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Magnification, f-number and Depth of Field (DOF)

Depth of field (DOF) is usually considered the distance that your object can move toward or away from the camera lens while still maintaining adequate focus for the inspection task. What's adequate focus? That depends on what you're trying to achieve; it will vary from inspection to inspection.

What doesn't vary are the two "levers" you have for adjusting DOF for a given inspection.

The first lever is well-known, and it's the setting of the f-number or f-stop of your lens. As you may know, a higher f-number corresponds to a smaller aperture or entrance pupil hole of the lens. Make that hole smaller (higher f-number), and you increase the DOF.

As a matter of fact, if all other things are equal then the DOF increases in linear proportion to the f-number. Thus, if you double your f-number from F/8 to F/16, you'll double the depth of field and vice versa.

The down side is that you will reduce the amount of light the lens collects by a factor of 4. Sometimes you can afford this, sometimes not. (Because f-number is related to the diameter of the lens aperture -- although inversely -- if you double or halve the f-number, the *area* of the aperture will decrease or increase by a factor of 4.)

The second DOF lever is the optical magnification, or the ratio of the image size to the object size. In this case if all other things are equal, then the DOF is inversely proportional to the *square* of the magnification. That is, if you double the magnification, then the DOF is reduced to 1/4th of what you started with and vice versa. This is why high power microscopes have such extremely short DOF.

I must also note that if you double the magnification (make the image twice as large as before), then you are taking the same amount of collected light and spreading it out over four times as much area. Thus, the light intensity at the image is reduced by a factor of 4. There really is no free lunch. In fact, it sometimes feels like you have to pay for the other guy's lunch too!

Here's a quick example using both levers:

Suppose you start with a 1/3" format camera (4.8mm x 3.6mm detector) and you are imaging a scene that is 9.6mm x 7.2mm. Image size divided by object size gives you a magnification of 0.5X.

You set up your lens at F/8 and you have an adequate amount of light.

BUT... you only have a depth of field of say +/-1.0mm and you really need +/-2.0mm.

If you increase the lens aperture to F/16 your depth of field increases, but in order to have the same signal level, you need to pour on 4 times as much light. Furthermore, although your DOF has increased, the peak or best focus quality is less than the best focus quality of the lens at F/8. This is due to the additional effect of diffraction -- a subject for another time.

So, what to do?

Let's try setting the lens at F/11. This will increase the DOF to about +/-1.4mm, and require only twice as much light to match the original state.

But let's also increase the lens to object distance slightly and re-focus in order to decrease the magnification a little bit. If we reduce the magnification to about 0.42X (new field of view of 11.4mm x 8.6mm), then our system ends up with a full +/-2mm DOF. We lose only a little bit of resolution, and we gain back a good percentage of our light at the image plane!