

A Second-Generation Portable Instrument for DOI (Distinctness of Image) Measurement

Ming-Kai Tse, Eugene Hong, and David Forrest; Quality Engineering Associates (QEA), Inc.; Burlington, MA, USA

Abstract

DOI or Distinctness of Image is now recognized as an important appearance attribute, particularly for photographic images. In NIP21, we introduced our first-generation portable instrument for DOI measurement, the DIAS. Since its introduction, the DIAS has been used primarily by printer and media manufacturers for quantitative analysis of print and media quality. In this paper, we describe the second generation device, the DIAS-II, with a broader measurement range capability. The DIAS-II is even more compact, more reliable, easier to use, and costs less than the first generation device. We discuss the new hardware design, improvements in the analysis method, techniques for enhancing the manufacturability and the performance of the system, and applications beyond print media characterization.

Gloss and Distinctness of Image (DOI)

Objective image quality assessment requires measurement of a set of image quality metrics. Each metric corresponds to a different print quality attribute affecting viewer preference. There are many print quality attributes including color accuracy, effective resolution, uniformity, line quality, etc… The subject of this paper is one specific quality attribute called distinctness of image (DOI) which is an aspect of gloss uniformity.

Gloss is the shiny or lustrous appearance of a surface due to the specular reflection of incident light. Hunter[1-2] in his seminal research pointed out that specular reflection can vary from one surface to another in many ways:

1) in the fraction of light reflected in the specular direction (specular gloss);

2) in the spreading of light to either side of the specular direction (DOI);

3) in the change in the nature of reflection as specular angle changes (sheen, luster or contrast gloss).

A traditional gloss meter only measures specular gloss. While specular gloss is important, for certain applications DOI has a strong correlation with viewer preference and should not be ignored. In the automotive industry, DOI has long been recognized as more important than specular gloss in characterizing the finish quality for automotive body paint. Similarly, in digital printing, particularly in media development, there is increasing awareness that DOI plays a critical role in quality perception, especially in the area of "photo-quality"[3-4].

Qualitatively, a high DOI surface approximates a good mirror: reflections are clear and sharp with high contrast and no spatial distortions or blurring. Lower DOI surfaces are more like a fogged-up mirror: reflections are hazy and blurred. In **Figure 1**, photographs of two different photo-grade media samples are shown, illustrating this qualitative difference in DOI. The samples in the figure are each 8.5×11 inch sheets printed in full black, and photographed with the camera positioned to show the reflection from a nearby window with silhouettes from vertical blinds and the leaves of a potted plant. Note that the *specular gloss* from the two samples is similar (the amount of light energy from the window reflected from the sample to the camera), but the *distinctness* of the reflected images is very different. A simple glossmeter does not reveal the difference between these two samples.

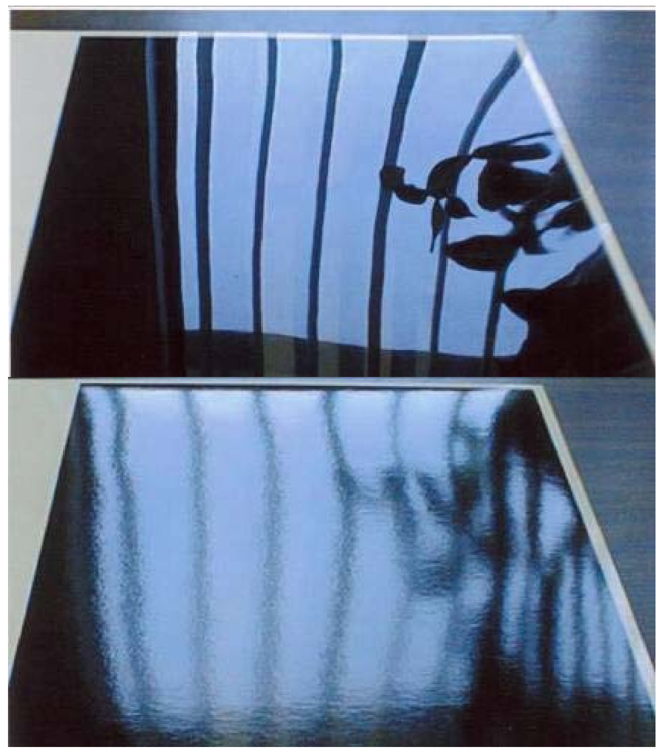

***Figure 1**. Two photo-grade inkjet media, both printed in full black, with reflections from a nearby window. The mirror-like reflection produced by the top sample exemplifies high DOI.*

