Adobe Camera Model

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Introduction

Cameras are light capturing devices. That light begins as rays emanating from some source like the sun, which travels through space until striking some object. When that light reaches the object, much spectrum of the light is absorbed, and what is not absorbed is reflected and some of it makes its way through the optics of the camera and is eventually deposited and collected on the camera sensor (or film). The geometric configuration of the passage of a bundle of light rays from the object through the lens to the image plane can be described mathematically by a parametric model, called the camera model.

The pin-hole camera model is a simplistic model where the bundle of light rays would pass from the object to the image plane through a single perspective center and form a sharp image on the plane of focus according to the fundamental physical laws of the ray optics. In this ideal model, there is no distortion in the images. The real world lens always involves design compromises and imperfect construction. It means that the pin-hole camera model is only good as a first order approximation. Deviations from the ideal model must be considered and mathematically modeled.

This document describes a standard camera model as proposed by Adobe. The Adobe® Photoshop, Adobe® Camera Raw and Adobe® LightRoom employ the Adobe Camera Model to correct for lens aberrations. The Adobe® Lens Profile Creator is a free Adobe application that allows anyone to characterize their own camera and lens, and create an Adobe Camera Model description as in a lens correction profile (LCP).

The report is intended for developers who wish to implement Adobe Camera Model in their products with intent to compensate for the lens aberrations, and partners who wish to create lens profiles for their cameras and lenses.

Terminology

Adobe® Lens Profile Creator: The Adobe application that is used to generate an Adobe camera model description for a camera, and create a Lens Correction Profile (a LCP file).

Camera Calibration: The process of estimating the camera model parameters that best describe what happens to a bundle of rays coming from the object when they pass through the lens and onto the image plane.

Fisheye Lens: A lens that generates a distorted image, bending light differently from a rectilinear lens, to encompass a very short, wide-angle focal length. The corners of an image will appear distorted and "squeezed-in" on a fisheye.

Focal Length: The perpendicular distance from the perspective center of the lens system to the image plane, also known as the principal distance.

Focus Distance: The actual distance of the camera from the subject being photographed, also called subject distance. It is the distance of the subject to the sensor/film plane.

Geometric Distortion: An optical aberration that bends the light rays that pass through the lens, particularly along the periphery of the image plane, to create a distorted-looking image. The most common forms of distortion are referred to as "barrel distortion" and "pincushion distortion", because of the characteristic shape of the distortion as it appears in the image.

Lateral Chromatic Aberration: An optical aberration that gives the appearance of color fringing, particularly along high-contrast areas of the image. This aberration is caused by different wavelengths that make up white light being magnified at different positions of the same focal plane.

Lens Correction Profile (LCP): A file that contains the Adobe camera model description for a specific camera body and lens combination. It is the common file format that tells Adobe applications on how to apply lens correction on an input image.

Principal Point: The location of an image on the image plane formed by the direct optical axial ray passing through the perspective center of the lens.

Rectilinear Lens: A lens that generates a "normal" looking image, matching closely to the perspective of the human eye; also known as the perspective lens.

Sensor Format Factor: The dimension of a camera's sensor imaging area relative to the 35 mm film format. It is the ratio of a 35 mm frame's diagonal (43.3 mm) to the

diagonal of the image sensor in question, i.e. $diag_{35mm}$ / $diag_{sensor}$. It is also known as the camera's crop factor, or the focal length multiplier.

Vignette: Light falloff at the periphery of an image, giving the appearance of a darker border along the edges of the image.

Adobe Camera Model

The Adobe Camera Model characterizes the most common form of lens aberrations, namely the geometric distortion (both radial and tangential distortions), the lateral chromatic aberration and the radial light falloff from the principal point (the vignetting), for both the rectilinear and fisheye type of lenses.

Geometric Distortion Model for Rectilinear Lenses

Before explaining the Adobe's geometric distortion model for rectilinear lenses, let's first introduce some notations. Figure 1 illustrates the pin-hole camera model. The image plane is setup at one focal length *F* distance away from the camera coordinate system's XY plane. The object point P in the camera coordinate system is projected onto the image plane with the emanating light ray passing through the camera's perspective center O. The resulting image point is referenced as point (u,v) in the image coordinate system, or equivalently as point (X,Y,F) in the camera coordinate system. Typically, the u-v coordinates are denoted in the number of pixels; whereas the X-Y-Z coordinates are represented in the real world physical unit such as millimeters.

