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THE INFLUENCE OF DEPTH OF FIELD ON THE APPEARANCE OF CHROMATIC ABERRATION

Iva Juretić, Gala Golubović, Ivana Jurič, Stefan Đurđević
University of Novi Sad, Faculty of technical sciences,
Department of graphic engineering and design, Novi Sad, Serbia

Abstract: *Chromatic aberration is an optical defect that causes light rays of different wavelengths to focus at different points along the optical axis of the lens. It is manifested as band of one color at frame transitions around contrasting edges in the photo. There are two types of chromatic aberration: longitudinal and lateral. Lateral chromatic aberration is the color fringing that occurs because the magnification of the image differs with wavelength. It tends to be far more visible than longitudinal. The aim of this research is to examine the influence of depth of field on the appearance of lateral chromatic aberration. For the purposes of the experiment, we used one mirrorless camera (Sony a1), while the lenses were variable. We used Sigma 85mm f/1.4 DG DN and Sigma 40mm f/1.4 to check which type of lens shows the most chromatic aberration and how much the change in f-number affects its appearance.*

Keywords: *chromatic aberration, digital camera, depth of field, f-number*

1. INTRODUCTION

Chromatic aberration was chosen as the subject of investigation. Chromatic aberration is an error that occurs due to inadequate use of the camera, inadequate conditions for photography or a constructive imperfection of the lens. The aim of this paper is to determine the effect of changing the depth of field on the occurrence of chromatic aberration error. The processing of the problem, the causes and consequences of the chromatic aberration error is done in the theoretical part. While in the experimental part the examination of chromatic aberration was carried out. In the continuation of the paper, the performance and results of the lens test in the experiment are presented.

2. THEORETICAL PART

2.1 Chromatic aberration

Chromatic aberration is an optical defect that causes light rays of different wavelengths to focus at different points along the optical axis of the lens (Figure 1). The consequence of this is that all wavelengths (which we see as colors) of the visible part of the spectrum are not refracted in the same focal plane, but in front or behind it. Also, since the magnification of the lens depends on the wavelength of the light, then the components of the visible spectrum are focused on different parts of the focal plane. If the point of refraction moves along the horizontal axis (in front of or behind the focal plane), it is called longitudinal (axial, longitudinal) chromatic aberration, and if it happens on different parts of the focal plane, then these are transverse (lateral, side) aberrations.
Chromatic aberrations are manifested as bands of one color (most often light blue - cyan or red) at the (for example a dark stone, and behind it a bright sky). These imperfections are solved more or less successfully in the lens itself, by installing several different convex and concave lenses. In addition, they can be removed by software (Mehić, 2011).

Figure 1: Chromatic aberration

2.2 Types of chromatic aberration

There are two types of chromatic aberration:

1) Longitudinal (axial, longitudinal) chromatic aberration - Longitudinal chromatic aberration results in blurred colors in front of and behind the focal point due to color differences in the focal point. This phenomenon is very noticeable on the periphery of very bright parts of the image, but it can occur anywhere in the image, not just at the edges.
2) Transverse (lateral, side) chromatic aberration - Transverse chromatic aberration primarily leads to color fringing on the edges of the object and on the periphery of the frame, and it is caused by the fact that the lens has a different magnification for different colors. These different levels of magnification lead to a colored glow around the edges of some objects. It is important to keep in mind that transverse chromatic aberration appears only at the edges of the frame (Mehić, 2011).

2.3 Factors influencing the appearance of chromatic aberration

The cause of chromatic aberration usually lies in the fact that the refractive index of light in a certain medium depends on the wavelength. Rays of shorter wavelengths (for example blue) are refracted more (ie at a larger exit angle) than those of longer wavelengths. Rays of shorter wavelengths are focused closer to the lens than rays of longer wavelengths (for example red). These imperfections are solved more or less successfully in the lens itself, by installing several different convex and concave lenses (Husić, 2012).