DOI Measurement Instruments

DOI is classically measured using a gonioreflectometer to obtain a bidirectional reflectance distribution function, defining how light reflects from the surface under test. Due to the complexity (and cost) of instrumentation and the tedium in operation, the goniometer is simply not a practical instrument for industrial use. For day-to-day material development and inspection, practitioners need a simple instrument that gives a small set of metrics (preferably one) that has direct relevance to the attribute (i.e. DOI) of interest. Accordingly, in 2005 QEA introduced the portable DIAS™ (Distinctness-of-Image Analysis System)[5-6]. The instrument is now commercially available and has been adopted by many media and printer manufacturers for R&D and production quality control. Several years of field experience and further product development has yielded a second generation instrument (the DIAS™-II).

DIAS Measurement Principle

The basic principle in our compact DOI instrument is to project a sharp edge onto the surface-under-test, capture the reflected image digitally, and analyze the reflected edge (see **Figure 2**). The analysis is fundamentally an "edge gradient method" as illustrated in **Figure 3** and summarized as follows:

1) The edge spread function (ESF, which is essentially the reflectance profile) is obtained from a region-of-interest enclosing the edge.

2) The corresponding line spread function (LSF) is obtained by taking the first derivative of the ESF (and using appropriate smoothing).

3) The DOI metrics are derived from the LSF: a) the peak, and b) the 50% width (blurriness). The inverse of the 50% width (sharpness) is sometimes used as an alternative to blurriness.

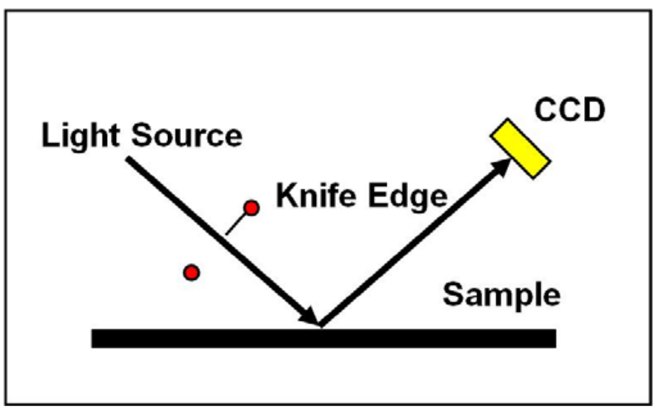

***Figure 2**. Schematic of the DIAS design*

The above procedure is implemented in our first generation of DIAS™ and the instrument has been used in the field satisfactorily for several years. The instrument works particularly well with relatively high gloss and high DOI materials. However, for less glossy and lower DOI materials, the reproducibility and repeatability is poor, particularly for surfaces with anisotropic (i.e., orientation-dependent) texture and properties. We believe much of the problem is due to the inherent noise in the ESF that leads to a noisy LSF and hence unreliable DOI results. An improved technique is needed to obtain more robust measurements and to extend the range of DOI measurements to less glossy and lower DOI materials.

