automatic mode, balance the aperture size preventing significant spatial frequency loss due to photon diffraction and a shallow depth of field, increasing focus selectivity and focus error as a side-effect. Due to the camera's automatic behavior, ACA is nominally minimized to imperceivable levels. Further, photographers generally reserve the use of large apertures for shooting portraiture and low-light pictures where maximum light flux is needed; lenses suitable for these situations with larger maximum apertures, typically have stronger compensation for ACA. (Blueman, 2011, p. 14). See figures (4) & (5).

Lateral chromatic aberration (LCA)

LCA is the relative and non-linear displacement of the three color planes, across the image plane, conceptually shown in

Figure (6). The result of this chromatic distortion introduces undesired artifacts and thus information, which leads to a perceived detail loss in the image, due to the misaligning of coincident features throughout the image. Less perceptible impact in lower-contrast areas reduces texture detail and generally tends to reduce the perception that LCA compromises image quality. LCA occurs along the sagittal or oblique direction to the optical axis. See figure (7). It illustrates that LCA only affects detail running orthogonal to the line through the center of the image, due to the different distortion paths for the red, green and blue planes. Taking an example shown in Figure (8), shot in near-ideal real world conditions with reduced aperture, no image shake and correct focus, we see crops from various zones of the image showing significant LCA, estimated at around an order of magnitude higher error than the Nyquist limits of the sensor, i.e. Up to around 10 pixels. The frame was taken at the optimal aperture of f/8.0 at 18mm focal length (equivalent to 27mm on a full frame sensor) on a Nikon D90 digital SLR with a Nikon 18–200mm VR lens, considered as basic professional equipment. It is clear that chromatic aberration limits image detail, even without spatial frequencies approaching the Nyquist limits of the Bayer sensor array. Since the crops show the chromatic aberration being asymmetric, LCA is therefore the dominant aberration and attenuating quality. ACA occurs symmetrically in the image feature and is shown to be far less significant.

Optics

Chromatic aberration (CA) results in each color channel having its own focal surface being deviated from the ideal flat field.

Lens Aberration

Lens chromatic aberration is caused by light of different wavelengths being bent or refracted by the lens to different degrees. This phenomenon is responsible for the familiar ability of a prism to split white light into a rainbow of colors. The reason for it is the variation of the refractive index of glass with wavelength. See figure (9).

This variation causes the focal planes for different colors of light to be at different distances from the lens and the plane of the digital camera sensors.Light is in focus in some average sense. We can say that intermediate wavelengths (i.e. Green) are in focus on the detector, but shorter wavelengths (i.e. Blue) and longer wavelengths (i.e. Red) are focused on planes slightly above and below the detector plane. See figure (10).

The lens can be thought of as made up of prisms with a continuously varying prism angle. The inset in the figure shows how this focus effect looks in a laboratory demonstration using a dark scattering background. (Zaklika, 2004, p. 2). Lens chromatic aberration cause fuzziness at object edges, because the different colors do not align exactly. Usually this is most evident at strong (i.e. High contrast or sharp) straight edges as a magenta, green, orange or blue band along the edge. Typical locations where this effect is observed might be door frames or windows. Examples of this are shown in figure (11).

The central portions of the images have had their saturation drastically increased to make the effect still more evident. When the geometrical consequences of ray tracing through the lens are examined, it becomes clear that the edge misalignment increases with distance from the optical axis. As a result, the color banding at edges within the image is most pronounced near the borders of the image and far from the optical axis coincident with the center of the image. Image corners will show the most effect if there is suitable content in the image. This is illustrated below using the stripes on a zebra. See figure (12).

Sidestepping the deeply philosophical issue of whether a zebra is black with white stripes or white with black stripes, we will focus on white stripes and choose some at the left and right edges along with one near the center. The original image was 3072 x 2048 pixels in size and has been reduced in size for this document. The insets are shown at the original actual size. Again, the saturation has been drastically increased in the center portion of the insets to make the aberration easier to see. It is quite clear that the stripes Near the image edges have green borders on one side and blue borders on the other, while the central stripe is essentially homogeneous in color. (Black stripes give the same result, of course, except for the reversal of the colors). (Zaklika, 2004, p. 3) Lens chromatic aberration typically increases with the lens aperture since light rays farther from the optical axis can be captured with a larger aperture. Telephoto and zoom lenses are often more prone to this defect than other lenses. (Zaklika, 2004, p. 4).