Let *F* be the focal length in millimeters. Let s_x and s_y denote the width and height of the sensor pixels measured in the number of pixels per millimeter. Let $f_x = s_x F$ and $f_y = s_y F$, which are the focal lengths expressed in the number of X and Y pixels respectively. Note that when the individual pixels on the sensor are not square, the two focal lengths f_x and f_y would be different.

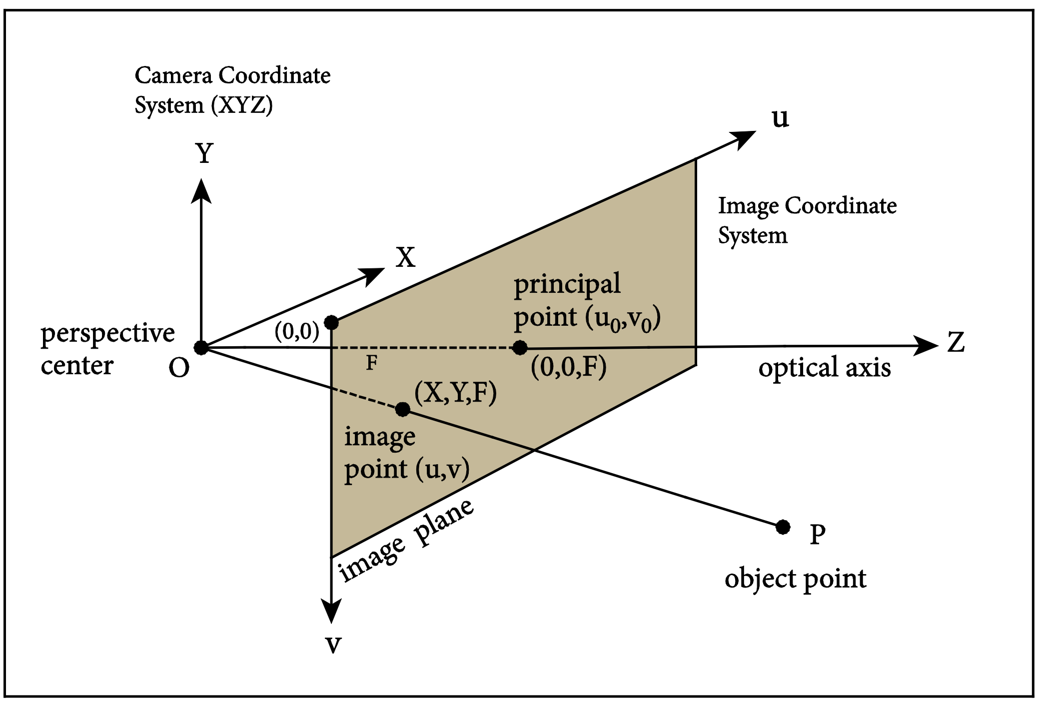

Figure 1 depicts the pin-hole camera model.

In the pin-hole camera model, all points along the ray from the perspective center O towards the object point P share the same image point (X,Y,F). We can thus uniquely represent the projective mapping of the object points along ray using the homogenous coordinates (x,y,1) of the image point (X,Y,F), where $x = X/F, y = Y/F$. The point (x,y) is considered the ideal image point location before the lens distortion is introduced. Let (x_d, y_d) be the distorted image point after the lens distortion, which is the actual point observed on the image.

The Adobe geometric distortion model for the rectilinear lenses can be formulated as follows:

$$\begin{bmatrix} x_d \\ y_d \end{bmatrix} = \begin{bmatrix} (1 + k_1 r^2 + k_2 r^4 + k_3 r^6)x + 2(k_4 y + k_5 x)x + k_5 r^2 \\ (1 + k_1 r^2 + k_2 r^4 + k_3 r^6)y + 2(k_4 y + k_5 x)y + k_4 r^2 \end{bmatrix}$$

Where $r^2 = x^2 + y^2$ and k_1, k_2, k_3 are parameters for the radial distortion and k_4, k_5 are parameters for the tangential distortion.