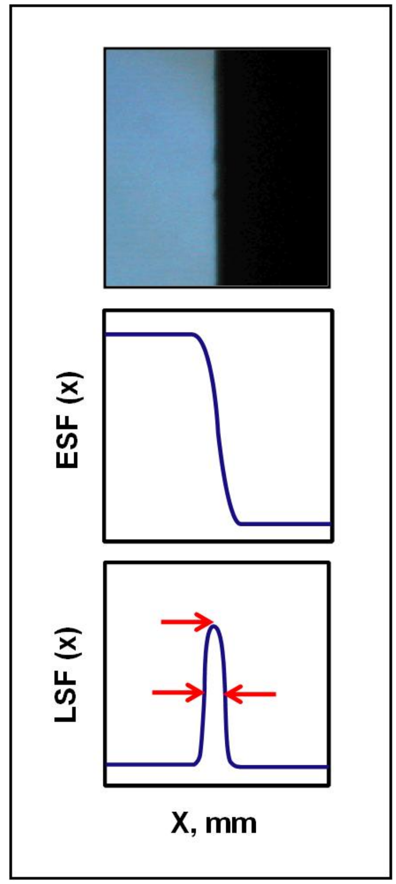

***Figure 3**. Principle of DOI Measurement*

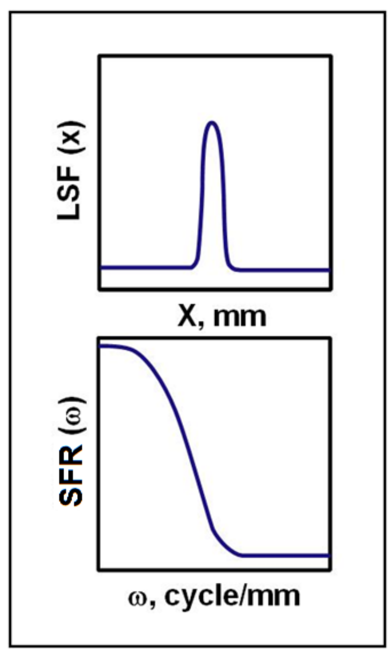

***Figure 4**. Fourier transformation of LSF yields SFR*

DIAS-II Improvements

In 2009, QEA incorporated several key improvements into a second generation DOI measurement tool (DIAS-II):

1. Frequency Domain Analysis
2. Slanted Edge
3. Subjective Quality Factor

Each of these improvements is described below.

Frequency Domain Analysis

In the DIAS, all the DOI metrics are extracted directly from the LSF in the spatial domain. In DIAS-II, the analysis goes a step further and transforms the LSF into the frequency domain to obtain the Spatial Frequency Response (SFR) function. The SFR (also called MTF, or Modulation Transfer Function) is obtained by applying a Fourier transform to the LSF as illustrated in **Figure 4**.

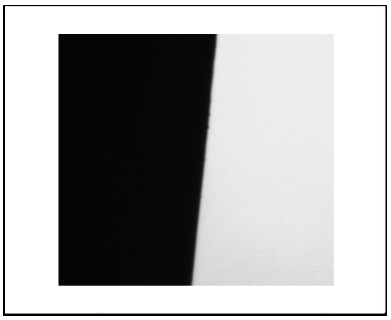

***Figure 5**. Example image featuring a "slanted edge"*

Slanted Edge

A standard method and algorithm for obtaining the spatial frequency response (SFR) is described for imaging systems in ISO-12233 [7] and has been adapted for DOI measurement in the DIAS-II. This method requires imaging a slanted edge (see **Figure 5**) so that the ESF is presented to each horizontal scan line of the imager is slightly phase shifted. These phase shifts provide two advantages compared to an orthogonal edge: a) artifacts from the imager are reduced, and b) "super-sampling" is made possible so that the effective spatial resolution is increased [8-9].

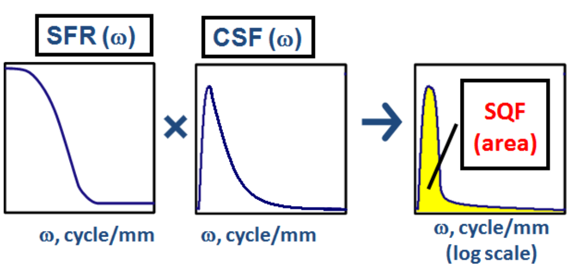

***Figure 6**. SQF (subjective quality factor) is the area under the convolution of the SFR and CSF curves, when the spatial frequency is plotted on a logarithmic scale*

Subjective Quality Factor (SQF)

The "Subjective Quality Factor (SQF)" [10], first introduced by Granger [11], is essentially the area under the convolution of the SFR and CSF (contrast sensitivity function) curves, when the spatial frequency is plotted on a logarithmic scale. In DIAS-II, the SQF is presented as a DOI metric. Taking advantage of the CSF, the SQF metric is much less vulnerable to high frequency noise in the image compared to the spatial domain metrics provided by the DIAS. This means the SQF metric is more repeatable and more relevant to viewer preference since variations beyond the frequency range of human sensitivity are ignored.

