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# Image Signal-to-Noise Ratio– Part 2
## What does SNR look like, and when does it break down?

Peter D. Burns

Burns Digital Imaging

Testing shows the presence, not the absence of bugs

- Edsger Dijkstra

In Part 1 we discussed the origin and calculation of Signal-to-noise ratio as an imaging performance measure, and its use on a logarithmic (Decibel, dB) scale. For digital imaging systems, the signal and noise characteristics vary with signal (exposure) level, and we usually evaluate SNR at various scene/object exposure levels. For a nominally uniform image area, we compute signal and noise variation levels. The SNR in dB is computed as

$$SNR_{dB} = 20\log_{10}\left(\frac{\mu_{signal}}{\sigma_{noise}}\right). \quad (1)$$

SNR, whether expressed as a ratio or in dB, is a measure based on imaging performance *statistics*. We now turn to some visual examples of such characteristics.

### *What does 0 dB, 6 dB look like?*

*Example 1:* To demonstrate the appearance of various levels of SNR we start with a noise-free image array as shown in Fig. 1. We take the outer, lighter border to be the background reference level, and the inner, darker region as the signal area. The corresponding grayscale levels are 150 and 125 respectively, so for our purposes we take the signal to be the difference, 25.

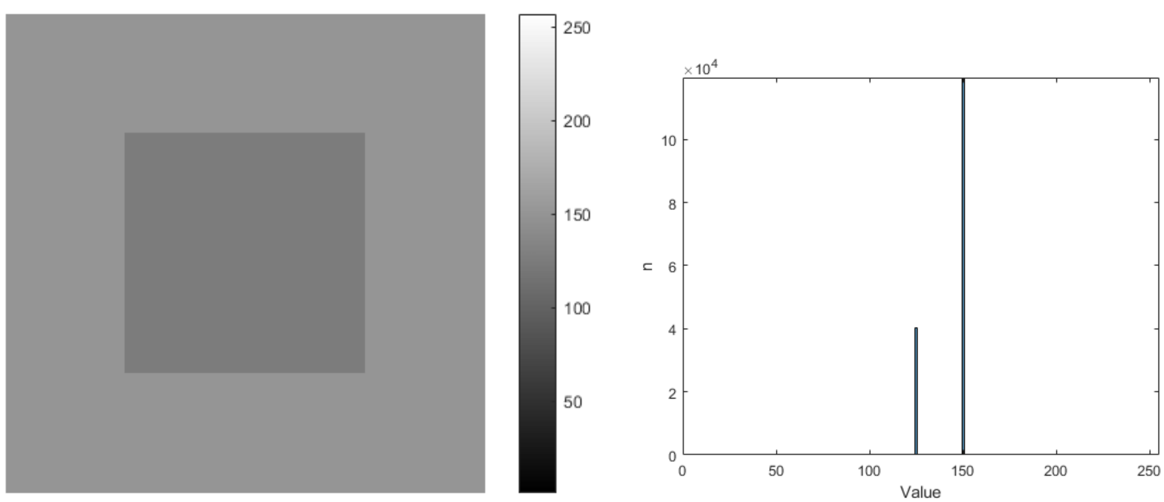


Figure 1: Demonstration image with signal amplitude = 25

For an image with *SNR* = 1 the noise statistic, $\sigma$, would also be equal to 25. Figure 2 shows the result of adding a Gaussian noise field to the signal. The noise field has no pixel-to-pixel correlation. Note that the signal levels are hard to identify from the histogram of pixel values but easy to see in the image.

