An Objectively-Measured Index of Banding

Anthony P. Stanton* and Phillip N. Hutton**

Keywords: Densitometric, Measurement, Problem

Abstract: The incidence of banding in printed vignettes was observed to be a common defect with prints generated from computer-to-plate (CTP) systems. The evaluation of banding has traditionally been a subjective visual assessment. This study compares subjective assessments of banding with an objectively derived index in a controlled experiment. Eleven printed samples from CTP systems were evaluated by nine judges, who identified the locations and severity of bands in the prints. The samples were then measured with a scanning densitometer to record the variations in reflectance. This data was subjected to non-linear regression analysis to identify a best-fitting third-order equation to model the changes in density. Differences between the predicted and measured densities were calculated ($\hat{Y}$ values). Next the changes in $\hat{Y}$ ($\Delta \hat{Y}$), along with the density level involved, were used to formulate a predictive equation that was found to correlate with the subjective values for banding.

Background

The term "vignette" refers to a smooth transition of tones where a darker value is seen to fade into a lighter one. Vignettes commonly occur in nature, for instance in the sky at sunset. Vignettes can occur in any color or combination of colors. It is common in portrait photography to manipulate the lights to create a vignette behind the subject.

---

*Carnegie Mellon University, GSIA #135, Pittsburgh, PA 15213, 412-268-2313

**Graphic Arts Technical Foundation, 200 Deer Run Rd., Sewickley, PA 15143, 412-741-6860

Vignettes are also generated as graphic elements for various design purposes. This use of vignettes has increased dramatically as the graphics industry has moved from photomechanical to electronic imaging. With photomechanical techniques, vignettes were difficult to generate, but with electronic (and now desktop) systems, the computer generation of vignettes has become trivial. This study utilized only computer-generated vignettes.

"Banding" is the term applied to the most common defect found with computer-generated vignettes. It refers to an abrupt shift of tones that breaks up the otherwise smooth transition. Bands vary in their width, location, and severity. Banding is often traceable to the electronic imaging system: the raster image processor (RIP), the filmsetter, or the platesetter. The same file can be sent to different imaging systems, and some will exhibit banding while others will not.

In a 1995 GATF study of the reproduction characteristics of CTP systems, it was found that many of the platesetters used in the study exhibited some degree of banding.[1] The black and white test page that contained the vignette is shown in Figure 1.

Of the eleven systems studies, five were judged to have slight to moderate banding, and three were found to exhibit severe banding. Only one of the samples was judged to have a vignette that was "smooth and even". The vignette used for the study was a 1.3 x 3.5-inch computer-generated black and white vignette that went from 1% to 99% tone value. During the 1995 study, the vignette densities were measured at 0.1 inch increments and graphs were constructed showing the progression of density readings for each sample. These graphs showed sudden density shifts at locations where severe banding had occurred. Further study was needed to determine whether more precise density measurements could be used to calculate a numerical index that would predict the occurrence of objectionable bands. The current study was designed to fulfill that objective.

Description of the Study

This study used the printed samples from the 1995 study, which had been stored in a light safe environment. Representative prints from eleven different imaging systems were selected. Ten of the samples were from CTP imaging systems while the eleventh print was the GATF control print made from a conventional plate imaged from film generated from a filmsetter. The data presented in this report is in coded form. A list of the imaging systems that were used is shown in Table I.

The vignettes were cut out from the test page and mounted beside an arbitrary scale of 52 units on heavy white paper as shown in Figure 2. The scale was added to provide a means for the judges to specify the positions of observed bands. The vignettes were cut out from the rest of the test form to minimize the distractions that the judges faced when concentrating on the identification of banding.

Figure 1. Black and white test page (60% size).

Participant	Platesetter	Plate	RIP
Kodak	Ektron 6447	Kodak X-919 Lithoplate	Harlequin ScriptWorks
Gerber	Gerber Crescent 42	Polychrome CTX	Harlequin ScriptWorks
Screen	DS PlateRite PI-R1080	Mitsubishi DiamondPlate	TaigaEdge T-RIP700
Krause	Krause LaserStar 140C	Hoechst N90	Hyphen P.C.
Creo	Creo 3244	Hoechst N90	Harlequin ScriptWorks
Creo	Creo 3244	Agfa Lithostar	Harlequin ScriptWorks
DuPont	Optronics XLP	DuPont Silverlith	Optronics CAI
Mitsubishi	Escher-Grad EG-8000	Mitsubishi DigiPlate	Escher-Grad
Agfa	Agfa Avantra 44	Agfa Setprint	Star 800
Misomex	Misomex 5040	DuPont Silverlith	Harlequin

Table I. Participants in the study (from 1995 CTP study).