DIAS-II Performance

To test the relevance of the SQF metric, 10 inkjet photo media with a range of DOI were measured using a second generation DIAS (the DIAS-II). The samples were also ranked subjectively by a panel of judges. The correlation of the SQF metric with the visual ranking test are shown in **Figure 7**. The results indicate that the objective SQF metric is strongly correlated with subjective perception of DOI.

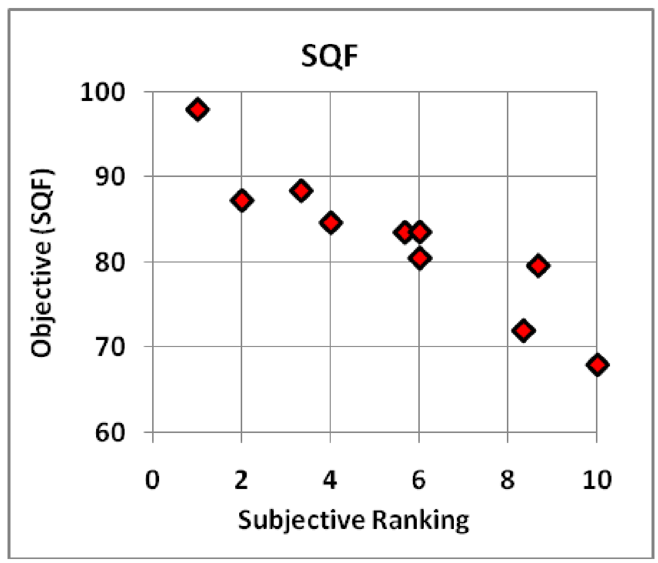

***Figure 7**. Correlation between SQF metric and subjective ranking of DOI samples*

The inherent precision of the DIAS-II instrument is established by measurement repeatability. Repeatability is the variability of the measurements obtained by one person while measuring the same sample repeatedly. The average repeatability for three different DOI metrics is shown in **Figure 8**. The spatial domain metrics, *Peak* and *Blurriness*, which are derived from the LSF, suffer from poor repeatability. The coefficient of variation (standard deviation from ten trials by the same operator on the same sample divided by the mean from the ten trials) for the *Blurriness* is almost 40%, indicating that for this set of samples the *Blurriness* metric is very imprecise. In general, the spatial domain metrics are quite vulnerable to image noise. To obtain reliable values for these spatial domain metrics, it is necessary to find the mean of many repeated measurements on the same sample so that the central tendency can be determined with acceptable certainty.

Better repeatability of DOI metrics was the main goal for the second generation improvements to the DIAS-II. Indeed, **Figure 8** shows that the repeatability of the SQF metric, which benefits from the frequency domain analysis and filtering by the CSF, is significantly better than the repeatability of the spatial domain metrics.

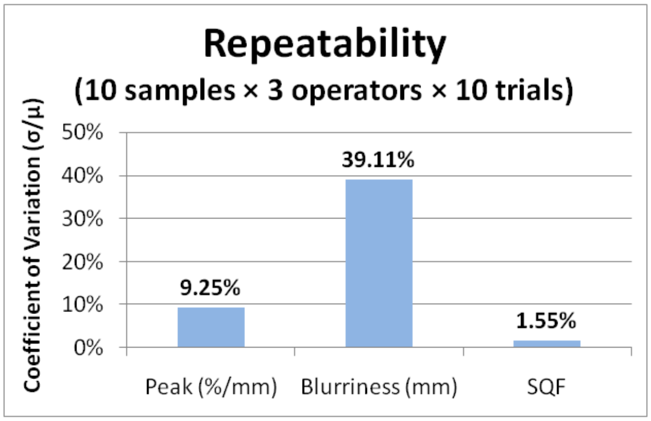

***Figure 8**. Repeatability of the SQF metric compared to the spatial domain metrics Peak and Blurriness*

Reproducibility is the variability of the measurements caused by differences in operator behavior. Mathematically, it is the variability of the average values obtained by several operators while measuring the same sample. As shown in Figure 9, the reproducibility of the DOI metrics follows the same pattern as the repeatability. The improvements to the DIAS-II allow computation of SQF, which is a significantly more reproducible metric than the spatial domain metrics such as *Peak* and *Blurriness*.

