

Perceptual Scaling of Quality Metrics for Hardcopy Image Evaluation

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Abstract

The printing industry has quantified metrics for several kinds of image distortions. Each of these metrics refers to a particular artifact, and thereby to a mechanical origin of the artifact. A metric does not assign a perceptual significance to its associated artifact, but such an assessment is needed, e.g., when one wants to adjust a printing process to trade one sort of distortion against another. A way is needed to assess the perceptual significance of each artifact. Accordingly, this paper describes a perception-based evaluation of individual print-quality metrics, by applying a vision model (the Sarnoff JND Vision Model) that is being used successfully to predict digital-video quality. To adapt this model to the printing application, the following steps have been taken. (1) For several printed renditions of a KDY test pattern, sub-images containing individual artifacts are selected. (2) For each of these images, appropriate KDY ImageXpert quality metrics are computed. (3) The Sarnoff model is used to compare these sub-images with their corresponding bitmaps (warped so as to achieve registration). (4) The Sarnoff model values are compared with representative KDY metrics for each sub-image. From the comparison, it was learned that the perceived distortion in black characters on a white background is less than for white characters on a black background. The JND model separates these categories more completely than many of the KDY metrics. It is expected that if both ImageXpert and JND metrics are used in printing applications, the result will be an accurate assessment of the perceptual magnitude of artifacts (from the JND model), also means to correct them (from ImageXpert).

Background

Print quality assessment has traditionally relied on subjective human judgment. However, there is an expanding need for repeatable, automated assessments of image quality. At last year's NIP conference, Wolin et al.[1,2] discussed a new method (incorporated in a KDY product called ImageXpert) that examines selected parts of a printed test pattern and returns metrics on various artifacts such as line jaggedness and alphanumeric circumference.

The ImageXpert product is an important step toward an objective assessment of image quality, but the perceptual impact of the quality variables has yet to be determined. Therefore, another model has been brought to bear on the test-patterns that yield the ImageXpert metrics. This model, developed by Sarnoff Corporation, is called JNDmetrix. The Sarnoff model is a fast computational method for predicting the perceptual ratings that human subjects will assign to a degraded image relative to its non-degraded counterpart. The differences are quantified in units of the modeled human a *just-noticeable difference* (JND) of local image contrast. Figure 1 shows sample inputs (Image 1 and Image 2) of the Sarnoff model, and the output *JND Map*. The unit of the map, 1 JND, is a visual stimulus difference seen by observers 75 percent of the time. Also shown in Figure 1 is a schematic of the architecture of the JND model: At several spatial scales, the model evaluates measures of contrast through oriented filters, weights them by channel sensitivities derived from contrast-detection data, and nonlinearly compresses them to reflect that features become less detectable when seen on a non-uniform background. The JND Map derived from this model is useful because it shows not only the magnitude, but also the position of noticeable differences between the two input images. It is also valuable because all image distortions are rendered in the same units, and are hence quantitatively comparable with each other.

As an example of the usefulness of the JND model in applications related to printing, a study was conducted to determine the perceptual tradeoff between spatial resolution and gray-level resolution in displayed images.[6] The results are shown in Figure 2. It can be seen that unambiguous recommendations were possible based on this study.

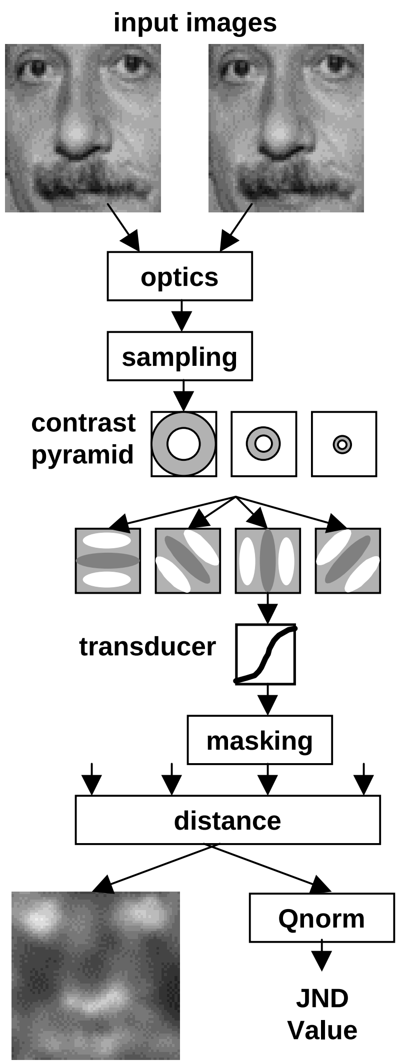

Figure 1. Architecture of Sarnoff JND model, with specimen images and derived JND map.

Based on the extensive use of both ImageXpert and JNDmetrix technologies, it was natural to consider combining the technologies. By correlating the evaluations of the JNDmetrix model with the specific evaluations of ImageXpert, we thought it would be possible to understand better the perceptual impact of the ImageXpert metrics. We also wanted to explore the possibility that the ImageXpert metric values could each be rescaled to have common perceptual units. In that event, printing tradeoffs could be performed using only the scaled ImageXpert values, without further input from the JND model.

Methods

Sixteen images (of dimension 640 x 480) were excerpted from a monochrome test pattern furnished by KDY, this test pattern having been printed on four kinds of paper (labeled a, b, c, d). Each of these images represented a separate kind of feature to which special printing metrics had been previously assigned--e.g. dots, fine lines, and printed characters, and either positive (black on white) or negative (white on black).[1] These printed sub-images were photographed by a high-resolution digital camera, and the digital values in each image were normalized to a minimum of 0 and a maximum of 255. Scores evaluated for the relevant KDY metrics were computed for each image and for each of the four printed media. These scores were saved for later correlation with the JND values computed from the Sarnoff Vision Model.

