Evaluation of Glossy Inkjet Papers Using Distinctness of Image (DOI) Measurement

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Abstract

There is growing recognition that besides specular gloss, the attribute of distinctness of image (DOI) is important in accurately characterizing the surface appearance of glossy inkjet paper. DOI refers to the sharpness of images reflected from a surface. At present, no consistent and quantitative method has been adopted to report DOI in the characterization of digital prints.

The objective of this study is to assess DOI as a suitable metric for characterization of glossy inkjet papers using currently available methods. This study was conducted on unprinted sheets due to the complexity of choosing an appropriate test image and printer combination. Commercial glossy inkjet papers, both porous and swellable, were measured using three different methods for measuring DOI. The results were compared to each other and to surface smoothness, 60° gloss, and panel studies on visual perception of photo-like glossy appearance. The results demonstrate that even low gloss sheets (< 40 units), typically porous, may be perceived as having a photo-like surface due to high DOI. Certain measured parameters using available methods do correlate with the perception of DOI.

Introduction

A major objective of glossy inkjet papers has been to achieve the look and feel of a traditional glossy photograph. The main metric that has been used in characterization is gloss, typically reported for a 60° geometry. However, there is growing realization that 60° gloss alone does not completely describe a glossy photo-like appearance,[1-3] and that other attributes such as distinctness of image (DOI) are equally important to the perception of gloss.

There is a considerable body of work on gloss perception, universally recognizing it to be a very complex phenomenon. In early work, Hunter[4] separated gloss perception into six categories: specular gloss, sheen, contrast gloss, absence-of-bloom gloss, distinctness of image gloss, and surface uniformity gloss. The ASTM Standard for Specular Gloss[5] recognizes that measured gloss is affected more than visual gloss by differences in surface refractive index. More recent psychometric and computer simulation[6-13] studies have tried to quantify and develop models for the perception of gloss.

ASTM has a test-procedure[14] that deals with measurement of DOI for high-gloss surfaces using spectrogoniophotometry. In this standard, DOI is evaluated by gloss measured at an angle 0.3° off-specular. ASTM also has a work-item in progress on DOI measurement for high-gloss surfaces.[15]

The objective of this study is: (i) to understand the influence of DOI on the perception of glossy photo-like appearance, and (ii) to determine whether a quantitative measurement that correlates visually is possible with available laboratory-scale instruments. Identifying an appropriate parameter would be valuable to manufacturers of glossy coated inkjet media in developing coating formulations, as well as choosing appropriate coating and finishing technologies.

The scope of this study was limited to the unprinted paper surface, which would influence initial customer perception of sheet quality. Although it was recognized that a judgment of photographic quality would ultimately be determined by the appearance of the printed sheet, the complexity involved in selecting an appropriate test image, and the variety of OEM and printer combinations precluded choosing conditions that would be considered typical.

Experimental

Twenty-one commercial glossy inkjet papers were studied, selected on the basis of being marketed as glossy, photo-quality sheets. The sheets are listed alphabetically in Table 1. Two silver halide papers, Ilford Multigrade IV (RC Deluxe) and Kodak Polycontrast III RC Glossy, were used as reference sheets. All the sheets were purchased from retail outlets.

Glossy inkjet papers may be classified based on the ink-absorptive characteristics of the coating as: (a) Porous (predominantly pigment-based), and (b) Swellable (predominantly polymer-based). The study sheets were identified as porous or swellable based on a combination of SEM and chemical analyses, and a water-smudge test, wherein a wet finger was rubbed on the coated surface. The swellable polymer sheets became either tacky or slippery when rubbed, due to the water-sensitive nature of the polymer. The wet spot also took tens of seconds to dry. By contrast, the porous sheets did not get tacky, and most maintained coating integrity when rubbed. They also demonstrated almost instant drying, as the wet spot disappeared in a few seconds. Prior experience has shown this to be a reliable method of estimating coating-type. Twelve sheets were identified as porous, while nine were identified as swellable.