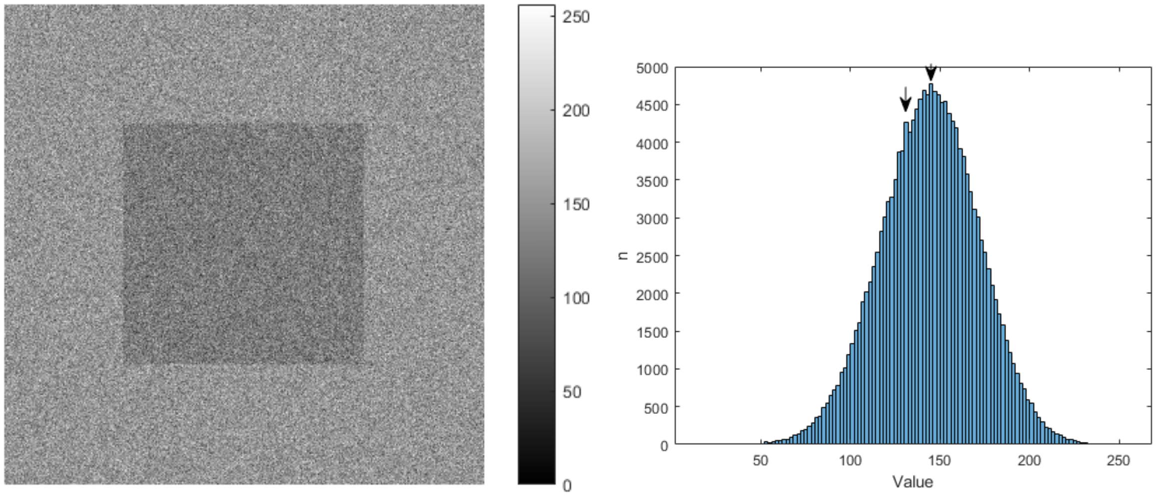


Figure 2: Example with SNR = 1 (0 dB) and histogram

***Limitations to SNR as an Image Quality Measure***

This demonstration was extended by introducing a texture (spatial correlation) to the image noise. The previous random array was filtered by a 3x3 digital (convolution) filter. The results are shown in Fig. 3. Although the appearance is different, the pixel-by-pixel noise standard deviation (and variance) and SNR are the same as shown in Fig. 2.

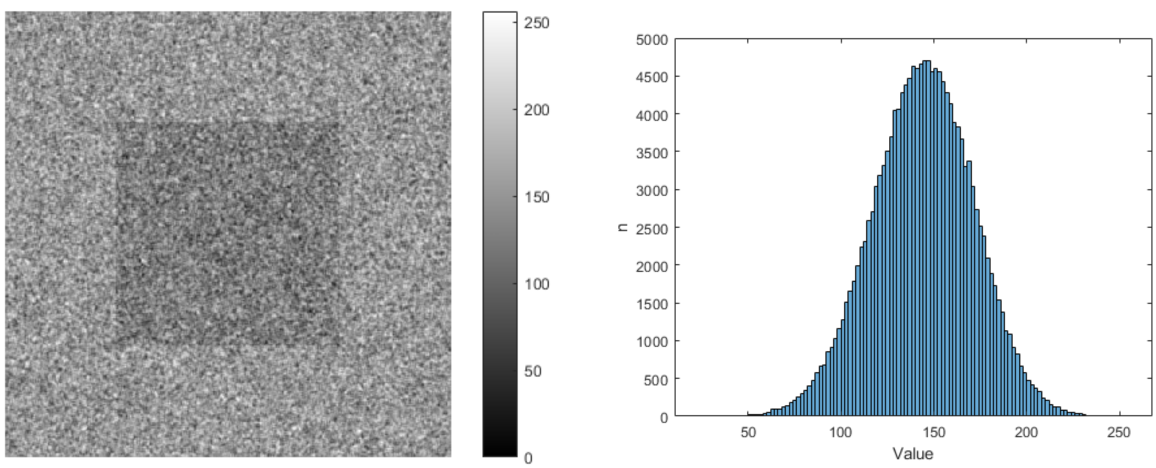


Figure 3: Example with filtered noise, SNR = 1 and histogram

Comparing Figs. 2 and 3, we see that SNR does not measure or predict the visual impression. The reason is the different textured nature of the image noise statistics. Including these spatial characteristics is the basis of the addition of the visual-noise measure to the ISO 15739 for camera noise.[1] This is done using a spatial-frequency description of the image noise (the noise-power spectrum), and a human contrast-sensitivity function (CSF).

***Two Versions of SNR = 6dB***

*Example 2:* We now show two examples of increased SNR. Taking the previous example (Fig. 3) we can achieve an $SNR_1$ = 4 ($SNR_2$ = 2), or 6dB by either *increasing* the signal (contrast) by two times, or *reducing* the noise variation (standard deviation). These cases are shown in Fig. 4.

