The principles of CCTV design in VideoCAD

Part VI   Lens distortion in CCTV design

Edition for VideoCAD 8 Professional   **S. Utochkin**

In the first article of this cycle we represented the camera view area in the form of a regular pyramid (**Fig 1**).
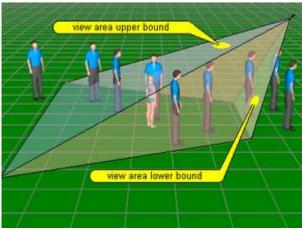

Fig. 1. Camera view area without lens distortion.

This simplification is acceptable, if requirements for precision are not high.

However, the actual shape of the view area can differ from a regular pyramid because of influence of lens distortion.

In addition to the view area shape, the lens distortion distorts distribution of spatial resolution (pixel density), considered in the second article in this cycle, and shape of objects on the image from the camera.

In this article, we will examine effects of the distortion and will consider a practical example of accurate simulation of a camera with short-focus lens.

Contents

Lens distortion in photography and CCTV

Influence of lens distortion on image is well known in photography. Because of the lens distortion straight lines on the scene are transformed into curves on the image and rectangular objects become similar to barrels or pillows. (**Fig.2, Fig.3**).

Fig 2. Lens distortion is absent.

Fig 3. Barrel distortion is visible

In most cases, the image distortion do not lead to a significant loss of its information, at the same time accounting the distortion is quite complicated. Therefore, in designing CCTV systems influence of lens distortion is usually neglected.

However, under the influence of the lens distortion not only the image itself is distorted, but the *angles of view*, *the shape of the field of view* of and *distribution of spatial resolution (pixel density)*. These parameters are not important in the photography, so the impact on them of lens distortion is not usually mentioned. However, these parameters are highly important in CCTV design.
Under the influence of the lens distortion, field of view ceases to be rectangular, and actual viewing angles horizontally, vertically and diagonally may differ significantly from the angles calculated based on the size of image sensor and the lens focal length.

Distortion in parameters of a short-focus (wide angle) lens

For example, let's consider the specification of a typical short focus lens **T2314FICS-3** (Computar):

Model No.		T2314FICS-3		Effective	Front	⌀22.8mm		
Focal Length		2.3mm		Lens Aperture	Rear	⌀7.0mm		
Max. Aperture Ratio		1:1.4		Back Focal Length		7.1mm		
Max. Image Format		4.8mm x 3.6mm(⌀6mm)		Flange Back Length		12.5mm		
Operation Range	Iris	F1.4 - F16C		Mount		CS-Mount		
	Focus	0.2m - Inf.		Filter Size		—		
Control	Iris	Manual		Dimensions		⌀34.5mm x 35.4mm		
	Focus	Manual		Weight		43g		
Object Dimension at M.O.D.		60.8cm x 37.5cm						
Angle of View	D	1/3 type	137.9°	1/4 type	106.7°			
	H		113.3°		86.3°			
	V		86.3°		65.3°			
Operating Temperature		−20°C - +50°C						

Fig. 4. Specification of a typical short focus lens.

With lens focal length of **2.3 mm** and the size of the image sensor **1/3"** real horizontal view angle is **113.3 deg**., and the vertical view angle is **86.3 deg**. But calculation gives lower values - **92.4 deg**. and **76.1 deg**.

The form of the camera view area with this lens differs from the standard pyramid (**Fig.10**) and therefore cannot be accurately calculated by lens calculators or modeled by simple CCTV design software. The cause of warping the view area is the Lens distortion.

Physical nature of lens distortion

The **optical magnification** of a lens is the ratio of the size of image of an object projected by the lens on the image sensor to the real size of this object.

If the optical magnification is constant within the field of view, we obtain the projection of real objects without distortion of their form.

The **lens distortion** arises from the fact that the optical magnification of a real lens is not constant over the entire field of view. Optical magnification varies depending on the distance from the center to the edges of the field of view.

Depending on whether the optical magnification of a lens is decreased or increased with distance from the center of the field of view, the **barrel distortion** or the **pincushion distortion** is distinguished.

Traditionally from photography, the titles *barrel* and *pincushion* are associated with the distortion of cross-hatch on the image. But the shape of the field of view varies oppositely the title. Thus, with the *barrel distortion* the image resembles a *barrel* (**Fig.6**), and the shape of the field of view resembles a *pillow* (**Fig.8**),. With the *pincushion distortion*, the image resembles a *pillow* (**Fig.16**), and the shape of the field of view - a *barrel* (**Fig.18**).