Table 1. Sheets used in the study

INKJET PAPERS
Avery Ink Jet Greeting Cards, Glossy Photo Quality
Canon Glossy Photo Paper
Diamond Jet Artist 'Mirror Gloss Heavy' Mitsubishi
Diamond Jet Photograde 'Photogloss Heavy', Mitsubishi
Epson Glossy Photo Greeting Cards
Epson Photo Quality Glossy Paper
Epson Premium Glossy Photo Paper
HP Photo Greeting Cards
HP Photo Paper Glossy
HP Premium Photo Paper Glossy
HP Premium Plus Photo Paper
Jet PRINT PHOTO Multi-Project Photo Paper
Jet PRINT PHOTO Premium Photo Paper
Jet PRINT PHOTO Professional Photo Paper
Kodak Premium Picture Paper, High Gloss
Kodak Ultima Picture Paper, High Gloss
Optimum Photo Quality Paper, ICI Imagedata
Polaroid, Premium Photo Paper, Glossy
Royal Brites, Photo Paper, High Gloss
Smart Papers Kromekote Glossy
TDK Professional Grade Glossy Paper
REFERENCE PHOTOGRAPHIC PAPERS
Photographic Paper – Ilford Multigrade IV (RC Deluxe)
Photographic Paper - Kodak Polycontrast III RC Glossy

A panel study was conducted with 30 participants that included an equal number of men and women, as well as technical and non-technical personnel. The evaluations were performed in ambient indoor light, since the objective was to get qualitative assessments from a consumer's point-of-view. The sheets were shuffled before each evaluation to eliminate clusters of porous and swellable sheets.

First, the participants were asked to select up to three papers that in their judgment, most closely resemble silver halide inkjet papers, by direct comparison of the surface appearance to the reference sheets. The participants were asked to sort the sheets by gloss level into high, medium and low, and then by DOI into high, medium, low, and no DOI (i.e., reflection too blurry to see any detail). They were given the following practical definitions as guidelines:

Gloss: The intensity of the reflected light i.e., a measure of the shininess of the surface.
DOI: The sharpness/accuracy of an image reflected off the surface.

60° glosses of the sheets were measured using a 'Micro-Gloss' glossmeter from Byk-Gardner. The gloss value reported was the average of five measurements on the sheet.

DOI was measured using: (a) an I^2R DOI Light-Box, and (b) a Wave-Scan DOI meter from Byk-Gardner. QEA, Inc. also evaluated the sheets using a DOI test-method under development, and provided us with the data.

The I^2R unit consists of a light-box that sits atop a frame 10" above the test surface, face down with a backlit test pattern. The test pattern consists of ten bands of semicircles of decreasing size designated from 10-100 in increments of ten. The sheet to be evaluated is placed underneath the test pattern, and the reflection by the sheet is observed. The DOI to be reported is the smallest band where the semicircles are still discernible. The suggested procedure was modified for this study. Details are provided in the Results section.

The Wave-Scan DOI meter from Byk-Gardner is a portable instrument like the gloss-meter. The instrument uses a laser point light source to illuminate the surface at a 60° angle, and a detector measures the reflected light. The instrument is rolled slowly across the surface to make the measurement for a set path length, which can be set to 50, 100 or 200 mm. These measurements were made at a 100 mm path length. The instrument measures the surface structure in terms of four parameters that cover increasing wavelength ranges. They are W_a: 0.1 – 0.3 mm, W_b: 0.3 - 1 mm, W_c: 1-3 mm, and W_d: 3 – 10 mm. In addition, it also calculates a long-wave (LW: 1.2 – 12 mm) and a short-wave (SW: 0.3 –1.2 mm) parameter. The instrument also has a second mode, in which a CCD camera detects light diffused by structures smaller than 0.1 mm wavelength as dU, a 'dullness' factor. In this mode, the instrument also calculates a 'DOI' parameter, which is a function of (dU, W_a, and W_b). However, in this mode, insufficient gloss or non-uniformities can cause the instrument to fail to register a reading. The manufacturer recommends that caution be exercised in interpreting results from this mode for low-gloss sheets.

The Quality Engineering Associates (QEA), Inc. method is based on a digital image capture of a reflected image, followed by image analyses through software. They were sent the sheets labeled A through U, and reported back the results as parameters 'A' (DOI parameter), and 'B' and 'C' (gloss parameters).

Surface roughnesses of the sheets were measured using a Zygo NewView 100 Scanning White Light Interferometer. The parameter R_a is the average surface roughness or average deviation of all points from a plane fit to the test material surface.