Equivalently, the model can also be re-written in the image coordinate system as in the following equations:

$$\begin{bmatrix} x_d \\ y_d \end{bmatrix} = \begin{bmatrix} (u_d - u_0) / f_x \\ (v_d - v_0) / f_y \end{bmatrix} \qquad \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} (u - u_0) / f_x \\ (v - v_0) / f_y \end{bmatrix}$$

$$\begin{bmatrix} u_d \\ v_d \end{bmatrix} = \begin{bmatrix} u + f_x[(k_1 r^2 + k_2 r^4 + k_3 r^6)x + 2(k_4 y + k_5 x)x + k_5 r^2] \\ v + f_y[(k_1 r^2 + k_2 r^4 + k_3 r^6)y + 2(k_4 y + k_5 x)y + k_4 r^2] \end{bmatrix}$$

As part of the rectilinear lens model calibration process, $u_0, v_0, f_x, f_y, k_1, k_2, k_3, k_4, k_5$ are the set of model parameters that need to be estimated.

Geometric Distortion Model for Fisheye Lenses

Figure 2 illustrates the Adobe camera model for the fisheye lens. The image plane is setup at one focal length *F* distance away from the camera coordinate system's XY plane. The object point P in the camera coordinate system is projected onto the image plane with the emanating light ray passing through the camera's perspective center O. The incident angle of the incoming ray with the Z-axis is denoted as θ. In the pin-hole camera case, the ideal image point would be at (u,v) in the image coordinate system. However, because of the radial distortion of the fisheye lens, the distorted image point is actually observed at (u_d, v_d). Let r and r_d be the respective

radial distances of the ideal and the distorted image points to the principal point, in the camera coordinate system.

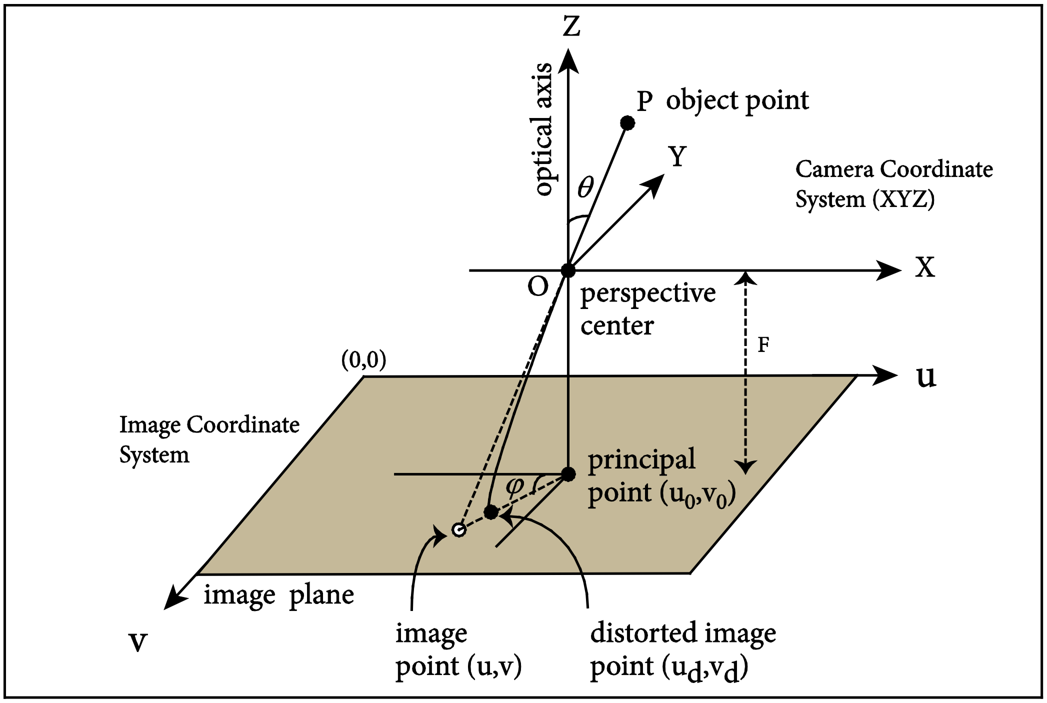

Figure 2 illustrates the fisheye camera model.