Paraxial optics

Paraxial (lit. Parallel-axial) optics model light as traversing optical elements within an optical system with an angle of incidence from the optical axis considered small. Due to this low-angle approximation, wavefronts propagating through the optical system are modeled as spherical chords, thus radiating equally at all angles, therefore free from a spherical aberration, as illustrated in Figure (13). (Blueman, 2011, p. 22).

Achromatic / Apochromatic Doublets

A Special lens systems (achromatic or apochromatic doublets) using two or more pieces of glass with different refractive indexes can reduce or eliminate this problem. However, not even these lens systems are completely perfect and still can lead to visible chromatic aberrations, especially at full wide angle. See figure (14).

Automatic correction

PhotoAcute is a leading edge tool for enhancing the quality of digital photographs. PhotoAcute processes sets of photographs taken in continuous mode to produce high-resolution, low-noise pictures. It increases image resolution, removes noise without losing image details, corrects image geometry and chromatic aberrations and expands the dynamic range. Every lens focuses the light of different wavelengths in different positions. This causes chromatic aberration that is seen as "fringes" of color around the image. PhotoAcute corrects this aberration, minimizing the circle of confusion. The correction is performed automatically, with no need of manual adjustments of any parameters. (Almalence, Chromatic Aberration, 2015). Color fringing correction is turned on/off with the Fix chromatic aberrations option the corresponding checkbox in the processing options pane. See figure (15).

Experimental Work

Lateral chromatic aberration is best measured using *tangential* edges near the sides or corners of the image, for example, edge B (above). It is not visible on radial edges such as A. See figure (16). The best edges for measuring CA are near-vertical edges on the left and right of the image. The thumbnail in figure (17) is from a 12 megapixel compact digital camera with fairly high chromatic aberration. Red fringing, the result of lateral CA, is clearly visible. The black-to-white edge to the right side of this rectangle has equally vivid green fringing. Analyzing the edge will produce a number that indicates the severity of the lateral chromatic aberration. (Imates, Chromatic Aberration, 2016). We'll run a test to compare between the images before and after automatic correction of chromatic aberration using the photo acute studio to see the impact of it on the quality of the image. We'll measure Lateral chromatic aberration using *tangential* edges near the sides of the image.

Test Methodology

4 crops are compared:

- Red fringing before automatic correction of chromatic aberration and the crop after automatic correction using Almalence's PhotoAcute Studio.
- Green fringing before automatic correction of chromatic aberration and the crop after automatic correction using Almalence's PhotoAcute Studio.

Casio EX-F1 camera with 6 Megapixel CMOS sensor

- Fully open aperture F2.7
- Studio Light
- All factory settings Default
- Exposure compensation +0.7EV
- Adobe Photoshop (info menu & guides)

RESULTS

The following figures show the result of the experimental procedures. Figure (18) shows the crop of red fringing before automatic correction of chromatic aberration. We measured the (X) position of the *tangential* edges near the sides of the image using Info menu in Adobe Photoshop. It was at 5.67. Figure (19) shows the crop of the automatic correction of chromatic aberration of red fringing using PhotoAcute studio. We measured the (X) position of the *tangential* edges near the sides of the image using Info menu in Adobe Photoshop. It was at 5.75. Table (1) summarizes the results of the comparison between the crop of red fringing before the automatic correction and the crop after the automatic correction of chromatic aberration of red fringing using PhotoAcute studio. The chart in figure (20) shows red fringing automatic correction comparison. Figure (21) shows the crop of green fringing before automatic correction of chromatic aberration.

We measured the (X) position of the *tangential* edges near the sides of the image using Info menu in Adobe Photoshop. It was at 6.74. Figure (22) shows the crop of the automatic correction of chromatic aberration of green fringing using PhotoAcute studio.

