An Improved Method for Distinctness of Image (DOI) Measurements

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Distinctness of Image (DOI) is an important gloss appearance attribute that contributes to the customer's perception of photo quality. We reported a novel method for measuring distinctness of image (DOI) on print media and printed images at Japan Hardcopy in 2005. The method has since been implemented in a practical, commercially available instrument and applied in many media R&D and quality control applications. In this paper, we describe several significant improvements in the measurement technology based on analysis in the frequency domain using the slanted edge technique for SFR or MTF and a perceptually meaningful metric called subjective quality factor (SQF) to improve the reliability and robustness of our DOI measurement method. The efficacy of the new method is demonstrated and a correlation between objective and subjective measures is also discussed.

1. Gloss Appearance and DOI Measurement

The assessment of image quality and appearance must include both chromatic attributes (i.e., color in terms of hue and saturation) and achromatic attributes (e.g., lightness, optical density, tonal rendition, gloss, …). This paper focuses on one specific gloss attribute called distinctness of image (DOI).

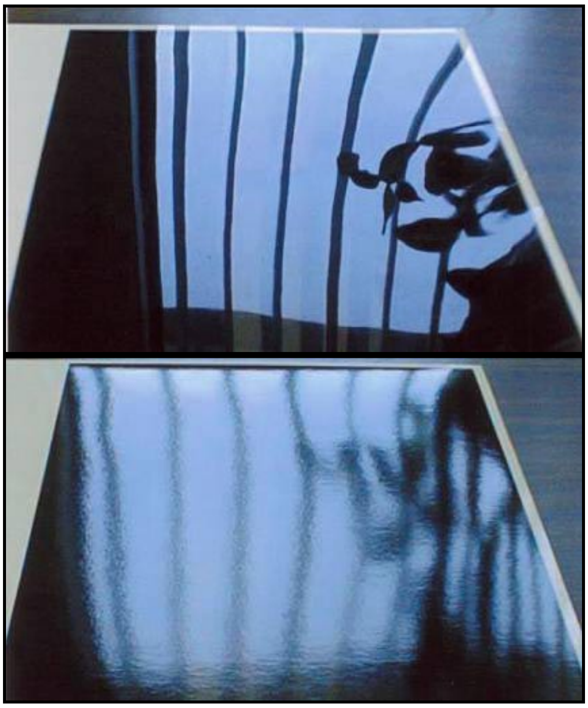

Fig.1 Two photo-grade inkjet media, both printed in full black, with reflections from a nearby window. The mirror-like reflection produced by the top sample exemplifies high DOI.

To many, gloss is a single attribute that characterizes the shiny or lustrous appearance of a surface and can be measured by the intensity of light reflection in the specular direction. However, gloss is actually more complicated. 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) the spreading of light to either side of the specular direction (DOI); and 3) change in the nature of reflection as specular angle changes (sheen, luster or contrast gloss). Consequently, a gloss meter that measures specular gloss alone often fails to predict or correlate with visual ranking. In the automotive industry, DOI has long been recognized as more important than specular gloss in characterizing the quality of 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].

Characterization of gloss in research, including DOI, typically relies on goniometry techniques and instruments. 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).

DOI is the distinctness or sharpness of a reflected image. It is strongly dependent on the smoothness or the texture of the reflecting surface. Guided by this basic

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definition and inspired by the observations of the quality of reflections on a range of photo media (Fig. 1), 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 (Fig. 2). The analysis is fundamentally an "edge gradient method" as illustrated in Fig. 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.

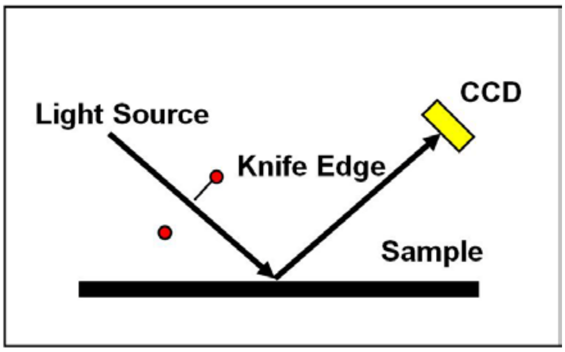

Fig.2 Schematic of the DIAS Design

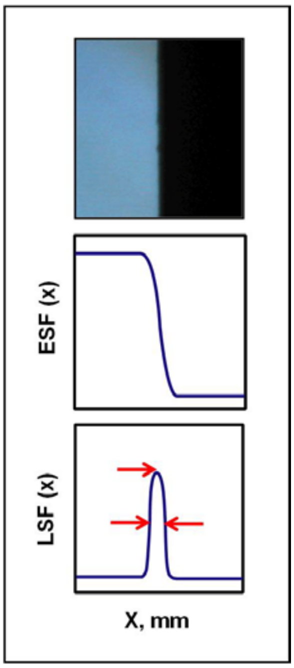

Fig.3 Principle of DOI Measurement

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.