Nine judges rated the banding found in the vignette samples. The judges included seven males and two females, all of whom work in the graphic communications industry. Seven of the judges made their evaluations under standard viewing conditions as specified in ANSI ph 2.15-1985. Standard viewing was unavailable for the other two judges.

A score sheet was made to help the judges organize their observations. The judges were asked to identify the locations (along the 52 increment scale) of any bands and to indicate whether the bands were "barely noticeable" or "very noticeable", where "barely noticeable" bands would not affect the quality of the reproduction and "very noticeable" bands would adversely affect reproduction quality. Some of the judges indicated that the gloss and mottle present in some of the prints was confusing the identification of banding. The observed number and severity of bands in the vignette samples varied remarkably between the nine judges. This may be a reflection of differences in visual acuity, experience, and quality expectations of the different judges. The scores from the nine judges were entered into a spreadsheet to facilitate the analysis of the data.

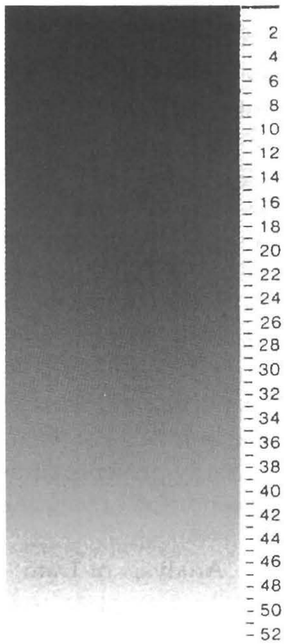

Figure 2. Sample vignette.

The mounted vignette samples were then measured with a Tobias SXY-40 scanning densitometer (Status-T response). A two-dimensional measurement array was used with 52 measurements made along the long dimension of the vignette corresponding to the 52 scale positions. At each scale position, eight measurements were made across the short dimension of the vignette to capture the effects of any non-uniform densities across the vignettes. The center six density readings from each scale position were averaged to determine the density value for that position. The two end readings were discarded to exclude edge effects from the average densities.

The density readings at the extreme highlight and shadow ends of the scale were not considered to be reliable, due, in part, to placement error during the reading. At the highlight end of the scale, the 52nd density reading was consistently higher than the 51st reading when it should have been lower. This was apparently due to the densitometer recording the shadows at the edge of the cut-out vignettes where they were mounted onto the base sheets that contained the positioning scales. The density readings from the first and last two scale positions were not used in the analysis.

The density measurements were then analyzed to establish an equation that would predict the subjective banding scores from the objective density measurements.

This study was conducted under the following limitations:

- The printed samples were two years old (although they were stored in a light-safe room-temperature environment).
- Only single copies from each imaging system were analyzed.
- Only black ink vignettes were analyzed.
- The size and orientation of the vignettes were not varied.
- The tonal range of the vignettes was from 1% to 99%

The results of this study are coded because it would be unfair to indict an imaging system as being prone to banding based on a single-sample analysis. Also, since the samples are two years old, it would be unfair to assume that the banding conditions that were evidenced from a given CTP system would be indicative of the output from that same system today. Instead, the study presents a possible method for the objective evaluation of the condition of banding.

Analysis of Data

The subjective scores from the nine judges were combined to establish total subjective scores for each of the printed vignettes. The exact scale position assigned to a band was, to some extent, a judgment call. When the judges were in broad agreement about the existence of a band, but they disagreed about the location, then the location given by the majority of the judges was used as the position for the composite score. This caused some of the scale positions given by the individual judges to be adjusted by one scale increment. Location differences of more than one scale increment were treated as different bands. An example of a situation were location adjustments were made is shown in Figure 3.

In the example shown in Figure 3, a severe band was noticed by most of the judges. Six of the judges located the band in scale position #26, but two of the judges located the band in scale position #27. In this instance, the scores for judges 1 and 4 were relocated to scale position #26 to conform with the band placement of the majority of the judges.