We measured the (X) position of the *tangential* edges near the sides of the image using Info menu in Adobe Photoshop. It was at 6.58. Table (2) summarizes the results of the comparison between the crop of green fringing before the automatic correction and the crop after the automatic correction of chromatic aberration of green fringing using PhotoAcute studio. The chart in figure (23) shows green fringing automatic correction comparison.

DISCUSSION

Almalence PhotoAcute studio

Compared to the original crops which suffering from red and green fringing and the other crops resulting from applying automatic chromatic aberration correction using the Almalence PhotoAcute studio, we found that the Almalence PhotoAcute studio was able to achieve the clearest images with no annoying chromatic aberration (red and green fringing) .

- The study carried out by Sing Bing Kang, (2007) referred to how to undo most of the effects of chromatic aberration from a single image, starting from the basic principles of image formation to characterize CA, and show how its effects can be substantially reduced, and this is consistent with our study.
- Compared to previous studies, this study focused on the impact of the Almalence PhotoAcute studio on chromatic aberration and its effect on the image quality.
- This study, was mainly interested in correcting the effects of Chromatic Aberration automatically and overcome the limitations of optics manufacturing technology through the use of Almalance's PhotoAcute Studio, which corrects this aberration automatically, minimizing the circle of confusion, with no need of manual adjustments of any parameters.
- The technological developments in

Image processing algorithms urged mainstream media and journalists to use images taken by 'normal people', and incorporate them increasingly in their own reporting, and that due to their high quality. For example, "AnaAra", the application of the "Al Arabiya" news channel, it is a unique app that allows users to upload images about live political incidents to "Al Arabiya" News Channel.

Conclusion

- **The Almalence PhotoAcute studio** was able to achieve high quality images without any annoying chromatic aberration (red and green fringing) .
- Using **Almalence PhotoAcute studio** as an easy to use program contributed to obtain high quality images and overcome the limitations of the optics manufacturing technology.
- High quality images help us to get our facts and figures straight.
- Images that are suffering from chromatic aberration can have a profoundly negative impact.

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Zaklika, K. 2004. Chromatic Aberration Filter. Pp.2-4 (Retrieved January 31,2016) From http://campratty.com/4tooltours/kz/pdf/ChromaticAberrationFilter2006.pdf

Appendix

Figure Legend

Figure 1. Example of Cyan & Red fringing

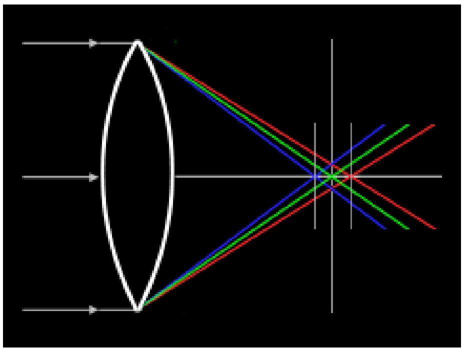

Figure 2. Axial or longitudinal chromatic aberration (ACA). Focal length varies with color wavelength

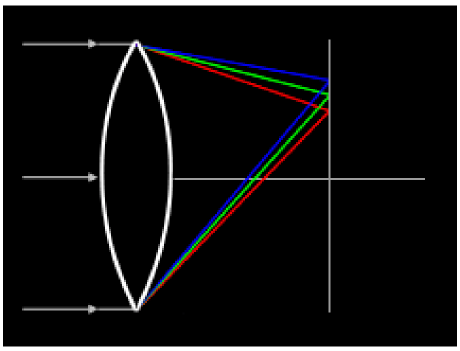

Figure 3. Lateral or transverse chromatic aberration (LCA). Magnification varies with color wavelength

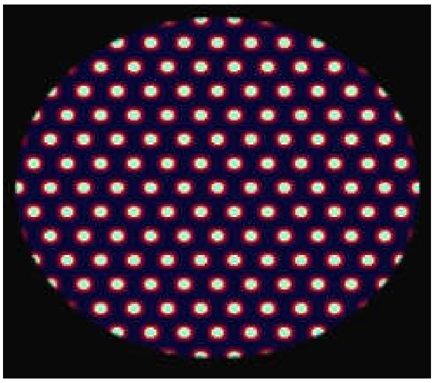

Figure 4. Axial or longitudinal chromatic aberration (ACA)