The Adobe fisheye geometric distortion model can then be formulated as follows:

$$r_d = f \cdot (\theta + k_1\theta^3 + k_2\theta^5)$$

where $\theta = \arctan(r / f)$ and k_1, k_2 are fisheye camera model parameters. It is possible to include higher order polynomial terms as part of the approximation in the future. We found that the approximation up to the 5th order term for θ is accurate enough for most applications.

Equivalently, the model can also be re-written in the image coordinate system as in the following equations:

$$\begin{bmatrix} u_d \\ v_d \end{bmatrix} = \frac{1}{r}(\theta + k_1\theta^3 + k_2\theta^5)\begin{bmatrix} f_x \cdot \Delta u \\ f_y \cdot \Delta v \end{bmatrix} + \begin{bmatrix} u_0 \\ v_0 \end{bmatrix}$$

where $\begin{bmatrix} \Delta u \\ \Delta v \end{bmatrix} = \begin{bmatrix} u - u_0 \\ v - v_0 \end{bmatrix}$, $\theta = \arctan(r / f)$, $r = \sqrt{\Delta u^2 + \Delta v^2}$, $f = \sqrt{f_x f_y}$. The formulation assumes re-sampling the output corrected image with a uniform square pixel size $s = f/F$.

As part of the fisheye lens model calibration process, $u_0, v_0, f_x, f_y, k_1, k_2$ are the set of model parameters that need to be estimated.

Lateral Chromatic Aberration Model

In color photography, the chromatic aberration describes the phenomenon of a lens failing to focus all colors of an object point to the same point on the image plane. It occurs because lenses have different refractive indices for different wavelengths of light, giving the appearance of color "fringes" of along object boundaries.

Chromatic aberration can be both longitudinal, in that different wavelengths are focused at a different distance along the optical axis, causing different levels of blurring for different colors; and lateral, in that different wavelengths are magnified differently within the image plane that is perpendicular to the optical axis. The problem of chromatic aberration becomes more visible as the digital camera sensor becomes ever more higher resolution.

Without the loss of generality, we describe the Adobe lateral chromatic aberration model in the context of three-color RGB image sensors. It can easily be extended to other multi-color image sensors.

The Adobe lateral chromatic aberration model for RGB image sensors contains three parts: First, there is description of the geometric distortion model for a reference color channel. In this case, the Green color channel is chosen as the reference color channel. This geometric distortion model can take on the form of the earlier geometric model for the rectilinear lens or the fisheye lens, depending on the type of lens used. Then there are descriptions of two differential geometric distortion models for both the Red and the Blue color channels relative to the Green reference color channel. The differential geometric model takes into account the additional parameters for scaling, radial and tangential distortions.

Let (x_d, y_d), (x_d^R, y_d^R) and (x_d^B, y_d^B) denote the respective coordinates of the distorted image points in the Green, Red and Blue color channels for the same object point P. The differential geometric distortion models are therefore formulated as follows:

$$\begin{bmatrix} x_d^R \\ y_d^R \end{bmatrix} = \alpha_0 \begin{bmatrix} (1+\alpha_1 r_d^2 + \alpha_2 r_d^4 + \alpha_3 r_d^6)x_d + 2(\alpha_4 y_d + \alpha_5 x_d)x_d + \alpha_5 r_d^2 \\ (1+\alpha_1 r_d^2 + \alpha_2 r_d^4 + \alpha_3 r_d^6)y_d + 2(\alpha_4 y_d + \alpha_5 x_d)y_d + \alpha_4 r_d^2 \end{bmatrix}$$

$$\begin{bmatrix} x_d^B \\ y_d^B \end{bmatrix} = \beta_0 \begin{bmatrix} (1+\beta_1 r_d^2 + \beta_2 r_d^4 + \beta_3 r_d^6)x_d + 2(\beta_4 y_d + \beta_5 x_d)x_d + \beta_5 r_d^2 \\ (1+\beta_1 r_d^2 + \beta_2 r_d^4 + \beta_3 r_d^6)y_d + 2(\beta_4 y_d + \beta_5 x_d)y_d + \beta_4 r_d^2 \end{bmatrix}$$

where $r_d^2 = x_d^2 + y_d^2$. The $\alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ are differential model parameters for the Red-Green color shift. The $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ are differential model parameters for the Blue-Green color shift.