The highest total subjective score possible was 18 (nine judges each giving a subjective score of two for severe banding). A total score of 4 or less was considered to be an unreliable indication of the presence of a band because the majority of the judges had scored the location as a zero.

Table II contains all of bands that were identified in this study with total subjective scores greater than 4. The columns labeled "A" and "B"

Sample #6

Location	Judges									
	1	2	3	4	5	6	7	8	9	Total
1										0
2										0
3										0
4										0
5										0
6			2		1					3
7										0
8										0
9										0
10										0
11		1			1	1				3
12										0
25										0
26										0
27		2	2		2	2	2	2		15
28	1			2						0
29										0

Figure 3. Subjective score scale position adjustment.

in Table II show the scale locations of the observed bands, where the A-values are the scale locations from the samples and the B-values are the transformed locations that were used during the analysis of data.

Examination of Table II reveals that samples 2, 7, and 11 were judged to be virtually free of banding; while samples 1, 3, 4, and 9 contained multiple bands. It is interesting to note that 8 of the 11 samples were judges to have bands in one of the last three scale positions (the lightest values of the vignettes). The judges may have been influenced by the same phenomenon that caused the densitometer to read higher densities at the extreme edge of the vignettes. Also, human observers are known to have high sensitivity to differences in light values, which might explain the high incidence of bands in the highlights. It might also be that CTP imaging systems are prone to banding in the highlights due to the thresholding effect of the light sensitive plate emulsions. The total subjective scores for these highlight bands were generally low indicating that they were not particularly objectionable to the judges.

					Samples							
A	B	1	2	3	4	5	6	7	8	9	10	11
5	92	9			5							
7	88				7							
8	87								6			
10	83				13							
13	77				16							
14	75	6										
16	71	7			11							
18	67			13								
23	58									12		
24	56										6	
25	54	9										
27	50						15			6		
29	46			13						5		
31	42					8						
33	38				6					12		
34	37										6	
37	31				5							
41	23				8							
47	12	7										
48	10				6							
49	8								7			
50	6			8								
51	4				8	6	6			6	6	
52	2							6				6

Table II. Locations and subjective scores of bands with total scores greater than 4

Graphs were then constructed for each sample plotting the average density readings against the scale locations. For these graphs, the scale locations were recalculated from the scale of 52 increments to make a scale that would range from zero to 100. A best-fitting third-order polynomial was calculated for each sample and is displayed on the graph along with the measured density values. The total subjective scores are superimposed on the graph with their scale values displayed on the vertical axis to the right. A sample graph in shown in Figure 4.

The third order polynomials were the lowest order models that produced sufficiently accurate correlations with the measured data. The chi-squared values of all the third-order polynomials were greater than 0.99. Different third-order polynomials were calculated for each vignette because there is no standard model that vignettes are expected to meet. Instead, different imaging systems might interpret smooth gradations

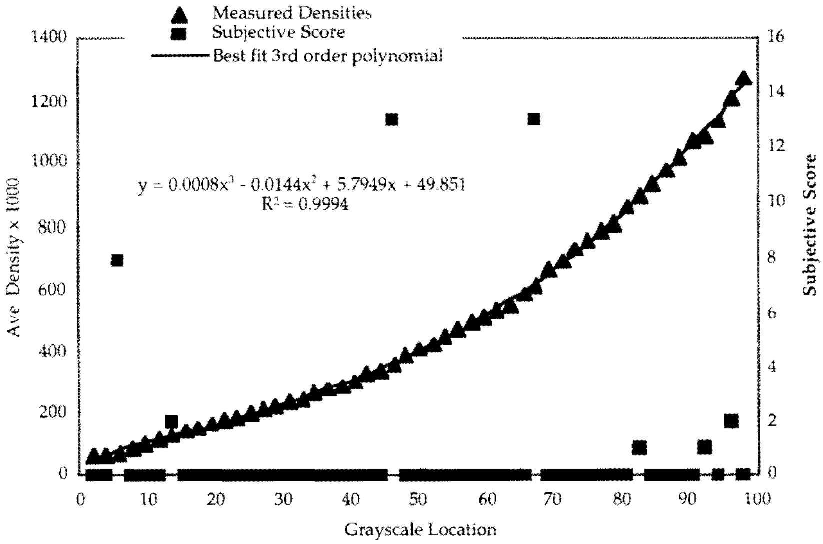

Figure 4. Measured density values vs. scale positions vs. subjective scores

differently. The focus of this study was the smoothness of each individual vignette, not how well it fit a standard mathematical model.