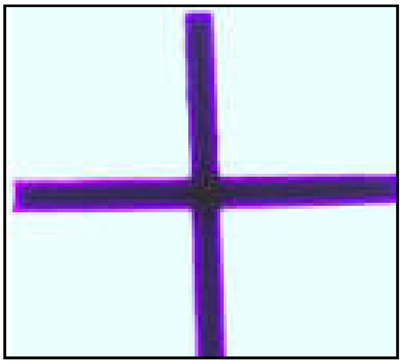

Figure 5. Axial or longitudinal chromatic aberration (ACA)

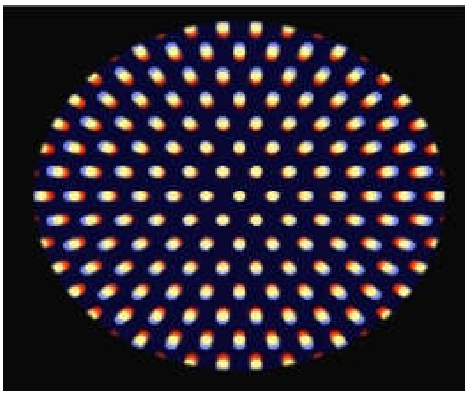

Figure 6. Lateral chromatic aberration (LCA)

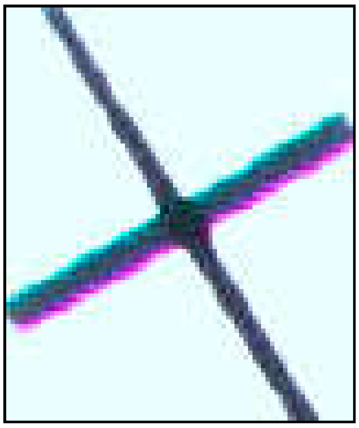

Figure 7. Lateral chromatic aberration (LCA)