3. EXPERIMENTAL PART

The experimental measurements were aimed at determining the influence of different lens characteristics and focal length on the appearance of chromatic aberration errors.
The testing was performed in accordance with the requirements of the ISO 12233 standard from 2012, a test card for determining the presence of chromatic aberration in digital cameras.
The experiment was conducted in six steps:

1) Choice of device body and lens
2) Selection of test card
3) Setting the scene, choosing lighting and additional devices,
4) Taking test photos
5) Analysis and evaluation of photographs for chromatic aberration errors
6) Assessment of results

3.1 Test card

The ISO 12233 test card is suitable for testing the transverse chromatic aberration of the lens (Figure 2). Aberrations of this type are best measured at the tangential edges near the sides or corners of the image. The ISO 12233 map contains several border areas that are placed at an angle of 5 degrees from the vertical.

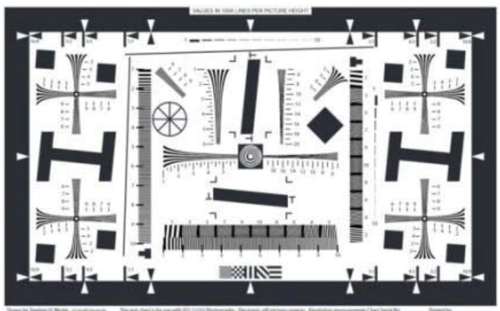

Figure 2: Test card ISO 12233

3.2 Software

Imatest is the most widely used software in the industry. It is currently the most popular digital photo quality testing software package in the world. Using the Imatest software, it is possible to analyze various factors of photo quality. This includes image sharpness, color gamut, noise, dynamic range, tonal reproduction, flare, lens distortion, lens vignetting, sensor non-uniformity, moire, and more.
SFR is a module that measures sharpness, chromatic aberrations and noise level (Figure 3.8). This module was used in the analysis of the photographed test card ISO 12233 (Vukojević, 2013).
Table 1 shows the categorization of the aberration surface by intensity expressed in pixels.

Table 1: Categorization of the surface of chromatic aberration by intensity expressed in pixels

Chromatic aberration surface	Intensity
under 0.5	insignificant
0.5-1	low (hard to see)
1-1.5	moderate (somewise visible in the case of large format printing)
above 1.5	strong (very visible in the case of large format printing)

3.3 Camera body

The Sony Alpha1, better known as the Sony A1, is a flagship model in every sense (Figure 3). This full-frame mirrorless device offers high resolution for photography and 8K for video, exceptional speed and the ability to produce the most demanding professional tasks.
At its core, the Sony a1 features a newly designed 50.1MP Exmor RS BSI full-frame CMOS sensor and BIONZ XR processor. Pairing an efficient sensor with optimized processing makes the a1 capable of full-resolution 30fps continuous shooting, 8K 30p and 4K 120p 10-bit video recording, and high sensitivity up to ISO 102400 for low-light shooting. The sensor design also includes a 759-point fast hybrid AF system, which offers advanced subject tracking and real-time eye AF (Foto Diskont, n.d.).

Figure 3: Camera body Sony Alpha 1

3.4 Lenses

The lens is a set of several plastic or glass elements, with glass usually giving a better quality and sharper result. Each element has a specific function in focusing light onto the sensor, whether it's shaping the light to match the size of the sensor, correcting it, or providing a final focus point (Schiesser, 2014).
In the experiment were used two lenses:

1) The Sigma 85mm f/1.4 DG DN Art for Sony is a premium portrait lens from the ART series (Figure 4). It is an upgraded version of the lens that has an aperture ring which can be switched to continuous mode (without clicks) which is particularly convenient for video recording. It has ultra-fast and quiet autofocus and 11 circular blades apertures that enable a beautiful bokeh effect. It is extremely well made with application of aluminum and thermally stable composite. (Foto Diskont, n.d.).
   Figure 4 shows the parts of the Sigma 85mm f/1.4 DG DN Art.