Results

Panel Study of Perception of Photo-Like Gloss

The objective was to gauge consumer preferences in determining a photo-like surface finish that might influence an initial buying decision. The inkjet sheets were labeled solely as letters A through U. Note that the order does not correspond to the order of sheets in Table 1. Participants were asked to pick up to three sheets that most resembled the photographic reference papers. Table 2 shows the number of times each sheet was picked to be in the top three for photo-like appearance. Participants were also asked to sort the sheets separately by gloss and DOI alone, and then rank all sheets in descending order for that property. Thorough analyses of these data are in progress. The main trends are:

(a) Most participants picked either sheet B or L as having the highest DOI. Sheet B is porous, while sheet L is swellable.
(b) Sheets B, D, E, and L were picked significantly more often than the others as being most photo-like in appearance.
(c) Interestingly, of the three swellable sheets among the top-rated sheets, more participants rated sheet E as having the most photo-like surface, although sheet L was picked to be highest for DOI. A possible reason is that sheet E more closely resembled the reference silver-halide papers in direct comparison. The results may have been different if the participants had been asked to pick the most photo-like sheets without the reference sheets for comparison.
(d) When asked to pick three sheets that most resembled photographic paper, participants tended to pick all sheets from the same category, either porous or swellable, suggesting a preference for one type over the other.
(e) Participants had a more difficult time when asked to sort the sheets by gloss alone, compared to sorting by DOI alone. They reported that it was difficult to ignore the influence of DOI in gloss-perception.

It should be mentioned that the photographic sheets used in the study became gray upon exposure to light, but after comparing a sheet right out of the package to one that had been exposed, participants agreed that the shade difference did not alter their perception of photo-like surface appearance.

Measured Gloss vs. Perceived Photo-Quality

Table 2 also shows the 60° gloss values for the sheets. As mentioned in the earlier paragraph, sheets B, D, E, and L received the most votes as being photo-like in appearance. Of these sheets, B, which is porous, has a gloss of only 35 units. Other low-gloss sheets which received votes as being photo-like were H, M, O and T, all of which have glosses below 40 units. These data indicate that 60° gloss alone does not explain the perception of photo-quality.

Qualitative Rating of Distinctness of Image

As mentioned earlier, the panel study results of ranking by DOI are undergoing further analyses. In this paper, the I^2R light-box was used to rate DOI of the sheets to understand the factors influencing DOI perception. The suggested method of assigning a DOI value, i.e., identifying the smallest band of semicircles reflected clearly, was found to be subjective due to differences in lighting conditions, viewer vision and viewing angle, thus making ranking difficult. However, it was possible to use the instrument to classify the sheets into five DOI ratings from 1 (highest) to 5 (lowest), based on overall image contrast and sharpness of the reflected test pattern. These assignments were in good agreement between three individuals and formed the basis for correlations with measured parameters. The assigned ratings are also provided in Table 2. As suggested by the panel study, sheets B and L, which were picked to be highest for DOI among the inkjet papers, also rated higher than the other papers when classified with the instrument.

Table 2. Results of Panel Study

Coating Type	Sheet	'Photo-Like' Votes	60° Gloss	I^2R DOI Rating*
Porous	A	1	38.3	5
Porous	B	10	34.7	2
Porous	C	0	50.8	3
Porous	H	3	35.3	3
Porous	I	0	37.9	5
Porous	J	0	35.2	3
Porous	M	2	34.1	4
Porous	O	3	35.2	3
Porous	P	0	53.8	4
Porous	S	0	35.7	4
Porous	T	1	34.8	3
Porous	U	1	57.1	3
Swellable	D	9	85.3	3
Swellable	E	14	82.0	3
Swellable	F	3	73.3	4
Swellable	G	2	73.5	4
Swellable	K	0	65.5	5
Swellable	L	7	84.3	2
Swellable	N	1	67.9	5
Swellable	Q	0	36.8	5
Swellable	R	0	37.4	5
AgX	Ref. 1	-	95.4	1
AgX	Ref. 2	-	96.0	1

* 1 = Highest (Best), 5 = Lowest (Worst)

Factors Influencing Perception of DOI

The sheets in this study appeared to vary widely in smoothness. Therefore, optical profilometry was used to characterize smoothness of the sheets. Figure 1 shows the average roughness (R_a) plotted against 60° gloss for all the sheets. The sheets selected as most photo-like in the panel study are indicated. Towards the lower end of the gloss scale, sheet B, which is porous, had the lowest roughness. On the higher end of the gloss scale, the three sheets that had the three highest gloss values were D, E, and L, all swellable, which were also rated most photo-like. Note also that most of the swellable sheets had gloss values greater than 60, with two notable exceptions with glosses around 37 (Q and R), which were also considerably rougher than the others. The porous sheets had glosses less than 60, and in general were smoother than the swellable sheets, except for one sheet (A), which was considerably rougher due to a different surface texture.