Figure 8. Cropped sections exhibiting LCA

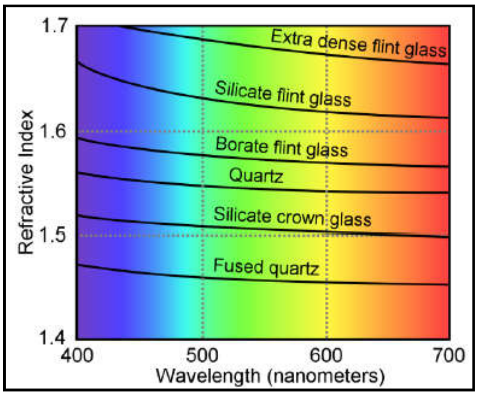

Figure 9. The variation of the refractive index of glass with wavelength

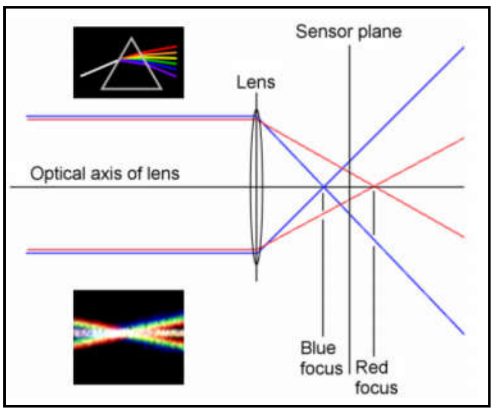

Figure 10. Light is in focus in some average sense

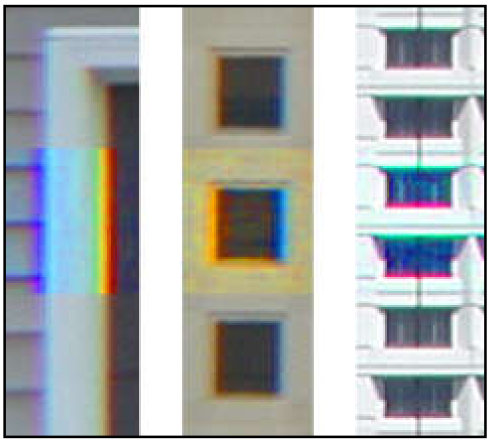

Figure 11. Lens chromatic aberration cause fuzziness at object edges

