A Comparison of Different Print Mottle Evaluation Models

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Abstract: Print mottle, i.e. unwanted reflectance variation patterns, is perhaps one of the factors most detrimental to general print quality, and it is therefore important that it is evaluated in a proper and understandable manner. Several models have, over the years, been developed to evaluate mottle instrumentally. Today, there is also an ISO Standard for evaluating print mottle. The theoretical foundation of this standard is not however entirely reassuring. This paper attempts to examine a number of different print mottle evaluation models, including ISO 13660, conceptually and to compare the extents to which they correlate with visual print mottle assessment. Results suggest that three aspects of stochastic monochrome print mottle must be considered in any attempt to evaluate print mottle instrumentally: the amplitude of the variation, the coarseness of the variation, and the mean reflectance level of the print. The way in which this is carried out is however somewhat less crucial. We question whether an ISO standard for print mottle evaluation should indeed be based on a specific model such as the one described in ISO 13660. A standard based on a rigorous visual assessment of artificially created mottle would perhaps serve a better purpose.

Introduction

The absence of print mottle is probably among the most central aspects of general print quality. This is hardly surprising since print mottle can be thought of as being unwanted reflectance variations that make the interpretation of the printed information more difficult for the Human Visual System (HVS).

The ability to evaluate print mottle, not with costly and time-consuming visual evaluations, but with an efficient, reliable and reproducible instrumental evaluation is therefore important in most printing trials. Over the years, several models for how to evaluate print mottle instrumentally have therefore been introduced, and an ISO Standard for the evaluation of reflectance inhomogeneities in prints was recently published (ISO 13660:2001).

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This International Standard has been produced by a Joint Technical Committee of ISO/IEC working in the general field of Information Technology and is directed towards the “measurement of image quality attributes of hardcopy output” in relation to office equipment. Neither the theoretical foundation of this standard nor its success when it comes to achieving a correlation with visual assessment are however entirely reassuring.

A number of instrumental print mottle evaluation models flourish in the research community and in the printing industry. These models are sometimes very similar, but they often appear to differ quite extensively from each other in principle, and this is probably one reason why there is little consensus as to how print mottle evaluation should be carried out. The fact that several of the models exist only as commercial software and are not always well documented in the literature merely enhances the mystification.

Nevertheless is it important to acknowledge that they usually have one vital thing in common, namely that they all, for various reasons, have acknowledged the fact that the failure to fully recognize the contrast sensitivity of the HVS is a possible objection against this ISO Standard on print mottle. This is perhaps also the main reason why this standard model does not always properly correspond to visual assessment.

This paper attempts to illustrate, both by conceptual examination and also empirically by comparison with visual assessment, the underlying reasons why a given print mottle evaluation model is successful or not. By carrying out this comparison for a number of different print mottle evaluation models, the paper also attempts to pin down what is important to consider when evaluating stochastic monochrome print mottle instrumentally and what is presumably less crucial.

Theoretical Analysis

This section covers a number of different approaches to the evaluation of print mottle. It does not however claim to be complete. The models are described in the way in which they have been interpreted by the present authors from the original documents referred to.

ISO Graininess and Mottle

The ISO 13660:2001 standard includes two measures of variation in prints, Graininess and Mottle, defined as follows.

Graininess. Aperiodic fluctuations of density at a spatial frequency greater than 0.4 cycles per millimetre in all directions. The measure of graininess across the Region of Interest (ROI) is:

$$ISO\ Graininess = \sqrt{\sum_{i=1}^{n} \frac{\sigma_i^{\,2}}{n}}\,, \tag{1}$$

where σ_i is the standard deviation of optical density measurements within cell i, and n is the total number of cells.

Mottle. Aperiodic fluctuations of density at a spatial frequency of less than 0.4 cycles per millimetre in all directions. The measure of mottle across the ROI is the standard deviation of the m_i, where m_i is the average of density measurements within cell i:

$$ISO\ Mottle = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(m_i - \left(\frac{1}{n}\sum_{i=1}^{n} m_i\right)\right)^2}\,. \tag{2}$$

Sampling for the graininess and mottle measurements. The ROI is a region of at least 161mm^2 with smallest dimension at least 12.7mm, contained wholly in the area. The ROI should be divided into at least 100 uniform, non-overlapping square tiles with area at least 1.61mm^2 and smallest dimension at least 1.27mm. Within each tile, make 900 evenly-spaced, non-overlapping measurements of density. For each tile i, m_i is the average of these measurements; σ_i is the standard deviation of the measurements.