The *lens distortion* should not be confused with the *perspective distortion* (**Fig.11**), which is normal on all images obtained with wide-angle lenses. Perspective distortion does not change pyramidal shape of the view area, rectangular shape of field of view and distribution of the spatial resolution.

Barrel distortion

When by moving away from the center of the field of view the *optical magnification* **decreases**, then objects at the edges of the field of view seem compressed, and the *spatial resolution* decreases from the center to the edges, and the field of view is stretched to the edges. Real *angles of view* in this case are more than the *calculated angles* (**Fig.7,8**). This is called the **barrel distortion**. The barrel distortion is most common and usual for wide angle lenses.

In particular, the lens considered above has just the **barrel distortion**. Let's consider VideoCAD model of image from this lens, the model of field of view, view area projections built with and without simulating distortion. Position of the camera in both cases is constant (**Fig.5..15**). The left figures show models built without distortion, and the right figures - model taking into account the lens distortion.

Pay attention on the warping of distribution of the spatial resolution (**Fig.8**). Barrel distortion increases the field of view, but reduces the spatial resolution, the farther from the center of the field of view, the stronger.

Objects distant from the center of the field of view will be displayed with lower resolution than the objects at the center of the field of view. Since the lens calculators consider spatial resolution only at the center, the actual spatial resolution over most of the field of view will be worse than estimated one.

Without lens distortion simulation

With simulation of barrel distortion

Fig. 5, 6. View of a cross-hatch. With barrel distortion the cross-hatch resembles a barrel.
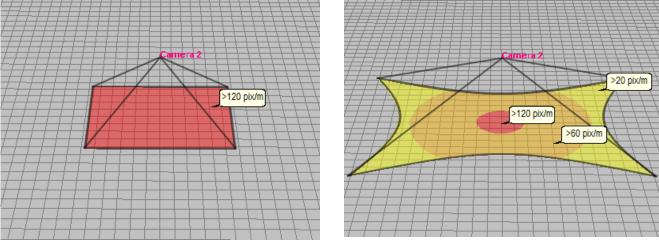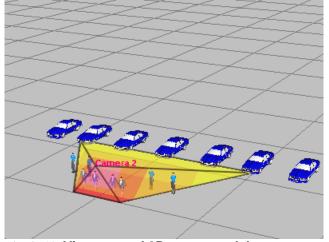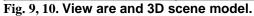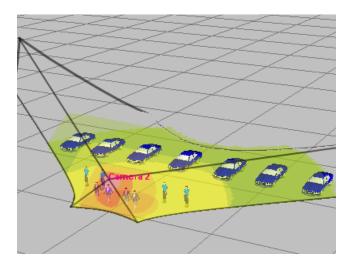

Fig. 7, 8. Field of view. With barrel distortion the cross-hatch resembles a *pillow*. The spatial resolution decreases from the center to the edges.

Fig. 9, 10. View are and 3D scene model.

Without lens distortion simulation   **With simulation of barrel distortion**

Fig. 11, 12. Camera image model. The slope of the men in the upper corners (Fig. 11) is caused not by the lens distortion but by the perspective distortion, which is natural for any wide-angle lens.
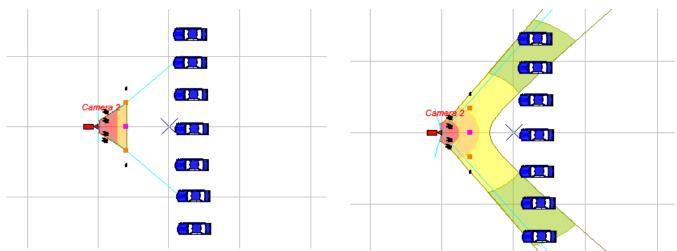

Fig. 13, 14. 2D View area projection.

Pincushion distortion

When by moving away from the center of the field of view the *optical magnification* **increases**, then objects at the edges of the field of view seem stretched, and the *spatial resolution* increases from the center to the edges, and the field of view is compressed to the edges. *Real view angles* in this case are less than the *calculated angles* (**Fig.17, 18**). This is called the *pincushion distortion*. The pincushion distortion occurs seldom with teleobjective lenses.

Let's consider models built with and without simulating distortion. The models are given to illustrate the pincushion distortion, they are not associated with a certain model of lens. Position of the camera in both cases is constant (**Fig.15..24**).