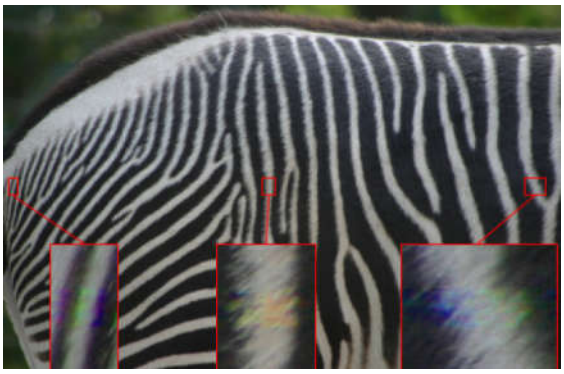

Figure 12. The edge misalignment increases with distance from the optical axis

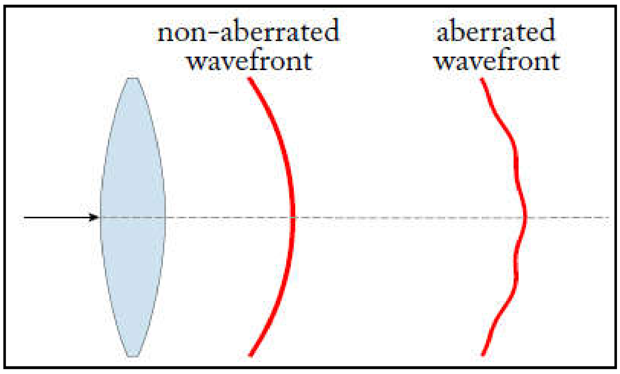

Figure 13. Paraxial approximation

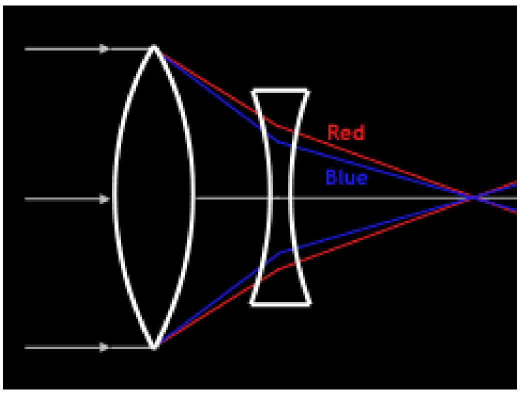

Figure 14. Achromatic / Apochromatic Doublets

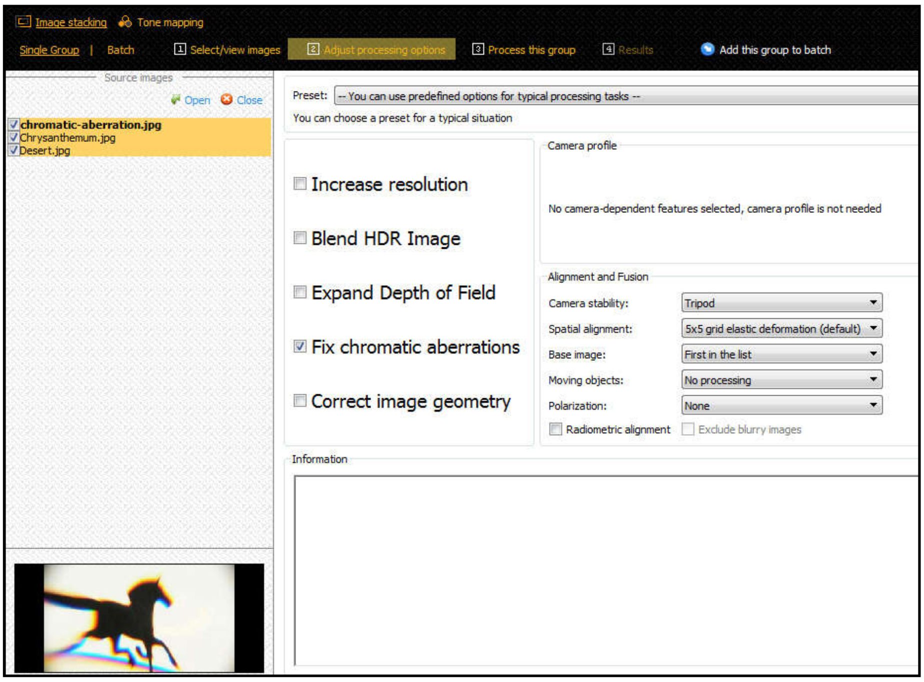

Figure 15. Fixing Chromatic Aberration by PhotoAcute