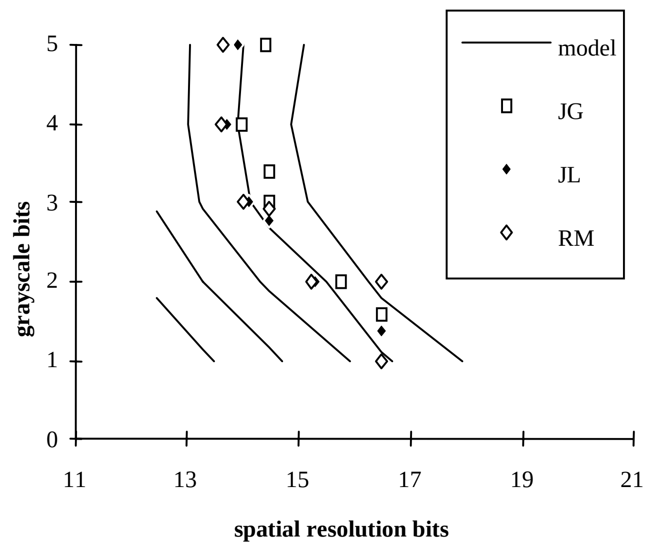

Figure 2. Tradeoff of Grey Level Resolution and Spatial Resolution in Displayed Images.[6]

To compute values for the Sarnoff JND metric, each test image was compared with the “perfect” bitmap image that generated it. The assumed viewing conditions for the JND model included a viewing distance of 33 mm (as if viewed through a loupe), a peak reflected luminance of 200 cd/m^2, and a digital camera with linear gamma. Each bitmap value was either 0 or 255. Because the Sarnoff Vision Model requires a pixel-by-pixel registration of two compared images, the bitmaps were subjected to an affine warping algorithm for best fit to each test image prior to the comparison. The registration software is part of the Sarnoff Image-Processing library.

Finally, for each sub-image feature (such as a fine horizontal line) and for the four printings of the sub-image, the JND values computed from the Sarnoff model are correlated with a representative KDY metric. The slope of the regression line is used to rescale the KDY metric to perceptual units. The metrics chosen for the sub-images were as follows:

1. For horizontal lines (positive and negative), the chosen metric is the sum of the top and bottom average edge deviations.

2. For vertical lines (positive and negative), the chosen metric is the sum of the left and right average edge deviations.
3. For text (both positive and negative), the chosen metric is the sum of the absolute deviations of letter-f and letter g circumference from the respective bitmap circumferences, each difference being divided by the respective bitmap circumference.

Note that a prerequisite for rescaling is that the KDY metric and the JND metric must both be zero for zero image distortion (i.e., for the bitmap itself). Furthermore, because the JND metric does not change when more pixels participate, the same must be true of the KDY metrics with which it is compared. Both these criteria are satisfied automatically for (1) and (2) above. However, in (3), the letter-circumference metrics must be normalized as indicated in (3).

Results

The individual KDY metrics were not found to correlate well enough with the JND metric to allow rescaling of the former to a common scale dictated by the latter. This result was to be expected. The KDY metrics were derived from a model that was connected to the character of the printing device, and the JND metric was derived from a model of human vision. The connection between these kinds of models is by no means trivial.

On the other hand, we learned that the JND model (and, we believe, also in human perception), the distortions perceived for black print on a white background are less than those of white print on a dark background. This tendency reveals itself in the KDY metrics (particularly in the loss of whole characters in the KDY metric for white-on-black). However, the tendency is more pronounced in the JND metric. The greater tendency of white-on-black to suffer perceptual distortion can be traced to both physical and psychophysical causes. From a physical perspective, the spread of ink from the black area into the white character can eliminate entirely certain narrow parts of the character. On the other hand, the visual system is confronted by a loss of figural integrity as well as contrast in the white-on-black renditions.

The relative perceptual distortions of white-on-black versus black-on-white can be seen in Figures 3-4 (both of which use the same printing device and paper). Figure 3 shows black text on white background, and Figure 4 shows the reverse. Note that the ink spread produces enough narrowing of characters in Figure 4 that readability would be impaired. The letters in Figure 3 do not show so severe a degradation.

Figure 3. Printed Black Text on a White Background, Showing Minimal Degradation.

Figure 4. Printed White Text on a Black Background, Showing Substantial Degradation

Conclusion

This effort was an attempt to connect a model of perception with metrics more closely connected to the mechanics of printing on paper. We did not observe good enough correlation between ImageXpert and JND metrics to be able to assign a rescaling of the ImageXpert metrics to a common JND scale. However, we learned that the JND model predicts a more pronounced perceived degradation for white text on a black background than for the reverse. This bias is also visible in the ImagExpert metrics, but is more pronounced for the JND metric.

If both ImageXpert and JND metrics are used in printing applications, we expect to understand the perceptual magnitude of artifacts (from the JND model), and also means to correct the artifacts (from ImageXpert).

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Biography

Michael H. Brill is a Member of the Technical Staff of Sarnoff Corporation, where he writes display-metrology standards and develops models of color image quality for display design and for video encoding. He received his BA in physics at Case Western Reserve University, and his MS and PhD in physics at Syracuse University. He has made contributions to color management and also to colorant formulation in printed media. For work on human and machine color constancy, he received the 1996 Macbeth Award from the Inter-Society Color Council (ISCC), of which he is now President. He is a member of the Optical Society of America and the Society for Information Display.