Note the warping of distribution of the spatial resolution (**Fig.18**). Pincushion distortion decreases the field of view, but increases the spatial resolution, the farther from the center of the field of view, the stronger.
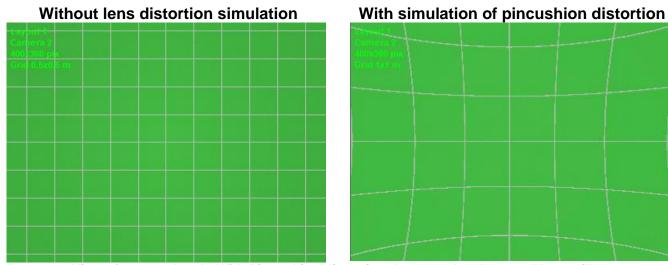
Without lens distortion simulation   With simulation of pincushion distortion

Fig. 15, 16. View of a cross-hatch. With Pincushion distortion the cross-hatch resembles a pillow.
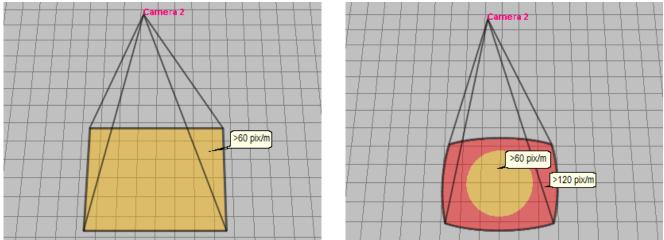
Fig. 17, 18. Field of view. With Pincushion distortion the cross-hatch resembles a barrel. The spatial resolution increases from the center to the edges.
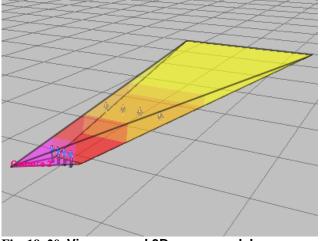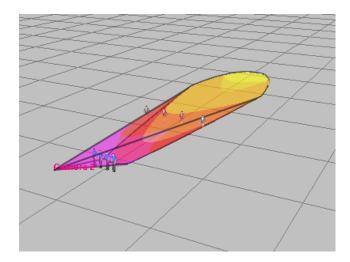
Fig. 19, 20. View are and 3D scene model.

Without lens distortion simulation   **With simulation of pincushion distortion**
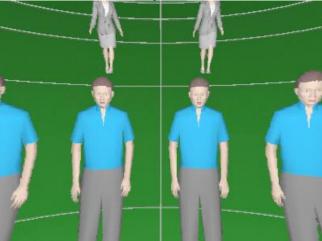

Fig. 21, 22. Camera image model. As the lens is teleobjective (narrow angles), the perspective distortion is not unnoticeable (compare with Fig. 11).
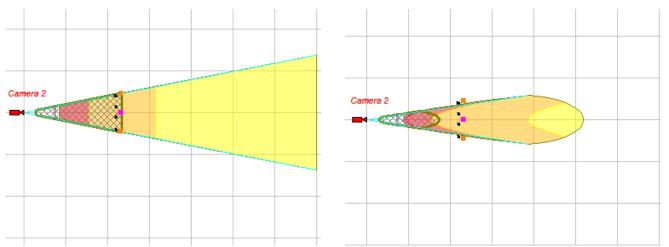

Fig. 23, 24. 2D view area projection.

Consideration of lens distortion in CCTV design

In practice, the effect of distortion is actual for lenses with focal length of less than **4mm**. For long-focus lenses the distortion is usually small and can be neglected.

The most common *barrel distortion of short-focus lenses* causes the actual camera field of view is wider than the calculated one, with stretched corners, and the actual spatial resolution equals to calculated one only at the center of the field of view. The rest of the field of view will have the spatial resolution worse than estimated. Moreover, at the corners of the field of view the spatial resolution may be worse in several times (**Fig.8**).

In cases required accuracy, compare the *actual angles of view* from the camera manufacturer's specifications or received by practical measurements with the *calculated angles of view* obtained from a lens calculator based on the lens focal length and the size of the image sensor. If the angles are significantly different, the distortion of the lens of the camera can be noticeable. (See example of the lens above).

Simulation of lens distortion is realized for the first time in the eighth version of VideoCAD.

Since the parameter "distortion" is missing in specifications of cameras and CCTV lenses, the lens distortion in VideoCAD is defined by a combination of *calculated view angle* and *real view angle*. The calculated view angles are calculated in the program from the *lens focal length* and *format or the actual size* of the image sensor.

The *real angles* are usually given in the specifications of cameras and lenses. If the angles are unknown, it is possible to get them by practical measuring.

To determine the lens distortion it is enough to set one of three real angles: *horizontal, vertical or diagonal*. It is preferable to set the *horizontal angle*. Missed real angles will be calculated by VideoCAD. For maximum accuracy, you can specify 2 or all 3 real angles.

