Depth of Field in Cinematography: Why Size Matters

by Mark Craig Gerchman and Jon Maxwell

Introduction

Depth of field plays an essential role in all fields of photography. Its use in cinematography differs substantially from still photography. This difference is primarily associated with the dynamic storytelling essence of cinematography, and how the eye examines stationary verses moving images.

With a still photograph, the eye has time to examine an image at a level of detail not possible at 24 frames per second. To support this level of examination, the still photographer may employ a large depth of field so that more detail can be recorded in the image. The opposite is true in cinematography where, by using a shallow depth of field, a viewer's attention is drawn to what the director chooses.

Our eyes see a surprisingly large field of view, yet our ability to see fine detail is restricted to a very small region in the center of the retina, the macula fovea centralis.

Check this out: next time you're in a movie theater, notice how the people in front of your are out of focus when you look at the screen.

Our eyes continuously move so that objects of interest are isolated and their images fall on this sensitive region. A shallow depth of field allows the cinematographer to mimic this isolation and thereby provide a natural look to a scene. By using careful focus pulls, realistic action can be captured in a way that advances the story line, often without the viewer being aware of how this has been achieved.

There are occasions in cinematography when a large depth of field is used. In these instances an unnatural look usually results. Viewers tolerate this unnatural look often because either the eye perceives that the scene it is seeing is intended to be abnormal or because the shot has been held for an extended period so that the viewer can examine it at length like a photograph.

Understanding the factors that influence depth of field for different cinematographic systems becomes critical to their artistic use. In particular, it is the size of the detector (film aperture or electronic chip) that drives the optical speed required to achieve any particular depth of field.

A technical definition of depth of field

Two points define the depth of field for a scene. The near limit point is where the foreground first comes into focus. The scene then stays in focus until the far limit point is reached. The far limit point is where the background just goes out of focus. When specifying these points they are measured from the position of the detector.

In reality, the transition from "in focus" to "out of focus" is a gradual one. However we generally perceive the transition as a threshold. Our perception is based on many different factors (e.g. the image contrast, illumination levels, chromatic content, and individual eye characteristics). Our eyes have, for a given set of conditions, a limit to their visual acuity (angular resolution) that helps to create this threshold. The angular resolution of the standard eye sees this threshold when the out-of-focus blur becomes approximately 1/1200 the diagonal of the overall image size. This is true whether the image is eventually seen in a cinema or on a smaller screen.

We can relate this focus blur-to-image size ratio back to a size on the film or solid-state detector that recorded the original image. The size of this focus blur on the original image is known by the whimsical technical name, the "circle of confusion". Since cine images come in different sizes, they therefore have different circles of confusion. In Super 35mm cinematography the circle of confusion is generally taken to have a diameter of 0.025 mm (0.001 inch). In Super 16mm cinematography this diameter becomes 0.0125 mm (0.0005 inch). And for 2/3-inch HD solid-state cameras it is smaller still at approximately 0.009 mm (0.0004 inch). We mathematically compute the depth of field by taking this circle of confusion and projecting it back through the camera lens and seeing where the limits of focus fall.

Influences on the depth of field

This projection back through the camera lens involves a subtle mathematical relationship. An exact calculation of depth of field involves the following:

- the circle of confusion
- the focal length of the lens
- the distance the lens is set to focus
- the optical speed (f#) of the lens
- the front nodal position of the lens, and:
- the entrance pupil position of the lens.

In general, the equations that have been published to allow the cinematographer to calculate depth of field can only yield approximate results, because nodal positions and entrance

pupil locations are seldom known. Rigorous calculations, which are published in tabular form by most lens manufactures, take into account all of the above influences.

Whatever the source of depth of field information, we should apply it with care and experience, since the eye's criteria of focus is never absolute and the artistic value of the final results is the only true arbiter.

As we have discussed, different cinematographic systems have different sized circles of confusion. The cinematographer's choice of camera system and its detector's size will therefore influence depth of field. The choice of origination image size also plays a part in another of these influences: the selection of the focal length of the lens. To obtain the same angular field of view, the ratio of the focal length of the lens to image diagonal must be constant between systems. For example, since the image on Super 16mm film is approximately half the diagonal of the image on Super 35mm film, then the focal length of the lens required to film the scene in Super 16mm must be half that of its Super 35mm equivalent. To understand how the influence of detector size effects depth of field, it is helpful to use the concept of the hyperfocal setting.

Hyperfocal Setting

When a lens is used at its hyperfocal setting, which is a focusing distance, the far limit of the depth of field is at infinity. In this situation, everything in the scene from infinity to approximately half the hyperfocal setting distance will appear in focus. The hyperfocal setting for a lens is calculated from a closely related quantity: the hyperfocal distance. While the hyperfocal setting is measured to the detector, the hyperfocal distance is measured to the front focal point of the lens. This difference is not generally appreciated.

The hyperfocal distance is given by the formula,

hyperfocal distance = $(\text{focal length})^2 / (\text{circle of confusion diameter} \times f\#)$

Here f# is the aperture setting (or "speed") of the lens. We can use this quantity to see what influence different detector sizes have on depth of field.

The influence of detector size on depth of field

To demonstrate this influence let's shoot identical scenes with two very different systems: Super 35mm film and 2/3-inch digital HD. In this example consider that we are using a Super 35mm lens with a focal length of 40mm. If we consider a typical Super 35mm lens to have a maximum aperture of f/1.9, then the hyperfocal distance for this lens would be just under 34 meters (110 feet).

Because the detector diagonals between 2/3-inch HD and Super 35mm are in the ratio of 11 mm to 30 mm the equivalent 2/3-inch HD lens required to shoot this scene would need a focal length of approximately 14.7 mm. To get the same hyperfocal distance as the Super 35mm lens in this situation we calculate (from the equation above) that the HD lens would require an optical speed of f/0.7. While this speed is not impossible, it does turn out to be economically impractical. However, in 2/3-inch HD camera systems there is a prismatic beam splitter that limits the optical speed of the system to a maximum (fastest) aperture of f/1.4. So while the 2/3-inch HD lens is faster than the equivalent Super 35mm lens it cannot produce as shallow a depth of field.

The lack of depth of field when using a 2/3-inch HD system has nothing to do with the digital nature of the detector. In a digital camera where the detector size is the same as a Super 35mm film camera the depth of field is the same. Nor does depth of field have anything to do with the higher resolution required of 2/3-inch HD lenses. This resolution is needed because the detector size is so much smaller than the Super 35mm film. The final image in both cases, however big the screen, should contain the same amount of detail.

Understanding these influences allows cinematographers and directors to use depth of field more creatively in their craft.

Mark Craig Gerchman and Jon Maxwell are optical designers at Cooke Optics Limited in the UK.

The large format stills showing examples of depth of field are by Clive Russ. (www.cliveruss.com)