2. Improved DOI Measurement

The improvements implemented in the second generation DOI measurement tool (DIAS-II) are based on two principles:

1) Instead of calculating all the DOI metrics from the LSF in the spatial domain, a corresponding set of metrics are obtained from the Spatial Frequency Response (SFR) function in the frequency domain. The SFR (also called MTF, or Modulation Transfer Function) is obtained by applying a Fourier transform to the LSF as illustrated in Figure 4.

2) Apply the visual contrast sensitivity function (CSF) in the frequency domain to guide the choice of appropriate DOI metrics that are relevant to human perception (e.g., humans cannot perceive high frequency details such as those at spatial frequency much higher than 5 cycles/mm at a viewing distance of about 350mm).

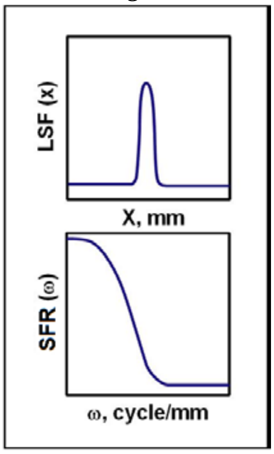

Fig.4 Fourier transformation of LSF yields SFR

Our hypothesis is that a good deal of the noise in the DOI measurement occurs at high frequencies, perhaps much higher frequencies than our perceptual capability. If so, we can filter out the noise by computing metrics in the limited frequency range that is relevant to human perception (as guided by the visual contrast sensitivity function, CSF). This idea is summarized in Fig. 5, where a typical CSF is superimposed onto the SFR, illustrating both frequency ranges of "relevance" and "irrelevance".

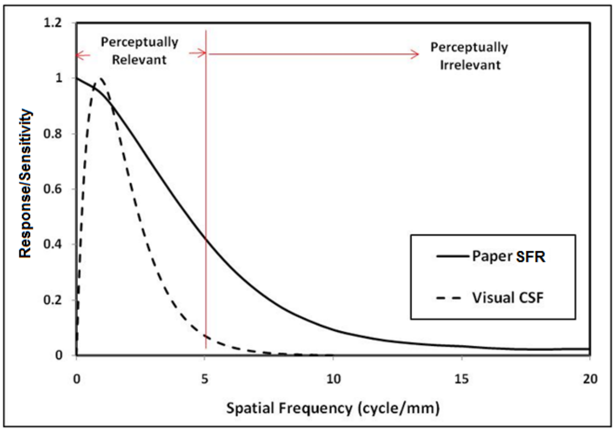

Fig.5 SFR of a high quality photo media and a CSF

In addition to the basic of idea of DOI analysis in the frequency (i.e. SFR) instead of the spatial (i.e. LSF) domain, there are two other significant improvements in our refined DOI measurement technique:

1) Adoption of the "Slanted Edge Method" in finding spatial frequency response (SFR) as described for imaging systems in ISO-12233[7]. The slanted edge method is advantageous in two ways: a) use of a standardized SFR algorithm as described in ISO-12233, and b) use of "super-sampling" to improve the spatial resolution of the analysis[8-9]. An example of a slanted edge is shown in Fig. 6.

2) Use of the "Subjective Quality Factor (SQF)"[10] in computing a robust and meaningful DOI metric. SQF, first introduced by Granger[11], is essentially the area under the convolution of the SFR and CSF curves, when the spatial frequency is plotted on a logarithmic scale. This metric corresponds to subjective sharpness. Since DOI describes the observation of sharpness of a reflected image, the use of the SQF methodology together with the slanted edge SFR technique provide the basis for obtaining a meaningful DOI metric.

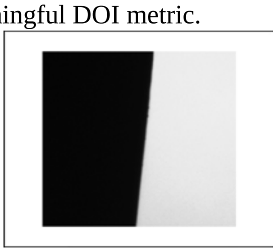

Fig.6 Example image featuring a "slanted edge"

3. Experimental Method

To test the efficacy of the techniques, a set of 10 inkjet photo media with a range of DOI was measured using a second generation DIAS (the DIAS-II) equipped with a slanted edge and corresponding software to compute the spatial frequency response (SFR) and the subjective quality factor (SQF). Several characteristic points on the SFR curve (e.g. response at 1, 1.5, and 2 cycle/mm, and the spatial frequency at response of 50%, 30% and 10%) were recorded. Note that in this implementation of the SFR method, the edge angle is known (fixed) because the "knife edge" producing the edge image is physically fixed with respect to the imager. This is an advantage in the SFR computation, as it eliminates one variable and its related uncertainty. Data were collected by 3 different operators who each conducted 10 trials. In each trial, the same 10 samples were measured. We computed the repeatability (inter-instrument agreement) and reproducibility (inter-operator agreement) of the measurements to assess the efficacy of the new approach and compared them with the same statistics for the old metrics (Peak and Blurriness).