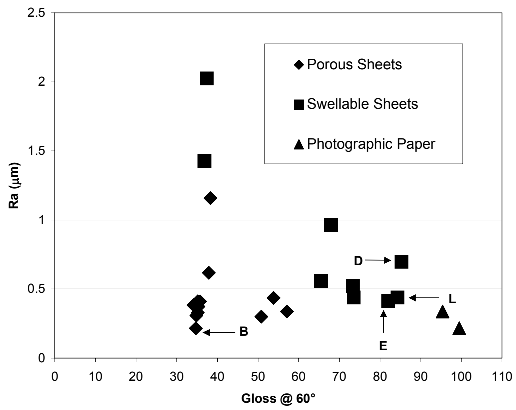

Figure 1. Average roughness (R_a) vs. 60° gloss for all sheets

The parameters of roughness and gloss by coating type are analyzed further in Figures 2 and 3. The one porous (A) and two swellable (Q and R) sheets that fell clearly outside the main data clusters were excluded from data fitting shown in the figures, although the goodness-of-fit (R^2) values with them included are mentioned in the discussion. They might represent significantly different sheet constructions or methods of manufacture.

Figure 2 shows a plot of 60° gloss vs. DOI rating for the sheets. For the swellable sheets with gloss values above 70, the DOI ratings correlate very well with measured gloss. If sheets Q and R are included, the goodness-of-fit (R^2) drops from 0.9036 to 0.6038. For the porous sheets, the DOI ratings did not correlate with gloss.

Figure 3 shows the average roughness (R_a) vs. DOI ratings for porous and swellable sheets. As the figure shows, R_a correlates very well with DOI rating for the porous sheets (R^2 = 0.8236). There was poor correlation between R_a and DOI ratings for the swellable sheets. The goodness-of-fit (R^2) with sheets Q and R excluded is 0.2707, and with Q and R included is 0.3603.

These data suggest that at lower gloss levels, smoothness has a significant influence on the perception of DOI, whereas at higher gloss levels, gloss dominates the perception of DOI, perhaps due to higher contrast between light and dark areas with increasing gloss.

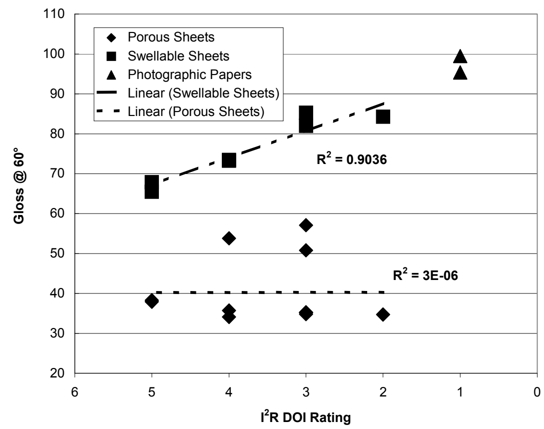

Figure 2. 60° gloss vs. I^2R DOI rating.

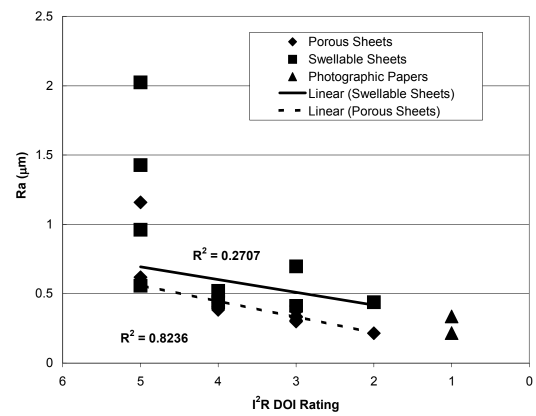

Figure 3. Average roughness (R_a) vs. I^2R DOI ratings.

Overall, although smoothness and gloss do correlate well with perception of DOI for the porous (lower-gloss) and swellable (higher-gloss) sheets respectively, it should be recognized that within each category, coating refractive index could have played an important role in the particular sheets that were considered most photo-like.

Quantitative Measurement of DOI

Wave-Scan DOI

This instrument was primarily developed for the automotive paints industry. The instrument has two modes, (i) camera-off, and (ii) camera-on. In the former, the instrument generates parameters in four wavelength ranges (W_a, W_b, W_c and W_d), as well as LW and SW, which are calculated for long and short wavelengths. Of these, the shorter wavelength parameters (W_a, W_b, and SW) correlated best with visual DOI across all sheets regardless of coating type. For example, SW vs. DOI rating is plotted in Figure 4. It is noteworthy that sheets E and L, which were perceived as highest in DOI in the panel study, also had the highest SW values.