Next, the differences between the density values predicted by the mathematical models and the measured density values were calculated at each scale position. These values, designated as $\hat{Y}$-values, could be either positive or negative depending on whether the measured density was less than or greater than the predicted density. The change in $\hat{Y}$-values ($\Delta\hat{Y}$) was calculated by subtracting each $\hat{Y}$ from the preceding one for successively increasing vignette locations. High $\Delta\hat{Y}$-values indicate abrupt changes in the agreement between the measured and the predicted density values. It was assumed that high $\Delta\hat{Y}$-values would be associated with visible bands in the reproduction. Figure 5 shows a section of a data table containing the scale locations, measured densities, predicted densities, $\hat{Y}$-values, $\Delta\hat{Y}$-values, and total subjective scores.

The correlations between the subjective scores and the $\Delta\hat{Y}$-values were found to be weak without considering the additional factor of where in the tone scale the measurements are being taken (i.e., the scale location). It was also found that a stronger relationship existed for

Scale Location	Measured Density	Predicted Density	$\hat{Y}$	$\Delta\hat{Y}$	Subjective Score
96	1.378	1.322	0.056	0.000	0
94	1.315	1.259	0.056	0.048	0
92	1.206	1.199	0.007	0.027	9
90	1.122	1.141	-0.019	0.036	0
88	1.030	1.086	-0.056	0.001	1
etc.	etc.	etc.	etc.	etc.	etc.

Figure 5. Data table section

positive $\Delta\hat{Y}$-values than for negative ones. Since each band was expected to have both a positive and a negative side, it was decided to use only the positive $\Delta\hat{Y}$-values for the predictive equation. The exact locations of bands was considered to be imprecise with respect to the measured densities because the judges did not always agree on the locations for bands and because there was some difference in sample placement during the densitometric measuring operation. The $\Delta\hat{Y}$-values from four successive scale locations were averaged and used in the predictive equation. These average $\Delta\hat{Y}$-values were found to yield better results than the individual values for predicting the subjective banding scores.

To evaluate the relationship between the $\Delta\hat{Y}$-values, the subjective scores, and the scale locations, a three-dimensional plot was constructed as shown in Figure 6. It was observed from examining the graph from different perspectives that the relationship between scale location and subjective scores approximated a normal distribution (Figure 6a), while the relationship between subjective scores and average positive $\Delta\hat{Y}$-values was approximately linear (Figure 6b).

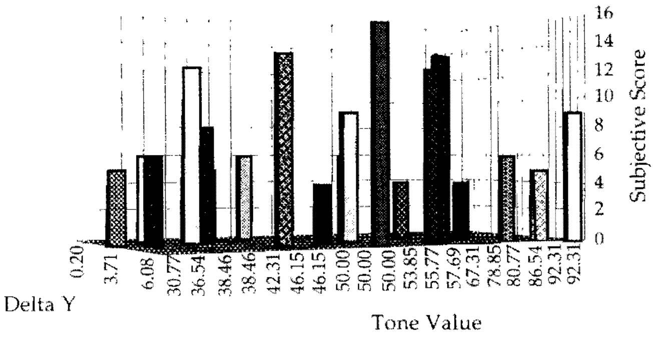

Figure 6a. Scale locations vs. average $\Delta\hat{Y}$-values vs. subjective scores

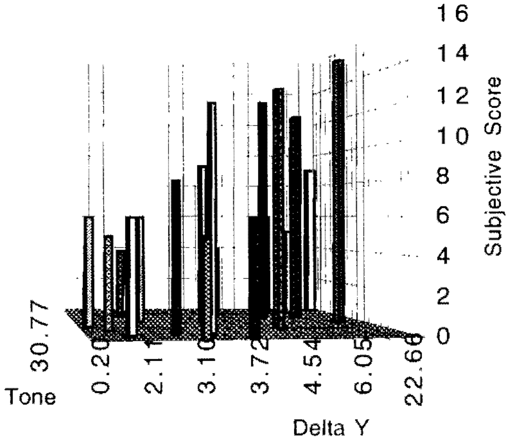

Figure 6b. Scale locations vs. average $\Delta\hat{Y}$-values vs. subjective scores