Finally, the 10 samples were ranked subjectively by a panel of judges. Each judge independently sorted the samples via paired comparisons with a 1 cycle/mm pattern projected onto the samples under test. The correlation between the objective measures obtained and the subjective ranking was examined.

4 Results and Discussion

The repeatability (or precision, inter-instrument agreement) of the new instrument and measurement method is determined by pooling the data obtained by the three operators on the 10 samples with 10 repetitions. Results are summarized in Table 1:

Table 1 Repeatability (precision) of the old and new DOI metrics

	DOI Metric	Coefficient of Variation (Stdev/Mean, σ/μ)
LSF Metrics (Spatial Domain)	Peak (%/mm)	9.25%
	Blurriness (mm)	39.11%
SFR Metrics (Frequency Domain)	SQF	1.55%
	SFR %;1.0 cy/mm	0.70%
	SFR %;1.5 cy/mm	1.56%
	SFR %;2.0 cy/mm	2.72%

The coefficients of variation clearly indicate that the new metrics (i.e., SQF and SFR at 1, 1,5 and 2 cycle/mm) are significantly more repeatable than the old metrics (i.e., Peak and Blurriness).

The reproducibility (inter-operator agreement) of the new instrument and measurement method is determined from pooling the data obtained the 10 samples for each operator. The results are summarized in Table 2.

Table 2 Reproducibility of the old and new DOI metrics

	DOI Metric	Coefficient of Variation (Stdev/Mean, σ/μ)
LSF Metrics (Spatial Domain)	Peak (%/mm)	10.90%
	Blurriness (mm)	47.70%
SFR Metrics (Frequency Domain)	SQF	0.90%
	SFR %;1.0 cy/mm	0.50%
	SFR %;1.5 cy/mm	1.10%
	SFR %;2.0 cy/mm	2.30%

Again, the SFR metrics, including SQF, are much more robust than the old metrics. These results confirm the idea that by focusing the DOI analysis in relatively low spatial frequencies (< 5 cycle/mm), the impact of any high frequency noise on measurement performance is minimized. The remaining question is on perceptual relevance, i.e., does this set of new metrics agree with visual ranking?

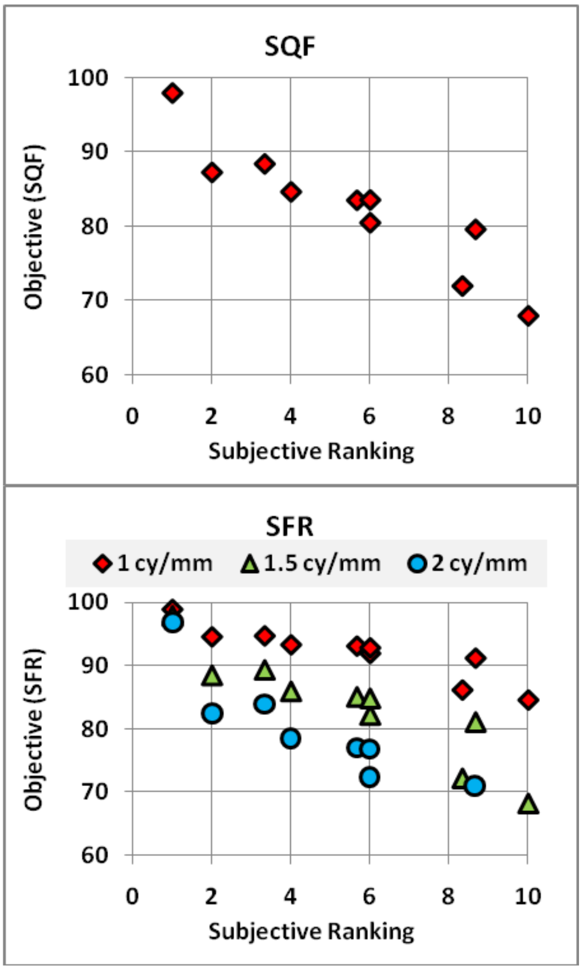

Fig.7 Correlation between SQF/SFR metrics and subjective ranking of DOI samples

The correlations of the SQF and the SFR measurements with the visual ranking test are shown in Fig. 7. The results indicate that the objective metrics are strongly correlated with subjective perception of DOI. However, it is also clear from these results that SQF and the set of SFR metrics are not independent and probably the use of a single metric from this group such as SQF is sufficient for DOI characterization.

5. Summary

The original idea of using an edge gradient method and spatial domain analysis laid a solid foundation for a compact, portable instrument for measuring distinctness-of-image (DOI) gloss. Building on this foundation, a new method using an ISO-based slanted edge technique for spatial frequency response (SFR) analysis in the frequency domain, together with the concept of subjective quality factor (SQF) has been demonstrated. The new method provides the basis for a second generation instrument that holds promise to be an invaluable tool for digital print media R&D and production quality control.

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