In the work described in this paper all images where scanned at 300ppi, which did not give the 900 measurements necessary to calculate the Graininess measure without violating the 0.4 cycles per millimetre limit specified in the ISO Standard. The 512x512 pixel square image with an edge length of 43.3 mm was divided into 32 x 32 non-overlapping squares with a side length of 1.35 mm, containing 16 x 16 pixels. Hence, the Graininess measure was calculated on the basis of 256 values instead of the 900 specified by ISO. In practice, however, this merely means that variations with frequencies higher than 5.8 cycles per millimetre are not considered.

Further, the calculations of Graininess and Mottle were based on the reflectance values of the print, R, rather than on the density, D. However, since:

$$D = \log_{10}(R_{paper}) - \log_{10}(R)\,, \tag{3}$$

and

$$\mathrm{d}D = -\frac{\mathrm{d}R}{R}\log(\mathrm{e})\,, \tag{4}$$

where d*R/R* is the Coefficient of Variation, the division by the mean reflectance value in (4) should give the same correlation with visual assessment as if density values had been used (Johansson, 1993).

Conceptual Analysis. Since ISO 13660 is based on density variations, it considers both the magnitude of the variation in the print and the mean reflectance level of the print. The division into two measurements, Graininess and Mottle, may be considered to be a crude band-pass partitioning, and in some sense one may therefore say that the coarseness also is considered, although only in a rather rough way. The choice of ROI is however rather mysterious for two reasons, a) the cut-off frequency will differ depending on both the full sample size and choices made by the evaluator, and b) this cut-off frequency will in any case be too low to allow the mottle measure to properly consider the important mid-range variations (1-2 mm). Nevertheless, *ISO Mottle* will presumably correlate far better with the visual assessment of print mottle than *ISO Graininess* due to the shape of the contrast sensitivity of the HVS, which is much higher at frequencies in the *ISO Mottle* passband than in the *ISO Graininess* passband (De Valois & De Valois, 1988). It should however be pointed out that *ISO Graininess* is presumably not intended primarily to evaluate print mottle but rather to measure graininess in high quality image reproduction such as photography.

Specific Perimeter, Jordan & Nguyen (1986)
This mottle measurement, *Mottle Index*, considers the coarseness of the variation by normalization of the Coefficient of Variation, d*R/R*, with respect to the Specific Perimeter:

$$Mottle\ Index = \frac{\mathrm{d}R}{R}\frac{1}{\sqrt{SP}}, \tag{5}$$

where the Specific Perimeter, *SP*, is defined as the total pattern border length divided by the image area when the image is thresholded to 50% feature area. For a chessboard pattern 1/*SP* is equal to half the edge length of a chessboard square. For a snake-like pattern, 1/*SP* is equal to the snake diameter. The inverse of the Specific Perimeter is thus a measure of pattern coarseness.

Conceptual Analysis. By normalizing the Coefficient of Variation using the Specific Perimeter, the Mottle Index measurement considers the magnitude of the variation, the mean reflectance of the print, and also the coarseness of the variation. The coarser the variation, the higher is the value of the Mottle Index.

Two main objections can however be made concerning this approach. Firstly, thresholding at 50% feature area and using the pattern border length as an estimate of coarseness may not correspond well with the way in which the HVS experiences the coarseness of print inhomogeneity; since both the pattern border length and also the specific character of the pattern are very dependent on the level of the threshold. Secondly, psychophysical evidence clearly suggests that the character of the luminance contrast sensitivity of the HVS is band-pass rather than low-pass (De Valois & De Valois, 1988). Since the Specific Perimeter approach zero as the coarseness of the variation increases, the *SP* normalization corresponds to low-pass, and not band-pass filtration. The normalization is actually not a true cut-off low-pass filter but rather a gain factor that continuously increases the amplification of the signal with decreasing frequency.

Today, any modern computer delivers a power spectrum in a split second using the Fast Fourier transform, and the approach may thus be considered rather outdated. Nevertheless, it demonstrates an elegant way of how to bypass the use of frequency analysis and still consider not only the magnitude of variation, but also the coarseness of variation and the mean reflectance level of the print.