Equivalently, the differential models can also be re-written in the image coordinate system as in the following equations:

$$\begin{bmatrix} u_d^R \\ v_d^R \end{bmatrix} = \begin{bmatrix} f_x \cdot x_d^R + u_0 \\ f_y \cdot y_d^R + v_0 \end{bmatrix} \qquad \begin{bmatrix} u_d^B \\ v_d^B \end{bmatrix} = \begin{bmatrix} f_x \cdot x_d^B + u_0 \\ f_y \cdot y_d^B + v_0 \end{bmatrix}$$

As part of the lateral chromatic aberration model calibration process, the geometric distortion model for the Green reference color channel needs to be estimated. In addition, the two sets of Red/Green and Blue/Green differential model parameters $\alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ and $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ also need to be estimated.

Vignette Model

The Adobe Vignette Model characterizes the radial falloff of the sensor response from the principal point. Let $I(x_d, y_d)$ and $I_{ideal}(x_d, y_d)$ be the observed and the ideal (or vignette corrected) raw sensor values at the distorted image point (x_d, y_d). The raw sensor values are assumed to be linearly proportional to the radiance incident upon the image point, i.e. assuming a linear camera sensor response curve. The vignette function can be expressed as a polynomial radial loss function:

$$L(x_d, y_d) = 1 + \alpha_1 r_d^2 + \alpha_2 r_d^4 + \alpha_3 r_d^6$$

$$I(x_d, y_d) = I_{ideal}(x_d, y_d) \cdot L(x_d, y_d)$$

where $r_d^2 = x_d^2 + y_d^2$ and $\begin{bmatrix} x_d \\ y_d \end{bmatrix} = \begin{bmatrix} (u_d - u_0)/f_x \\ (v_d - v_0)/f_y \end{bmatrix}$. Or equivalently, the vignette function can be approximated as a polynomial radial gain function, which might be more preferable in the numeric computation for the vignette correction, because it avoids the possible division by zero problems:

$$G(x_d, y_d) \approx 1 - \alpha_1 r_d^2 + (\alpha_1^2 - \alpha_2) r_d^4 - (\alpha_1^3 - 2\alpha_1\alpha_2 + \alpha_3) r_d^6 + (\alpha_1^4 + \alpha_2^2 + 2\alpha_1\alpha_3 - 3\alpha_1^2\alpha_2) r_d^8$$

$$I_{ideal}(x_d, y_d) = I(x_d, y_d) \cdot G(x_d, y_d)$$

As part of the vignette model calibration process, $u_0, v_0, f_x, f_y, \alpha_1, \alpha_2, \alpha_3$ are the set of model parameters that need to be estimated. Note that these model parameters are identical for all color channels.

Lens Correction Profile File Format

The Lens Correction Profile (LCP file for short) is a file format that contains the Adobe camera model description for a specific camera body and lens combination. It is the common file format that tells Adobe applications how to apply lens correction on an input image.

The LCP file is encoded in the standard Adobe Extensible Metadata Platform (XMP) file format. This XML based file format can be read/written using Adobe's open-sourced XMPCore Toolkit library.

A LCP file is designed to be a general container for a list of lens sub-profiles. However, Adobe applications require that all sub-profiles in a LCP file must be for the same camera body and lens model combination. Furthermore, Adobe® Lens Profile Creator also makes sure that all sub-profiles in a LCP file must be generated from the same type of source image file format (DNG, JPEG), the color mode (RGB or grayscale), the image pixel bit depths and the Adobe camera model type (rectilinear or fisheye lens model). Other camera settings such as focal length, aperture and focus distance are expected to change from one sub-profile to another in a LCP file. The additional file format constraints aim to simplify the interpolation of the lens profile among the multiple sub-profiles within a LCP file for the new un-observed camera settings. The LCP file format itself does not dictate how the interpolation should be done. It is totally up to the lens correction program.

