Improved Evaluation of Image Resolution for Digital Cameras and Scanners

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Abstract

Several years ago, a method for measurement of image resolution for digital cameras using slanted-edge gradient analysis was adopted by the ISO. More recently, this method has been applied to the spatial frequency response and MTF of film and print scanners and CRT displays. We have previously described several causes of both bias and variation error in terms of the various signal processing steps involved. This analysis, when combined with observations from practical system testing, suggests modifications and extensions to the original method.

We review several sources of measurement error and how to avoid them by careful data collection and processing. This involves refinements in data screening for signal encoding problems and improved edge-feature location and slope estimation.

Slanted-edge Analysis

The ISO Standard procedure[1,2] for camera resolution measurement is based on edge-gradient MTF analysis[3] methods. Although well-accepted, it is subject to error and can be influenced by digital image processing.[4,5] There are three basic parts to the method: acquiring an edge profile from the (image) data, computing the derivative in the direction of the edge, and computing the discrete Fourier transform of this derivative array.

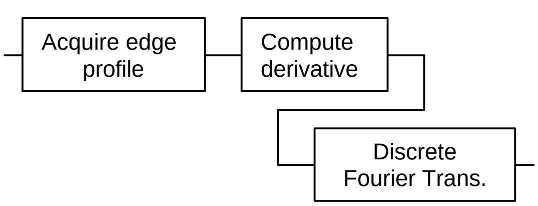

Fig. 1. Edge-gradient analysis steps.

One of the steps in acquiring the edge profile in the ISO method is the determination of the location and direction of the edge feature. The estimation of the direction (slope) of the edge has a direct effect on the computed spatial frequency response (SFR).[3] In the slanted-edge analysis, the processing of the image data by projection along the edge can be modeled as the synthesis of a sampling slit of length *m* pixels. The effective MTF caused by a slope error is [3]

$$T(u) = \frac{\sin(\pi\ ms\Delta u)}{\pi\ ms\Delta u}, \qquad (1)$$

where Δ is the original data sampling interval, *s* the slope misalignment error, and *u* the spatial frequency. The current ISO 12233 procedure computes independent, edge-slope estimates for each edge and color record. Improved estimates of the edge slope can be obtained, however, by combining results from several edges of a single target.

This is illustrated in Figure 2 for a monochrome scan of the ISO 16067-1 target. The small difference between all of the SFR measurements makes it unclear whether there are significant differences between horizontal and vertical directions. Using the same image data, but by pooling the two horizontal and two vertical common directional slope estimates, the directional uncertainty is removed in Figure 3. The horizontal and vertical performance differences are now evident.

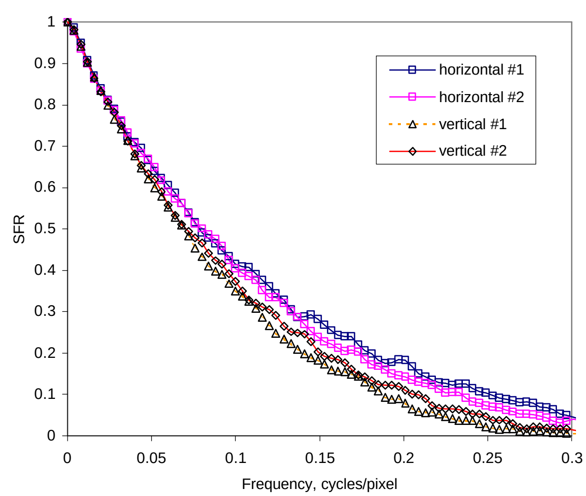

Fig. 2. SFR measurements from independent, edge slope-estimates for the same device.

In many cases, careful selection of input image data can improve the measured SFR. For practical imaging systems, signal fluctuations on either side of the edge feature contribute both a positive bias and variation to the resulting SFR. In the case of a flexible ISO

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procedure based on a user-selected image data, we have the opportunity to avoid the problem by limiting the data length to a region close to the edge feature. This applies to general statistical sources, such as shot noise, and artifacts caused by sampling, compression, etc.