From the specified angles VideoCAD calculates distortion, which will be taken into account when constructing models of view areas, distribution of spatial resolution and images from cameras.

Modeling a camera with short-focus lens

Camera parameters in specification

Suppose we have a camera **AXIS M1004-W**. We need to obtain a model of the view area, distribution of spatial resolution and image from this camera taking into account the distortion of its lens.

 Camera parameters according to manufacturer's specification:

•   Image sensor format - **1/4";**
•   Lens focal length - **2,8mm**;
•   Real horizontal view angle - **80 degrees**;
•   Number of pixels **1280x800** (max)

Note that the camera has a short focus lens (**2,8mm**). Short focus lenses tend to have appreciable distortion.
Aspect ratio of the camera image sensor and image aspect ratio are 1280/800 = **16: 10**.
The image sensor size is given by the format of **1/4".**

More on the impact of the aspect ratios and sensor size, see Specifying active area size of the image sensor.

In cases requiring accuracy it is recommended to check the actual angles of view by practical measurement

Specifying camera parameters in VideoCAD

Create new camera by clicking the **New camera** button on the toolbar of the **Graphics window** and place it on the layout.

Open the **Camera geometry box** and specify camera parameters:

- Sensor format - **1/4" 16:10**;
- Lens focal length - **2,8mm**;
- Aspect ratio: **16:10** (1280/800=16/10).

Click on the **+** button to open the **Sensor and lens** box.
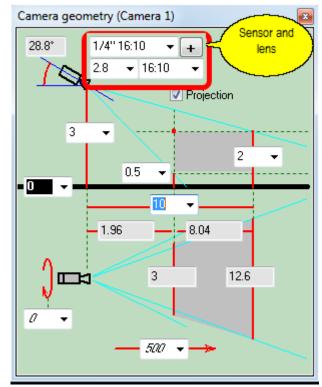

Fig. 25. Camera geometry box.

In the **Sensor and lens** box, pay attention to the difference between the calculated horizontal view angle - **68.6 degrees** and the actual view angle from the manufacturer's specification - **80 degrees**. The difference indicates that the lens distortion is present.

On the **Lens distortion** panel check the **Horiz.** checkbox and enter **80** to the box under it.

Clear the **Vert.** and **Diag**. checkboxes, because of the vertical and horizontal actual view angles are unknown.
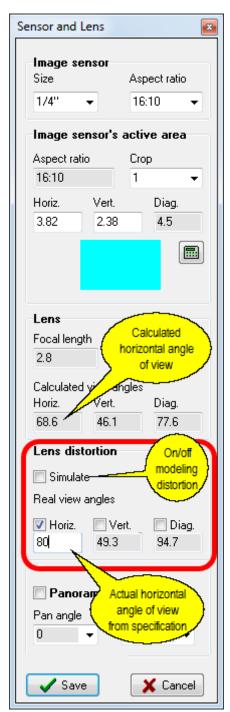
Fig. 26. Sensor and lens box.

Modeling view area projection in the Graphics window

Enable modeling lens distortion, by checking the **Simulate** checkbox in the **Sensor and lens** box, **Lens distortion** panel (**Fig.26**). After that we will see significant change of view area projection in the **Graphics window**.
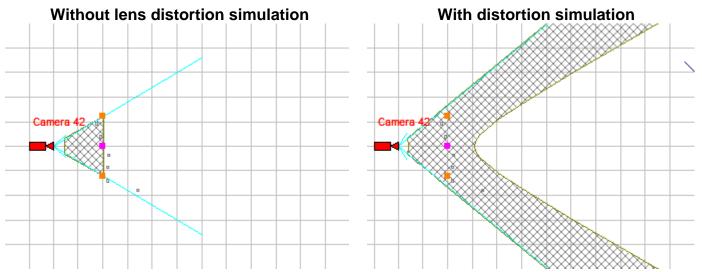
Without lens distortion simulation

Fig. 27. View area projection without distortion.

With distortion simulation

Fig. 28. View area projection with distortion.

Note that simulation of lens distortion increases demand for the computer speed.

Modeling distribution of the spatial resolution (pixel density)

To observe effect of the distortion on the distribution of spatial resolution you need to enter **number of pixels** of the camera (1280x800) in the **Sensitivity and resolution** box and enable modeling spatial resolution of the active camera.

Open the **Sensitivity and resolution** box by clicking the button on the toolbar of the **Graphics window**.