Coefficient of Variation by Band-Pass Image Analysis, Johansson (1993)

This model resembles both the ISO Mottle model and the Mottle Index model in its calculation of the Coefficient of Variation. In this case, the coarseness of the variation is however taken into account by band-pass filtration of the image. The model sums the variation within the 1-2, 2-4, and 4-8 mm octave bands:

$$CV_R \Big|_{1-8mm} = \frac{\mathrm{d}R_{1-8mm}}{R} \ . \tag{6}$$

Conceptual Analysis. This model considers all the three aspects, viz. the magnitude of variation, the coarseness of variation and the mean reflectance. The choice of adding the noise within the frequency range in which the HVS is most sensitive lessens the need for a weight function, although this rather unsophisticated way of considering several frequencies certainly will reduce the performance of the model somewhat.

Modified Coefficient of Variation, Fahlcrantz, Johansson & Åslund (2003)

Extensive research suggests that humans do experience neither the physical luminance level, Y, nor the logarithm corresponding to print density, D, of the reflected light, but rather a perceived luminance level, L^*, proportional to $Y^{1/3}$.

Both empirical testing and theoretical comparisons with the L^* equation of the CIELAB model suggest that the *Coefficient of Variation by Band Pass Image Analysis 1-8mm* overestimates the mottle in dark prints but underestimates its impact in lighter ones. Partly based on empirical results, but mainly based on the theoretical basis of the CIELAB equation, the following expression was therefore proposed:

$$dL^* = \frac{\mathrm{d}R}{R^{2/3}}\,. \qquad (7)$$

However a modification, solely based on empirical result, involving normalization with respect to the square root of the mean reflectance level gave a better correlation with visual assessment:

$$ModCV_R = \frac{\mathrm{d}R}{\sqrt{R}}\,. \qquad (8)$$

Conceptual Analysis. These models have the same strengths and weaknesses as the Coefficient of Variation by Band Pass Image Analysis, with the additional strength that they better compensate for differences in mean reflectance value. In other words, these models allow a better comparison of measurements between printed samples with different mean reflectance levels.

Integration Model, Fahlcrantz (2003)
This model, originally proposed for the evaluation of systematic print mottle, here presented without the compensation for systematic disturbances, is fully based on theoretical assumptions relating to the ability of the HVS to detect reflectance variations. The model considers the variation between wavelengths of 0.25 and 16 mm and uses a weight function based on the contrast sensitivity of the HVS to adjust for the different sensitivities to variation in different frequencies:

$$IM\,Mottle = \frac{1}{\sqrt{R}}\sqrt{\int_{0.0625}^{4} \sigma(u)^2\, w(u)^2\, \frac{du}{u}}\,, \qquad (9)$$

where:

$\sigma(u)^2$ - power at a frequency u of cycles per millimetre in the FFT power spectrum,

$w(u)$ – relative contrast sensitivity at u cycles per millimetre at normal viewing distance.

The model normalizes with respect to the square root of the mean reflectance level of the print, in accordance with the results of Fahlcrantz, Johansson & Åslund (2003).

Conceptual Analysis. This model basically considers the three important aspects previously explained in a way that corresponds well with the HVS. However, it still lacks the ability to make a local analysis of the printed area, and is, due to its consideration of frequencies as high as 4 cycles per millimetre, somewhat sensitive to half-tone screening effects.

Similar Approaches

The models indicated by equation (6), (7), (8) and (9), are all based on an estimation of the variation at different wavelengths by Fourier analysis, using the FFT algorithm. Two models, the Multi-Scale and the Wavelet Multi-Scale, explore alternatives to this approach.

Multi-Scale. An alternative approach to band-pass filtration using the Fourier Transform is to remain in the spatial domain and estimate the variation in different resolutions:

$$MultiScaleMottle = \frac{1}{\sqrt{R}} \sqrt{\sum_{ij=1}^{5} \frac{{\sigma_{ij}}^2 {w_{ij}}^2}{u_i^{mid}}}, \qquad (10)$$

where

$\sigma_{ij} = \sigma_i - \sigma_j$

(ij) – octaves with wavelength intervals:

0.34-0.68, 0.68-1.35, 1.35-2.71, 2.71-5.41, 5.41-10.8 mm

u^{mid} – frequency at the middle of the octave (ij)

w_{ij} – relative contrast sensitivity at frequency u^{mid}.

Wavelet Multi-Scale. Another alterative to equation (9) is to use Wavelets to estimate the variation at different resolution levels. The analysis is carried out in the same way as in (10) except that σ_{ij} are given by summation of the wavelet coefficients at each resolution level.

Conceptual Analysis. In practice (10) differs very little from (9), except that the precision will, perhaps, decrease slightly when the weight function is chosen more bluntly. The Wavelet approach should yield results similar to those given by (9) if the wavelet function is chosen properly. The use of wavelets opens up new possibilities of local analysis of the printed area and also a flexibility in the choice of base function. These possibilities are not however explored in this paper.