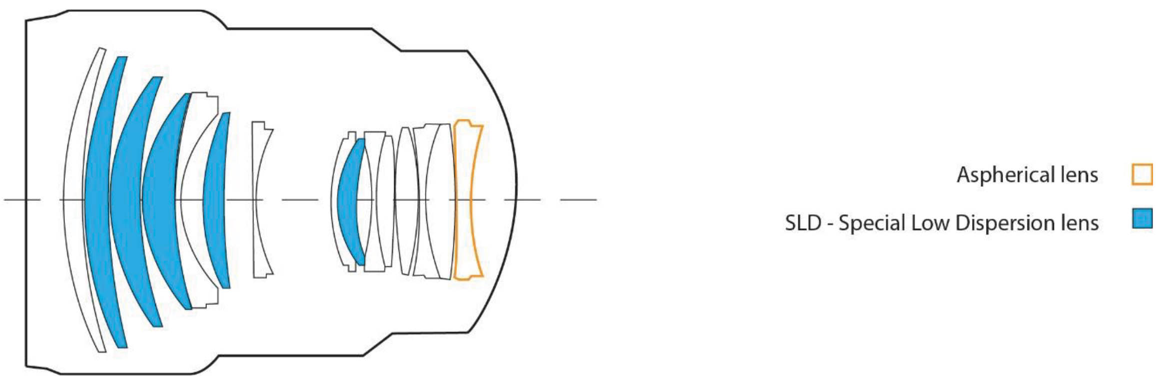

Figure 4: Parts of the Sigma 85mm f/1.4 DG DN Art

2) The Sigma 40 mm f/1.4 is a premium professional lens for Sony mirrorless cameras (Figure 5). On cameras with an APS-C sensor, its focal length is 64 mm. The lens has FLD and SLD optical elements that enable it to have superior optical characteristics. The maximum aperture of f/1.4 makes it ideal for shooting in poor light conditions. It also has an ultra-fast and quiet autofocus motor. It is resistant to weather influences (Foto Diskont, n.d.). The minimum focal length is 40 cm, the diameter of the filter is 82 mm, and the diaphragm is realized in the form of 9 rounded leaves (PCFoto, n.d.). Figure 5 shows the parts of the Sigma 40mm f/1.4

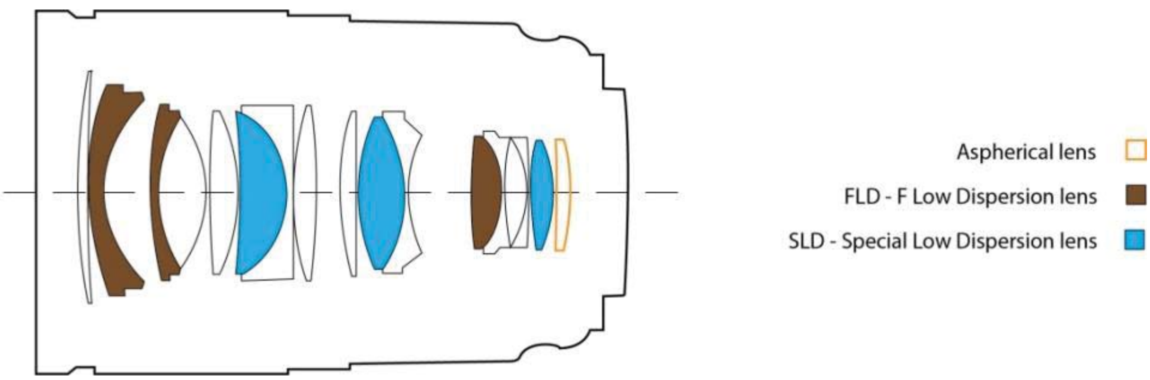

Figure 5: Parts of the Sigma 40mm f/1.4

3.5 Scene setting

The first step in setting the scene is finding a suitable space and providing a darkened room. LED lamps were used in the experimentwhich simulate daylight, with a strength of about 5000 K. They are placed so that the cornerlighting should be as recommended by Imatest, between 30 and 45 degrees, in order toavoided the problem of creating reflections or shadows on the test map.

The test card is placed on a neutral background, a wall, at an angle of 90 degrees.After that, the stand is placed, opposite the test card, on which it is placedthe camera that is used so that there is no blurring of the image due to hand tremors (Figure 6).