Assuming that the subjective score was separable with respect to the two variables, $\Delta\hat{Y}$ and scale location, a predictive function was developed using the separation of variables method. The equation was then optimized for the four parameters: slope and y-intercept for the linear part, and width and mid-point for the exponential part. The optimized predictive equation is as follows:

$$F(x,\Delta\hat{Y}) = (1.3\Delta\hat{Y} + 4.6)\exp[{}^{-(x-52)^2}/_{1352}]$$

A three-dimensional graph of the predicted subjective scores resulting from this equation is shown in Figure 7.

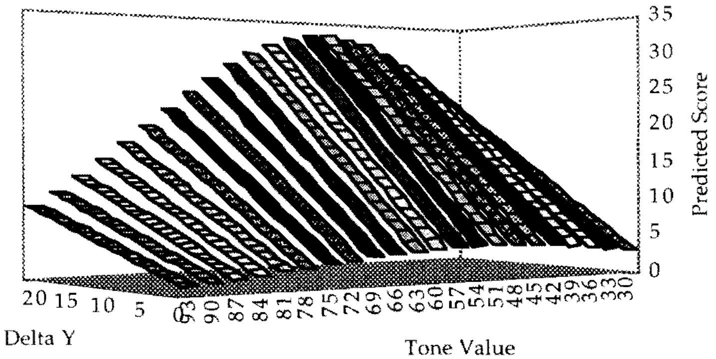

Figure 7. Predicted Subjective Scores

When the predicted scores were compared with the actual subjective scores above 4, a correlation of 0.79 was found. Figure 8 presents the predicted and the subjective score in relation to their scale positions.

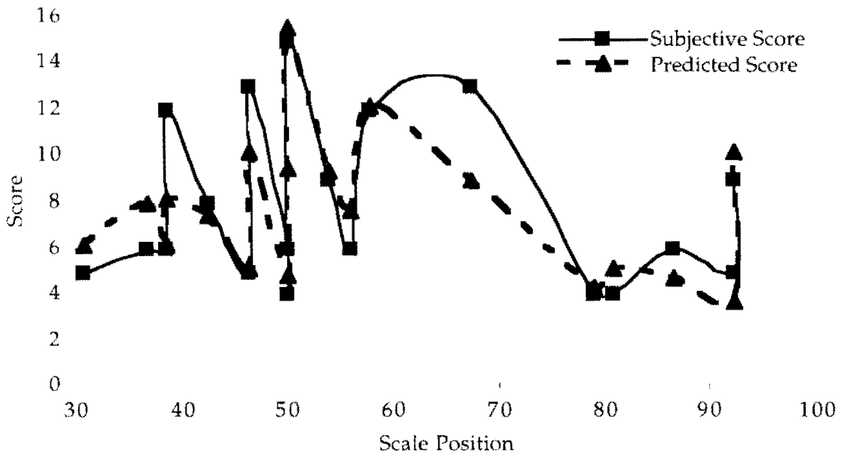

Figure 8. Predicted and actual subjective scores.

Conclusions and Recommendations

This study has demonstrated the feasibility for an objectively-measured index for banding under narrow conditions. Ideally, the techniques used in this study can be generalized for vignettes of various sizes, colors, and tonal values. The general form of the equation should be valid for other sizes and colors of vignettes, although the parameters might need to be optimized for each condition.

Although a high correlation was found between predicted and actual banding scores, there were some concerns that bear further investigation. Negative average $\Delta \hat{Y}$-values were weakly correlated with the subjective scores. They were omitted from the predictive equation in this study, but no clear reason for their ineffectiveness was found. The possibility of false positive predictions from the measured density data bears further investigation.

The eight density readings across the widths of the vignettes showed more variation than the researchers had anticipated. In this respect some of the imaging systems were better than others.

Reference

[1]Stanton, Anthony P., Reproduction Characteristics of Computer-to-Plate Imaging Systems, TAGA Proceedings 1995, pp. 1-29.