On the **Number of pixels** panel specify the number of pixels of the camera image sensor in horizontal (1280) and vertical (800).
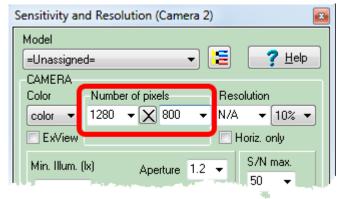
Close the **Sensitivity and resolution** box.

Fig. 29. Sensitivity and resolution box.

Enable modeling spatial resolution of the active camera by selecting **Discrete color** in the drop-down menu of the **Spatial resolution** button on the toolbar of the **Graphics window**.
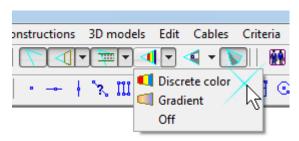

Fig. 30. Toolbar of the Graphics window

On the view area projections in the **Graphics window** the distribution of spatial resolution, taking into account the lens distortion will be displayed.
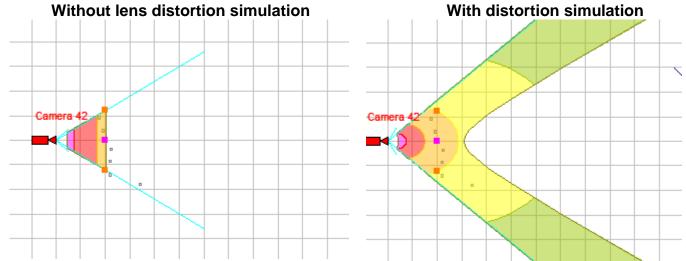
Without lens distortion simulation

Fig. 31. Spatial resolution without distortion.

With distortion simulation

Fig. 32. Spatial resolution with distortion.

You can quickly enable or disable simulation of the active camera lens distortion, using the **Simulate** checkbox on the **Lens distortion** panel in the **Sensor and lens** box.
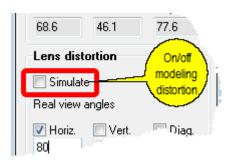

Fig. 33. Sensor and lens box.

Learn more about visualization of the spatial resolution, see the article Part II. Person detection area, person identification area, license plate reading area. Spatial resolution.

Modeling image from the camera with lens distortion

To observe influence of the lens distortion on the image from the camera, open the **3D Video** window by clicking the **3D Video** button on the toolbar and place several 3D models within camera's view area. Choose 3D models from the drop-down menu of the **3D Model** button on the toolbar of the **Graphics window**.

Without lens distortion simulation

Fig. 34. Image from the camera without distortion.

With distortion simulation

Fig. 35. Image from the camera with distortion.

We observe curvature of straight lines on the image in the **3D Video** window.

In the **3D Video** window the image with distortion is modeled with reduced resolution. You can get the image with distortion and actual resolution by two ways:

- Mark the menu item **Real frame size** in the main menu of the **3D Video** and save the image with distortion to a file by selecting **Image> Save As** from the main menu of the **3D Video** window. The saved file will have full size, actual resolution and distortion
- Activate **PiP** tool. In the distortion simulation, the particular view of **PIP** will have real resolution.

See details of PiP and main menu of the **3D Video** window in the Help system.

Modeling 3D view area in the 3D World window

To observe influence of the distortion on the form of the view area and spatial resolution distribution in 3D, open the **3D World** window**,** by clicking on the **3D World** button on the toolbar of the **Graphics window**.

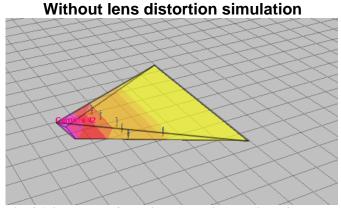See details of the 3D World window in the Help system.

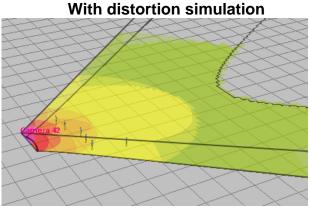| **Without lens distortion simulation**	**With distortion simulation**
Fig. 36. 3D model of the view area without distortion.	**Fig. 37. 3D model of the view area with distortion.**

Conclusion

In the first part of this article we examined effect of lens distortion on the image from the camera, shape of the view area and distribution of the spatial resolution in CCTV systems.
In the second part we looked at the capabilities of VideoCAD 8 for accounting the lens distortion when creating models of cameras for using in CCTV design.

Consideration of the lens distortion when designing CCTV systems allows obtaining model of the view areas and images closer to reality, and thus more fully take advantage of cameras in the project.

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To be continued.