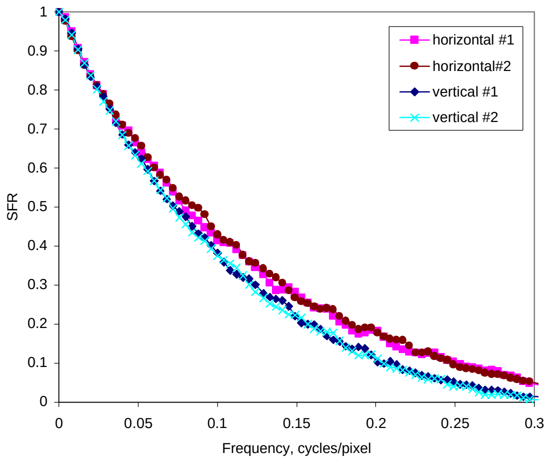

Fig. 3. Improved results based on pooled slope estimates.

The nonlinear effects of image clipping and quantization can also corrupt measurement results. Although part of many products, these operations are not consistent with the ISO resolution measurement. Clipping can occur in consumer digital cameras where noise reduction, coring, or sharpening operators are applied. It can have a serious effect on the measured SFR. Examples of measured SFRs derived from clipped and non-clipped data using the same sharpening filter are shown in Figure 4. The increase at high frequencies is because of the 'artificial' edges introduced by the signal processing. To help identify these occurrences, an analysis of the histogram of the input image data values can be used. This can take the form of a statistical test alerting the user to clipped data when a threshold is exceeded.

One requirement for edge-gradient analysis is the use of a straight edge image feature. Because spatial distortion is not usually the object of the SFR measurement, it can be viewed as a source of bias error. When the edge-spread function profile is estimated, position variation along the edge can introduce a significant component into the measured profile. This widens the profile and the resulting SFR is decreased by Fourier transform properties.

Although a source of bias error for the SFR, the slanted-edge method lends itself to simple diagnosis of the problem. Just as the intermediate fitting equation for the edge location has been used to detect color misregistration,[6] residual errors for this fit can be used to detect and measure edge distortion. Plotting the intermediate edge location data and the computed linear fit to them easily identifies the presence of this spatial distortion.

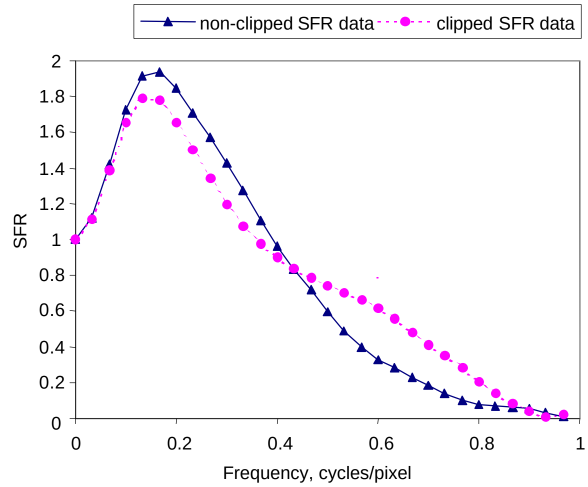

Fig. 4. Measured SFR for image data with sharpening filter applied, with and without signal clipping**.**

Conclusions

Several sources of error in practical SFR measurements can be understood by careful examination of each step in the method. Detection of clipped-image data, which causes bias error, is recommended. Spatial image distortion caused by optical aberration or position errors can reduce the measured SFR. Its presence, however, is also easy to detect by plotting intermediate edge location data already computed as part of the measurement. As usually practiced, the slanted-edge analysis is applied without using knowledge of the target configuration. When a standard test target is employed, information about the surrounding target features can be used to reduce the propagation of slope error to the measured SFR.

References

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