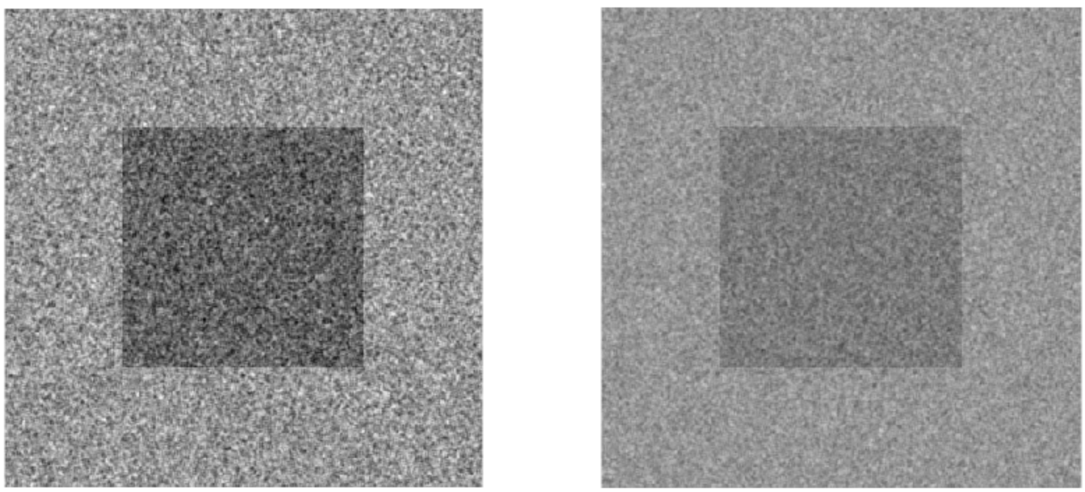

Figure 4: Examples of SNR = 6 dB, by increased signal (left) and reduced filtered noise (right)

The visual impression is again different for these two cases, with the higher signal contrast aiding in the object detection in spite of the noise. However, these SNR-equivalent examples may present a similar challenge to an automated detection algorithm.

*Example 3:* Another example of more structured image noise is shown in Fig. 5, where the variation is row-to-row, rather than pixel-to-pixel. The SNR here is also equal to 6 dB.

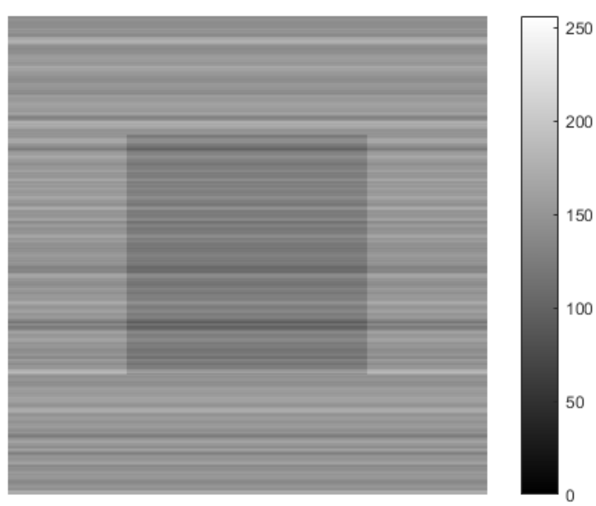


Figure 5: Examples row-noise leading to an SNR = 6 dB (same signal as for Fig. 5 (right)

Here we observe the greater visibility of the one-dimensional image noise, at least for me when a backed away from my display.

***Conclusion***

SNR measures are helpful for comparing imaging systems with similar signal and noise (spatial) characteristics. They can also be useful when specifying requirements for object-detection and recognition algorithms. However, these statistics cannot be expected to track the visual impression for image quality, or tasks such as object- or change-detection when these change.

A more complete understanding of the influence of such system characteristics is obtained when we include the spatial correlation of imaging performance. This can be done by using the spatial-frequency based Noise-Power Spectrum (NPS) for the noise, and the Modulation-Transfer Function measure for the image signal capture.

I will leave a discussion of how to make and use these measures for another time.

***References***

1. ISO 15739:2017 Photography — Electronic still-picture imaging — Noise measurements