Each sub-profile has a metadata descriptor and one or more descriptors that define the geometric distortion, the lateral chromatic aberration and the vignette models. Not all three model descriptors are required to be present. A minimum of one model descriptor is required. The following sections describe the content of each part.

Profile Metadata Descriptors

The lens profile metadata descriptors help the automatic lens profile matching and aid user selection. Most of these properties are populated from the EXIF/XMP metadata of the calibration chart images (also called the reference image set) that are used to create the lens profiles.

Property	Value Type	Category	Description
stCamera:Author	String	Optional	Creator credit info.
stCamera:Make	String	Required	Camera make. EXIF Make tag value.
stCamera:Model	String	Optional	Camera model. EXIF Model tag value.
stCamera:UniqueCameraModel	String	Optional	Unique locale independent camera model. DNG UniqueCameraModel tag value.
stCamera:CameraPrettyName	String	Required	Display name for the camera body as specified by the profile creator.
stCamera:Lens	String	Optional	Lens model info. DNG Lens tag value.
stCamera:LensInfo	String	Optional	Lens info that describes the min/max focal lengths and f-numbers. DNG LensInfo tag value.
stCamera:LensID	String	Optional	Lens ID info. DNG LensID tag value.
stCamera:LensPrettyName	String	Required	Display name for the lens as specified by the profile creator.
stCamera:ImageWidth	Number	Optional	Reference image width in number of pixels. EXIF ImageWidth tag value.
stCamera:ImageLength	Number	Optional	Reference image height in number of pixels. EXIF ImageLength tag value.
stCamera: XResolution	Number	Optional	Reference image X-resolution in DPI. EXIF XResolution tag value.
stCamera: YResolution	Number	Optional	Reference image Y-resolution in DPI. EXIF YResolution tag value.

stCamera:FocalLength	Number	Required	Focal length in millimeters. EXIF FocalLength tag value.
stCamera:ApertureValue	Number	Required	Aperture value in the APEX unit. EXIF ApertureValue tag value.
stCamera:CameraRawProfile	Boolean	Required	True if the profile is created from or for camera raw images. False if the profile is created from JPEG or TIFF images.
stCamera:FocusDistance	Number	Required	Average focus distance in meters of the reference image set.
stCamera:SensorFormatFactor	Number	Optional	Sensor format factor of the reference camera. If absent, default to match all camera sensor sizes.

Rectilinear Geometric Distortion Model Descriptors

These descriptors define the geometric distortion model parameters for the rectilinear lens. Let D_{max} be the maximum of the reference image width or height in the number of pixels.

Property	Value Type	Category	Description
stCamera: PerspectiveModel	Element Tag	Required	Element that defines the rectilinear lens geometric distortion model.
stCamera:Version	Integer	Required	Model version number.
stCamera:FocalLengthX	Number	Optional	f_x / D_{max}. If absent, default to stCamera:FocalLength in millimeters. Need to be multiplied by the D_{max} of the target image when applying the model for lens correction.
stCamera:FocalLengthY	Number	Optional	f_y/ D_{max}. If absent, default to stCamera:FocalLength in millimeters. Need to be multiplied by the D_{max} of the target image when applying the model for lens correction.
stCamera:ImageXCenter	Number	Optional	u_0 / D_{max}. If absent, default to 0.5. Need to be multiplied by the D_{max} of the target image when applying the model for lens correction.
stCamera:ImageYCenter	Number	Optional	v_0 / D_{max}. If absent, default to 0.5. Need to be multiplied by the D_{max} of the target image when applying the model for lens correction.
stCamera:ScaleFactor	Number	Optional	Scale factor. If absent, default to 1.0.

stCamera: RadialDistortParam1	Number	Required	k_1.
stCamera: RadialDistortParam2	Number	Optional	k_2. Required if k_3 is present.
stCamera: RadialDistortParam3	Number	Optional	k_3
stCamera: TangentialDistortParam1	Number	Optional	k_4
stCamera: TangentialDistortParam2	Number	Optional	k_5
stCamera: ResidualMeanError	Number	Optional	Expected relative model prediction error per pixel.
stCamera: ResidualStandardDeviation	Number	Optional	Expected standard deviation of the relative model prediction error.

