Dynamic Range

Dynamic range is perhaps the most abused technical parameter found in camera data sheets. At Salvador Imaging and other high-performance camera vendors, dynamic range is defined as the ratio of the largest signal the CCD can handle (linearly) to the readout noise (in the dark) of the CCD camera system. From an intuitive point of view, dynamic range defines the brightest and darkest data in a given image which can reliably and faithfully be reproduced by the camera electronics.

There are a number of situations where having a large dynamic range is advantageous. Radiology, motion-picture film scanning and microscopy are all applications where the image scene typically contains both very bright and very dim image information. In these applications, a large dynamic range (12 bits or more) allows the user to capture and reproduce extremely subtle gray-scale variations in both the bright and dark areas of the image. In contrast, an 8 bit camera used in these same applications would either lose data entirely by clipping gray-scale values at one end of the range, or provide insufficient quantization accuracy to reproduce subtle changes in gray level. Having a large dynamic range is also very helpful in situations where the experimenter has no a priori knowledge of scene illumination and the experiment is difficult or costly to repeat. In this case, the large dynamic range allows the user to have a wider window of gray scale values in which the scene may occur without loss of image data. Thus, the experimenter has a higher probability of getting useful data on the first try. As an example, by using a 12 bit camera, the experimenter is allowed up to 16 times as much error in estimating the scene illumination than with an 8 bit camera.

Other imaging applications benefit from a large dynamic range in more subtle ways. For example, in semiconductor inspection there is frequently a need to very accurately identify edge information. Typically, the image data to be captured is either black or white which, at first, would seem to imply the need for only a very limited dynamic range (1 bit). In practice however, system integrators use subpixel gray scale variations to provide positional information far beyond the resolution of a single pixel.

In this case, electronic noise, signal jitter and other camera parameters can dramatically effect subpixel measurements. In this and many other applications, the benefit of a high dynamic range camera really is not directly related to its ability to capture a wide range of gray-scale values. Instead, it has to do with the fact that a high dynamic range camera must inherently be more stable, linear and noise free over time and temperature.

A common misconception is that dynamic range equates to digitization level. For example, a camera with an 8-bit A/D converter is assumed to have 8 bits of dynamic range. Unfortunately this misconception is kept alive through the proliferation of technically incorrect data sheets. To understand why the two are not the same, consider two cameras which are digitized to 12 bits or 4096 gray scale levels. The first camera has an inherent rms noise of 8 A/D counts, and must have a minimum exposure large enough to overcome this basic noise floor to be detected. Although this camera is digitized to 12 bits, the effective dynamic range is actually 4096/8 = 512:1 = 9 bits. In contrast, the

second camera has a read noise floor of 1 A/D count. Since the noise in this camera is one A/D unit, the dynamic range becomes essentially the range of the A/D or 12 bits. Thus, while both cameras are digitized to the same level, there is an 8 to 1 difference in dynamic range! In data sheets, dynamic range may be presented as a ratio, bit depth or equivalent dB rating. For example a camera digitized to 12 bits with 2 counts of rms read noise would have a dynamic range of 4000/2 = 2000:1, which is equivalent to 20Log(4000/2) = 66dB or 11bits.

If you really want to know what the dynamic range of a camera is, ask the manufacturer to supply a Photon Transfer Curve for that camera (not just a typical curve). The Photon Transfer Curve is the only generally accepted way of characterizing camera performance.