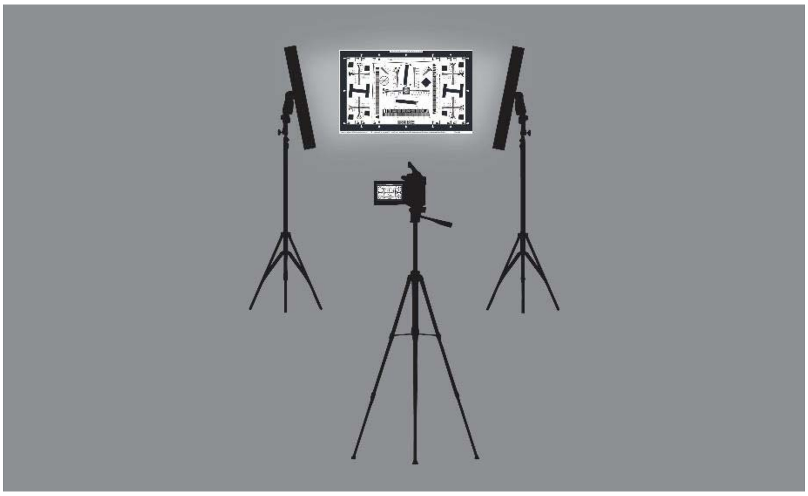

Figure 6: Scene setting

After the correct setting of all elements, a test card was photographed and then all other necessary photos, with one body and two different lenses.

Two different lenses were used at different distances from the test tickets. Sigma 85mm f/2.8 DG DN Art lens is placed at a distance of 180 cm from the test map, where is the aperture, and therefore the ISO, a variable factor while the focal length (85mm) and shutter speed (160) fixed value. When taking photos with the lens Sigma 40mm f/2.8 camera body is placed at a distance of 120 cm from the test card, where the apertur, and therefore ISO, were a variable factors while the focal length (40 mm) and shutter speed (1/80) were fixed values.

4. MEASUREMENT RESULTS

4.1 Test results on the Sigma 85mm lens f/1.4 DG DN

The test was performed on the Sigma 85mm f/2.8 DG DN lens at a distance of 180 cm from the test map, where the aperture, and therefore the ISO, is a variable factor while the focal length (85mm) and shutter speed (160) are fixed values.

On Figure 7. a graph is shown with the results for the tested lens at different apertures. The graph shows the X axis, on which the values are aperture, and two Y axes where the chromatic aberration is expressed for the ROI surface on the right and left side of the same image.

Based on the obtained results, according to the values from table 1. we conclude that the lens generally makes either insignificant or weak ones at any given aperture chromatic aberrations that are hard to notice or not noticeable.

The value of the left side is generally higher than the right side, except at the smallest aperture where the value of the left side is significantly higher compared to the previous point, while the opposite is true for the right side.

Correlation between left and right chromatic aberration values in this case is 0.79. Based on this information, as well as on the basis of graphics, we can observe that they behave relatively similarly, with the change being between steps more subtle on the left side.

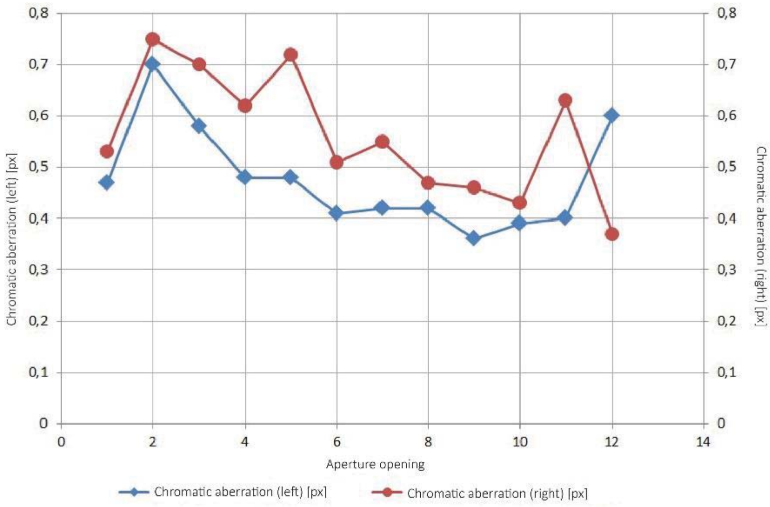

Figure 7: Graphic with the results obtained when photographing with the Sigma 85mm f/1.4 DG DN lens

On Figure 8. the ROI surfaces used in the measurement are shown, where the largest visible chromatic aberration for both sides, at an aperture of f/1.8, while on Figure 9. the smallest chromatic aberration shown for the left side at aperture of f/9.0, and f/11 for the right side.