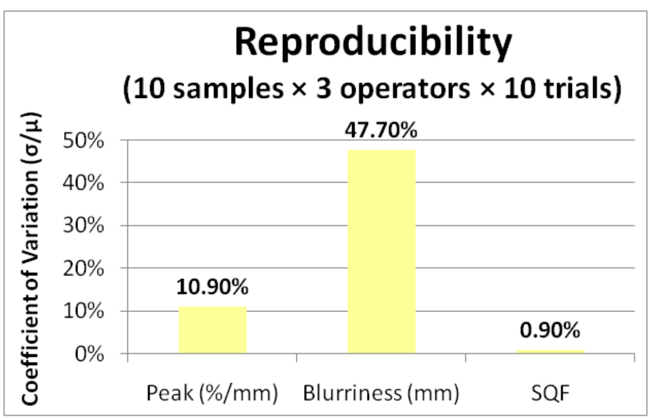

***Figure 9**. Reproducibility of the SQF metric compared to the spatial domain metrics Peak and Blurriness*

Conclusion

Improvements introduced in the DIAS-II, including frequency domain analysis, use of a slanted edge, and computation of the SQF metric employing CSF weighting, provide significantly more robust DOI measurements on a range of samples. The repeatability and reproducibility of measurements is demonstrably much better due to these improvements. Furthermore, a strong correlation exists between the objective SQF metric and subjective ranking of the samples tested.

References

[1] Hunter, R.S., Journal of Research, NBS, V. 17:77, pp.281, 1937.

[2] Hunter, R.S. and Harold, R.W., The Measurement of Appearance, 2nd Edition, Wiley-Interscience, 1987

[3] Monie, S.A., Stief, B.C., and Krupkin, N.V., “Evaluation of Glossy Inkjet Papers Using Distinctness of Image (DOI) Measurement,” IS&T NIP19, pp763-768, 2003

[4] Cheng, C., “Human gloss perception of unprinted inkjet media,” IS&T ICIS’06, Rochester, NY, pp420-423, May 7, 2006.

[5] Tse, M.K. and Briggs, J.C., “A New Instrument for Distinctness of Image (DOI) Measurements,” ISJ Japan Hardcopy, Tokyo, Japan, June 8-10, 2005.

[6] Tse, M.K., Briggs, J.C., and Graczyk, T., “Distinctness of Image (DOI) of Inkjet Photo Papers,” IS&T NIP21: International Conference on Digital Printing Technologies, Baltimore, Maryland, Sept. 18-23, 2005.

[7] ISO-12233, “Photography – Electronic still-picture camera – Resolution measurements,” September 1, 2000.

[8] Burns, P.D., “Slanted-edge MTF for Digital Camera and Scanner Analysis, “ IS&T PICS 2000.

[9] Burns, P.S., “Refined Slanted-edge Measurements for Digital Camera and Scanner Testing,” IS&T PICS 2002

[10] Atkins, R., “Modulation Transfer Function MTF and Subjective Quality Factor (SQF),” http://www.bobatkins.com/photography/technical/mtf/mtf1.html.

[11] Granger, E.M. and Cupery, K.N., “An Optical Merit Function (SQF), Which Correlates With Subjective Image Judgments,” Photographic Science and Engineering, Vol. 16, no. 3, pp 221-230, May-June 1973.

Author Biography

Dr. Ming-Kai Tse is the founder and president of Quality Engineering Associates (QEA), Inc. in Burlington, MA, USA. Prior to founding QEA, Dr. Tse was an Associate Professor of Mechanical Engineering at the Massachusetts Institute of Technology (MIT). His research interest is in measurement technology, with special application in digital printing and image quality analysis. He earned his BS at Cornell University and his SM and PhD at MIT. He is a Senior Member of IS&T. He can be reached at mingkaitse@qea.com or 1-781-221-0080.