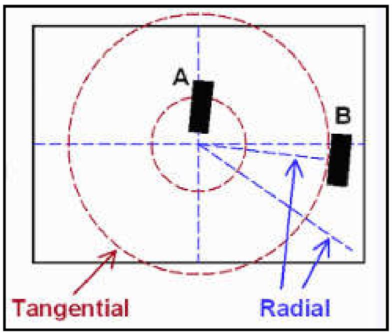

Figure 16. Measuring lateral Chromatic aberration using tangential edges

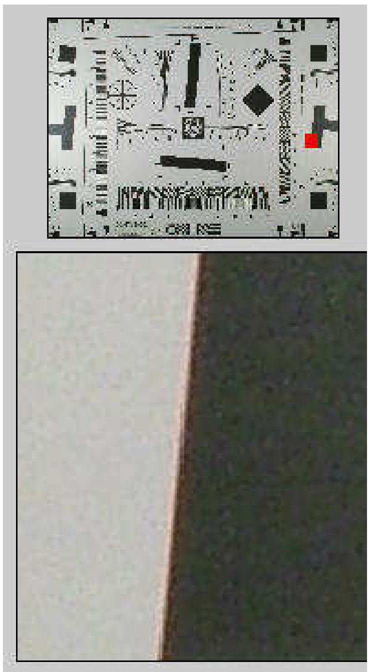

Figure 17. Red Fringing

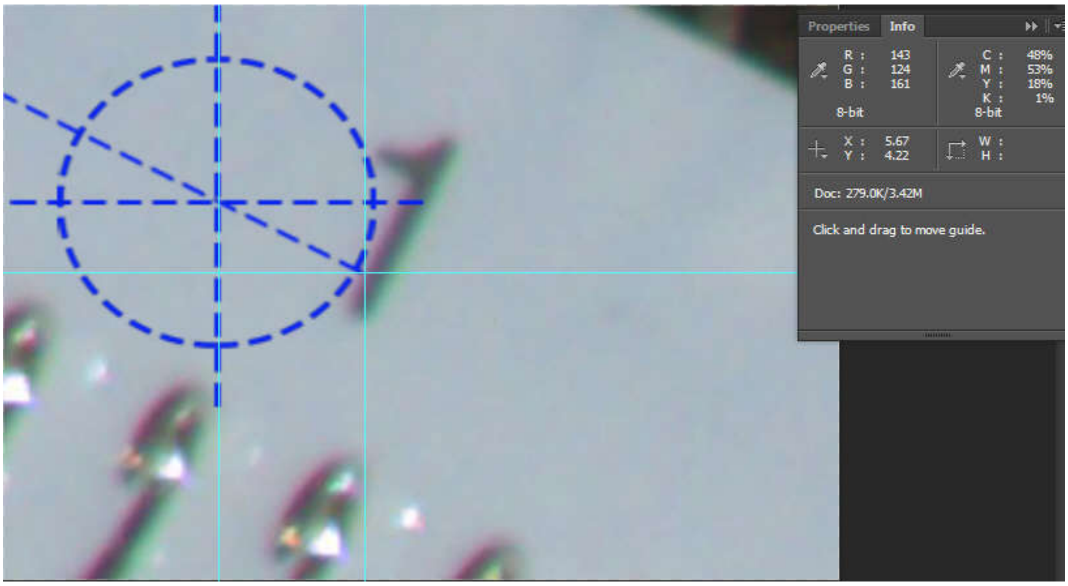

Figure 18. Red fringing (X) position

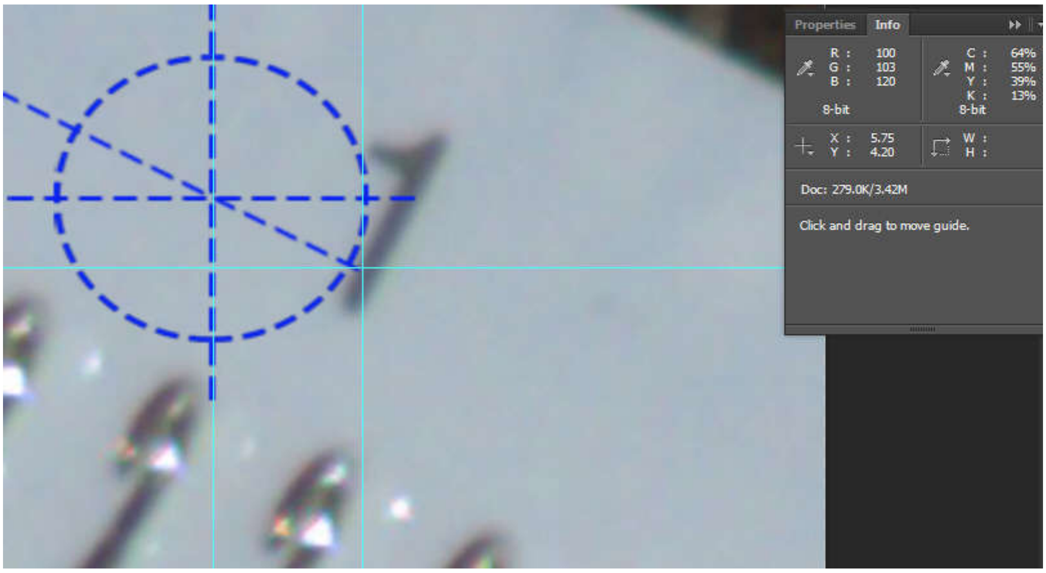

Figure 19. (X) position after red fringing automatic correction using PhotoAcute studio