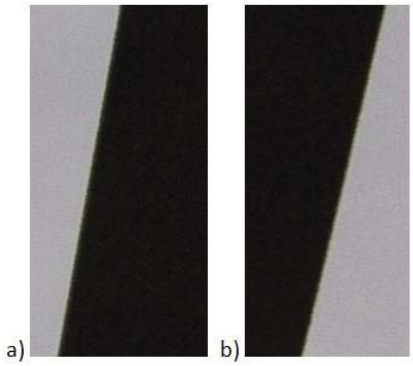

Figure 8: ROI of the surface with the largest chromatic aberration; a) left and b) right side

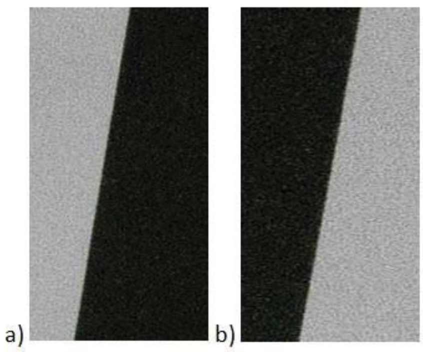

Figure 9: ROI surface with the smallest chromatic aberration; a) left and b) right side

4.2 Test results on the Sigma 40mm lens f/1.4

The test was performed on the Sigma 40mm f/2.8 lens at a distance of 120 cm from the test map, where the aperture, and therefore the ISO, is a variable factor while the focal length (40mm) and shutter speed (1/80) are fixed values.
On Figure 10. a graph is shown with the results for the tested lens at different apertures. The graphic shows the X axis, on which the aperture values are, and two Y axes, on which the chromatic aberration is expressed for the ROI area on the right and left side of the same image.
Based on the obtained results, according to the values from table 1. we conclude that the samples taken from the left side showed chromatic aberration below 0.5 at all apertures, which is insignificant chromatic aberration. They are on the right values in the range from 0.35 px to 0.59 px which, according to the table, are values that fall into insignificant chromatic aberrations and minimum values from the range of weak, that is, hard-to-notice chromatic aberrations.
In this case, the chromatic aberration values on the left and right side when changing the aperture are not correlated, it is very weak and the correlation coefficient is 0.26. Based on this information, we can see the basis of the graph that the left and right sides do not behave similarly in terms of increasing chromatic aberration with decreasing aperture.

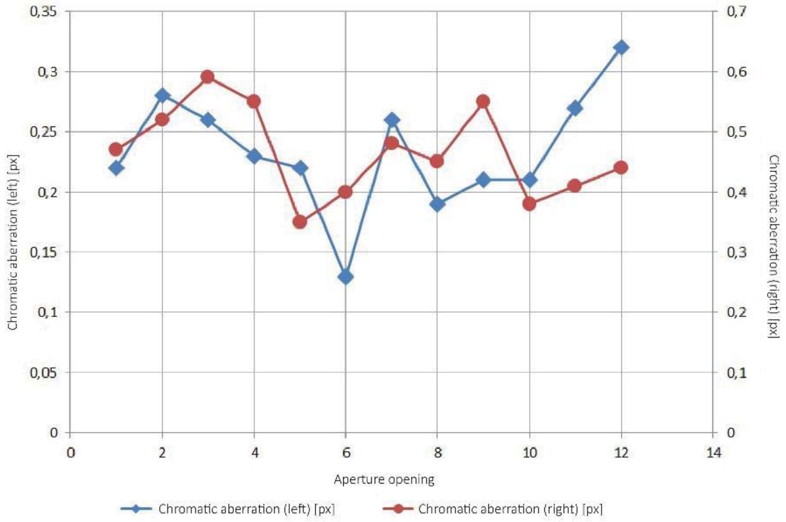

Figure 10: Graphic with the results obtained when photographing with the Sigma 40mm f/1.4

On Figure 11. the ROI surfaces used in the measurement are shown, where the largest chromatic aberration for the left side is at an aperture of f/16, and for the right side is f/2.2. While the values at medium apertures are the most ideal for photography, specifically the smallest chromatic aberration for the left side is at aperture of f/4.5, and for the right side f/3.5 shown on Figure 12.