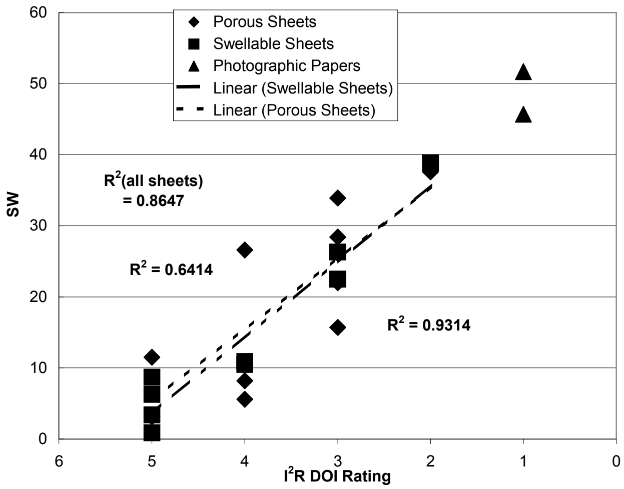

Figure 4. Wave-Scan 'SW' vs. I²R DOI Rating

In the latter mode (camera-on), the instrument generates dullness (dU) and DOI parameters, which correlate well with perceived DOI. However, in this mode, the instrument had a difficult time registering readings with low-gloss or non-uniform sheets, and in some cases, measurements had to be repeated multiple times to register a reading. In general, since the instrument has to be rolled across the sample surface, it requires a high degree of uniformity in order to make a measurement, although the path length can be changed if needed.

QEA Method

The goodness-of-fit (R^2) of the three parameters to the DOI ratings are shown in Figure 5. Of the three parameters, 'A' correlates best with DOI rating, especially for the swellable sheets.

According to QEA, a single measurement provides information on DOI in terms of the parameter 'A', whereas gloss is described by the parameters 'B' and 'C'. The QEA method is stationary.

Summary

Figure 5 shows the goodness-of-fit (R^2) for all the parameters generated in this study against the DOI ratings. The R^2 values for 'All Sheets' include the photographic reference sheets in all cases, except for the QEA parameters.

As shown earlier, 60° gloss correlates reasonably well with perceived DOI for the swellable sheets, whereas smoothness correlates very well for the porous sheets. The data show that the parameters that correlate best across independent of coating type are SW, W_a and W_b and to some extent W_c (i.e., shorter wavelengths). These may therefore be used to quantify DOI. LW and W_d parameters do not correlate with perceived DOI.

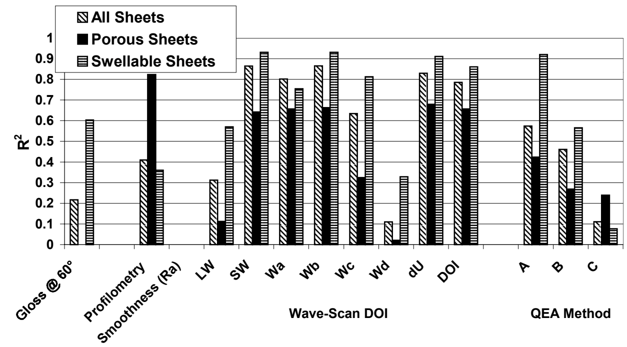

Figure 5. Correlation of individual parameters to perceived DOI.

In the CCD camera mode, dU and DOI parameters do correlate with perceived DOI. However, this mode requires high gloss and surface uniformity. One sheet (R) that could not register a reading had to be excluded from the data analysis. This might be a limitation for low-gloss or non-uniform samples such as laboratory prototypes.

Conclusions

Panel studies show that sheets perceived as having a glossy photo-like surface need not have a high measured gloss (typically > 80 units), as sheets with 60° gloss values lower than 40 units were selected as photo-like due to high DOI. For these lower gloss sheets (typically porous), the perception of DOI correlates well with smoothness. For the higher gloss sheets (typically swellable), the perception of DOI correlates well with gloss, perhaps due to enhanced contrast between light and dark areas. Of the instruments tested, the I²R light-box is qualitative, whereas the Byk-Gardner Wave-Scan and the QEA developmental method show potential for a quantitative determination of DOI. Based on this study, it is concluded that measuring DOI in addition to gloss is a more reliable method for evaluating photographic quality that measuring gloss alone.

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Biography

Sanjay Monie received his Ph.D. in Materials Science from The Pennsylvania State University in 1996. He has been involved in research and development of media for digital printing since 1996, first at Westvaco Corporation and presently at W. R. Grace and Company. He has served as Delaware Valley Section Chair of TAPPI and is a member of the ISO Working Group 5/Task Group 3 on 'Methods for Measuring the Stability of Color Pictorial Images'.