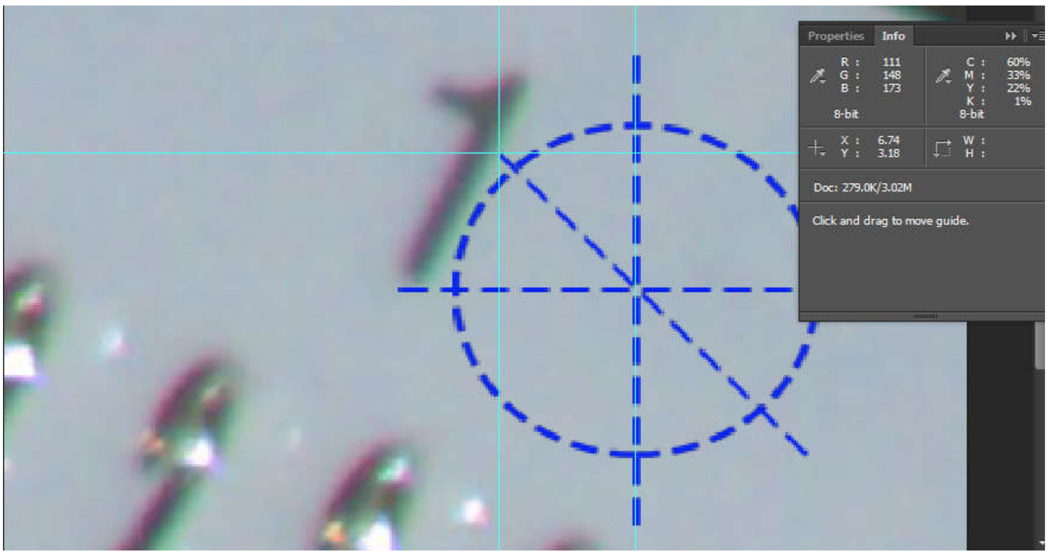

Figure 21. Green fringing (X) position

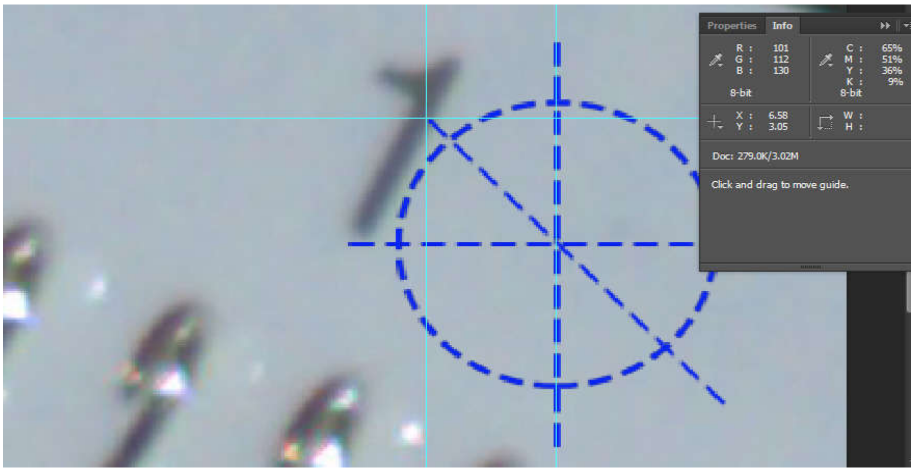

Figure 22. (X) position after green fringing automatic correction using PhotoAcute studio

Tables & Charts

Table 1. The automatic correction of chromatic aberration of red fringing

Crops	(X) Position of the tangential edges
Red fringing before the automatic correction	5.67
Red fringing after the automatic correction	5.75

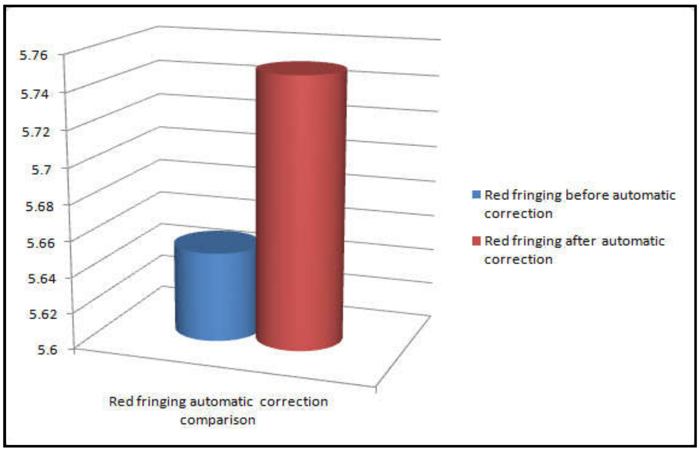

Figure 20. Red fringing automatic correction comparison

Table 2. The automatic correction of chromatic aberration of green fringing

Crops	(X) Position of the tangential edges
Green fringing before the automatic correction	6.74
Green fringing after the automatic correction	6.58

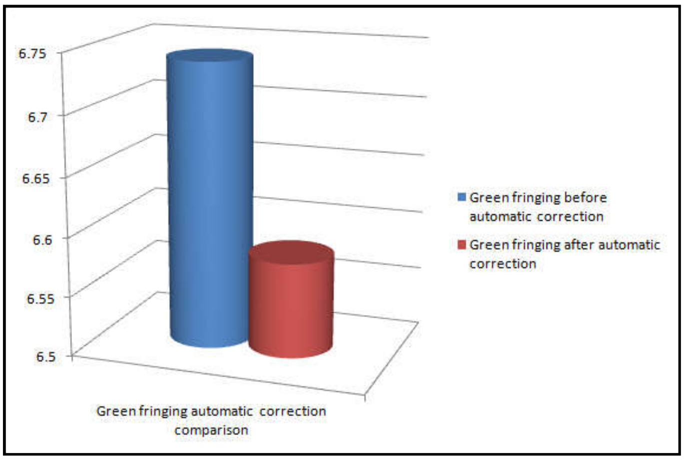

Figure 23. Green fringing automatic correction comparison

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