Fisheye Geometric Distortion Model Descriptors

These descriptors define the geometric distortion model parameters for the fisheye lens. Let D_{max} be the maximum of the reference image width or height in the number of pixels.

Property	Value Type	Category	Description
stCamera: FisheyeModel	Element Tag	Required	Element that defines the fisheye lens geometric distortion model.
stCamera:Version	Integer	Required	Model version number.
stCamera:FocalLengthX	Number	Optional	f_x / D_{max}. If absent, default to stCamera:FocalLength in millimeters. Need to be multiplied by the D_{max} of the target image when applying the model for lens correction.
stCamera:FocalLengthY	Number	Optional	f_y/ D_{max}. If absent, default to stCamera:FocalLength in millimeters. Need to be multiplied by the D_{max} of the target image when applying the model for lens correction.
stCamera:ImageXCenter	Number	Optional	u_0 / D_{max}. If absent, default to 0.5. Need to be multiplied by the D_{max} of the target image when applying the model for lens correction.
stCamera:ImageYCenter	Number	Optional	v_0 / D_{max}. If absent, default to 0.5. Need to be multiplied by the D_{max} of the target image when applying the model for lens correction.

stCamera: RadialDistortParam1	Number	Required	k_1.
stCamera: RadialDistortParam2	Number	Optional	k_2.
stCamera: ResidualMeanError	Number	Optional	Expected relative model prediction error per pixel.
stCamera: ResidualStandardDeviation	Number	Optional	Expected standard deviation of the relative model prediction error.

Lateral Chromatic Aberration Model Descriptors

These descriptors define the three components of the Adobe lateral chromatic aberration model for RGB color images.

Property	Value Type	Category	Description
stCamera: ChromaticGreenModel	Element Tag	Required	Element that defines the geometric distortion model of the reference Green color channel. The definition could be either for the rectilinear or for the fisheye lens.
stCamera: ChromaticRedGreenModel	Element Tag	Required	Element that defines the differential geometric distortion model that characterize the Red/Green color fringe. It shares the same set of descriptors as the rectilinear geometric distortion model, but the stCamera:ScaleFactor property (α_0) is required.
stCamera: ChromaticBlueGreenModel	Element Tag	Required	Element that defines the differential geometric distortion model that characterize the Blue/Green color fringe. It shares the same set of descriptors as the rectilinear geometric distortion model, but the stCamera:ScaleFactor property (β_0) is required.

Vignette Model Descriptors

These descriptors define the vignette model parameters. Let D_{max} be the maximum of the reference image width or height in the number of pixels.

Property	Value Type	Category	Description
stCamera:FocalLengthX	Number	Optional	f_x / D_{max}. If absent, default to stCamera:FocalLength in millimeters. Need to be multiplied by the D_{max} of the target image when applying the model for lens correction.
stCamera:FocalLengthY	Number	Optional	f_y/ D_{max}. If absent, default to stCamera:FocalLength in millimeters. Need to be multiplied by the D_{max} of the target image when applying the model for lens correction.
stCamera:ImageXCenter	Number	Optional	u_0 / D_{max}. If absent, default to 0.5. Need to be multiplied by the D_{max} of the target image when applying the model for lens correction.
stCamera:ImageYCenter	Number	Optional	v_0 / D_{max}. If absent, default to 0.5. Need to be multiplied by the D_{max} of the target image when applying the model for lens correction.
stCamera: VignetteModelParam1	Number	Required	$\alpha_{1.}$
stCamera: VignetteModelParam2	Number	Optional	$\alpha_{2.}$ Required if α_3 is present.
stCamera: VignetteModelParam3	Number	Optional	α_3
stCamera: ResidualMeanError	Number	Optional	Expected percentage model prediction error.