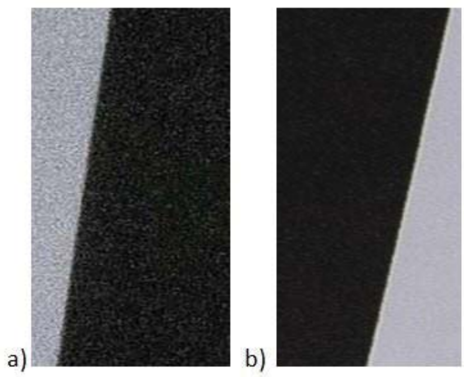

Figure 11: ROI of the surface with the largest chromatic aberration; a) left and b) right side

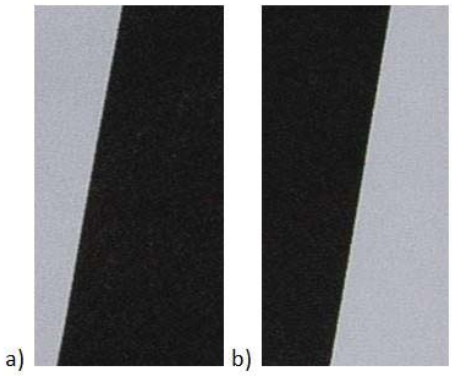

Figure 12: ROI surface with the smallest chromatic aberration; a) left and b) right side

5. CONCLUSION AND FURTHER RESEARCH

When studying the theoretical foundations of photography itself as well as individual parts of the camera system, we come to the conclusion that the theoretically perfect way of creating a photograph does not exist in practice. Deviations from perfect values
the consequence is the imperfection of parts of the photographic system where the construction and quality of the used lenses play a crucial role.

In order for the experimental part to be adequately done, it was necessary to study all the characteristics of the camera body as well as the lenses used, which significantly affect the final quality of the image. All the necessary knowledge for understanding the issues dealt with in this paper are clearly summarized and presented in the theoretical part.

In order to obtain relevant results, the test card was photographed in accordance with the appropriate standards and recommendations. With the help of Imatest software, analyzes were made that gave results about the quality of the tested lenses.

Changing the aperture did not drastically affect the increase in chromatic aberration either in the case of the Sigma 85mm f/1.4 DG DN, or in the case of the Sigma 40 mm f/1.4 lens. In general, at the average value of the examined apertures, the differences in chromatic aberration are the smallest, that is, negligible. Comparing these two lenses, the smallest measured value is for the Sigma 40mm f/1.4 and is 0.13 px at an aperture of f/4.5, and the largest is for the Sigma 85mm f/1.4 DG DN lens at an aperture of f/3.5 and is 0 ,72 px.

The camera body as well as the lens that will be used are of great importance because their selection directly affects the results obtained. Also, it is of great importance to choose the appropriate test procedure, properly light the scene, perform the photography itself, analyze the obtained photos for the aforementioned irregularities with specialized software tools, and then choose the best lens by evaluating the results.

It should also be borne in mind that for the full use of all the performance of the camera and lens, great knowledge and experience are needed, because otherwise the human factor can affect the degradation of the final quality.

By improving the lenses, where recently new materials are used to make the lenses themselves, as well as special coatings that compensate for imperfections, better and better results are obtained. In the future, it can be expected that during the construction and production of the lenses themselves, errors arising due to reduce lens imperfections to a minimum. In addition to the improvement of lens production, software tools for removing lens irregularities are also being improved in parallel.

6. ACKNOWLEDGMENTS

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