References

[1]. Clarke, T.A., Fryer, J.G., 1999. "Handbook of Practical Camera Calibration Methods and Models".

[2]. Zhang, Z., 1999. "Flexible Camera Calibration By Viewing a Plane From Unknown Orientations". *ICCV '99.*

[3]. Goldman, D.B., Chen, J.H., 2005. "Vignette and Exposure Calibration and Compensation". *ICCV'05, Volume 1.*

Appendix A: Sample Lens Profile - Rectilinear Lens


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            <stCamera:ImageXCenter>0.498820</stCamera:ImageXCenter>
            <stCamera:ImageYCenter>0.586521</stCamera:ImageYCenter>
            <stCamera:RadialDistortParam1>0.000194</stCamera:RadialDistortParam1>
            <stCamera:RadialDistortParam2>-0.003372</stCamera:RadialDistortParam2>
            <stCamera:RadialDistortParam3>0.009152</stCamera:RadialDistortParam3>
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```

```
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            <stCamera:FocalLengthY>1.380931</stCamera:FocalLengthY>
            <stCamera:ImageXCenter>0.498820</stCamera:ImageXCenter>
            <stCamera:ImageYCenter>0.586521</stCamera:ImageYCenter>
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            <stCamera:RadialDistortParam2>0.013032</stCamera:RadialDistortParam2>
            <stCamera:RadialDistortParam3>-0.040909</stCamera:RadialDistortParam3>
            <stCamera:ResidualMeanError>0.000118</stCamera:ResidualMeanError>
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            <stCamera:FocalLengthY>1.380495</stCamera:FocalLengthY>
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            <stCamera:ImageYCenter>0.586185</stCamera:ImageYCenter>
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            <stCamera:VignetteModelParam2>0.000000</stCamera:VignetteModelParam2>
            <stCamera:VignetteModelParam3>0.000000</stCamera:VignetteModelParam3>
            <stCamera:ResidualMeanError>0.057443</stCamera:ResidualMeanError>
           </stCamera:VignetteModel>
         </stCamera:PerspectiveModel>
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     </photoshop:CameraProfiles>
   </rdf:Description>
  </rdf:RDF>
</x:xmpmeta>
<?xpacket end="w"?>
```

Appendix B: Sample Lens Profile - Fisheye Lens


```
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2008/09/29-20:23:32">
  <rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#">
   <rdf:Description rdf:about=""
      xmlns:photoshop="http://ns.adobe.com/photoshop/1.0/"
      xmlns:stCamera="http://ns.adobe.com/photoshop/1.0/camera-profile">
     <photoshop:CameraProfiles>
      <rdf:Seq>
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         <stCamera:Model>Canon EOS-1Ds Mark III</stCamera:Model>
         <stCamera:Lens>EF15mm f/2.8 Fisheye</stCamera:Lens>
         <stCamera:ImageWidth>5616.000000</stCamera:ImageWidth>
         <stCamera:ImageLength>3744.000000</stCamera:ImageLength>
         <stCamera:FocalLength>15.000000</stCamera:FocalLength>
         <stCamera:ApertureValue>6.918863</stCamera:ApertureValue>
         <stCamera:LensPrettyName>Canon EF 15mm f/2.8</stCamera:LensPrettyName>
         <stCamera:CameraPrettyName>Canon EOS-1Ds Mark III</stCamera:CameraPrettyName>
         <stCamera:CameraRawProfile>False</stCamera:CameraRawProfile>
         <stCamera:FocusDistance>0.910356</stCamera:FocusDistance>
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           <stCamera:RadialDistortParam1>-0.022551</stCamera:RadialDistortParam1>
           <stCamera:RadialDistortParam2>-0.003229</stCamera:RadialDistortParam2>
           <stCamera:ResidualMeanError>0.000318</stCamera:ResidualMeanError>
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            <stCamera:ImageYCenter>0.504326</stCamera:ImageYCenter>
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```

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            <stCamera:ImageYCenter>0.504326</stCamera:ImageYCenter>
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            <stCamera:ImageYCenter>0.504309</stCamera:ImageYCenter>
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```