Spatial Distribution Mottle Profile (SDMP), Rosenberg (2002)

The SDMP model is another multi-scale approach, slightly different to the one previously introduced. The originally acquired N x N pixel 8-bit reflectance image is divided into N/2 x N/2 blocks each containing 2x2 pixels. Target width refers to the block size at each resolution level. For each block, the difference between the 4 pixels, $q(v,w)$, in the block is calculated as:

$$PctDiff(o,p) = \frac{100}{6*255} \sum_{i=1}^{6} |d(i)|, \qquad (11)$$

where

$$d(i) = |q(v,w)-q(v',w')|,\ vw \neq v'w',\ v,w,v',w' = 1\ldots2,$$

and

$$o = 1\ldots N/2,$$
$$p = 1\ldots N/2.$$

For each block, the average is calculated:

$$AveLV(o,p) = \frac{1}{4}\sum_{v=1}^{2}\sum_{w=1}^{2} q(v,w) \quad . \qquad (12)$$

The mottle for each target width is calculated as:

$$LayerMottle(j) = \sigma_{PctDiff} * m_{PctDiff} * \sigma_{AveLV} \ , \qquad (13)$$

where

$\sigma_{PctDiff}$ - Standard Deviation of *PctDiff*,
$m_{PctDiff}$ - Average value of *PctDiff*,
σ_{AveLV} - Standard Deviation of *AveLV*.

The procedure is repeated $\log_2(N)$-1 times using the $N/2$ x $N/2$ image *AveLV* as input image, doubling the target width at each repetition. Mottle is then calculated as:

$$SDMP = \frac{1}{\log_2(N)-1}\sum_{j=1}^{\log_2(N)-1} LayerMottle(j) \quad . \qquad (14)$$

Conceptual Analysis. This model is based on three estimates, the Standard Deviation of *PctDiff*, the Average value of *PctDiff*, and the Standard Deviation of *AveLV*. The Standard Deviation of *PctDiff* is a variation measure of a variation measure at target width n. The Average value of *PctDiff*, is a variation measure at target width n. The Standard Deviation of *AveLV* is a variation measure with a passband $n/2$ to the full image size. The $\sigma_{PctDiff}$ can be seen as an interesting approach to consider the locality of the variation at a given target width. Both $m_{PctDiff}$ and σ_{AveLV} are variation measures. The *LayerMottle* value at target width j can therefore be seen as a combination of the variations at target widths n and a broad passband. Since the low-frequency variation is represented in all the $\log_2(N)$-1 σ_{AveLV}-estimates, the model will favour coarse over fine-scale variations. The model thus considers both the magnitude of the variation in the print and, in some sense, the coarseness of the variation in the print, with the additional feature that it also considers the locality of the variation in the print.

What seems to be lacking, however, is a normalisation that takes into consideration the mean reflectance level of the print. We therefore expect that the model will perform less well if the differences in mean reflectance level between the samples are large.

Grey Level Histogram based Model (Verity IA, 2003)

The final model to be discussed in this paper is based on very straightforward reasoning. First, the median value of the grey level image is calculated. The mean value of the pixels below the median, med_{low}, and the mean value of the pixels above the median, med_{high}, are then calculated. Mottle is estimated as the range between these upper and lower mean values:

$$GLH\ Mottle = med_{high} - med_{low}. \qquad (15)$$

Conceptual Analysis. The *GLH Mottle* measure represents the average deviation from the median reflectance value of the print. It is based solely on the distribution of grey level values in the image at resolution level, and it takes into consideration neither the coarseness of the mottle nor the mean reflectance level of the print. It can thus be expected that the model will perform less well in a comparison of printed samples with different coarseness characters and/or different mean reflectance levels.

Method for Empirical Evaluation

Sample Creation

Twelve half-tone grey patches with four different levels of coarseness and with three different mean reflectance levels were created by digital simulation. Random noise images, Gaussian distributed, were created digitally and then filtered in the Fourier domain to produce images with a general appearance similar to the mottle occurring in conventional prints.

The digital images were then retransformed back into the spatial domain, and printed on a single substrate with a high-resolution ink-jet printer (Epson Color Proofer 5500). Since the same substrate was used for all the samples, and since the printer introduces only a small amount of noise, which can be assumed to be similar in magnitude in all the samples, the noise intentionally introduced in the digital simulation was basically the only variable that differed among the samples.

Visual Evaluation

Observers. A panel of 10 judges, 4 male and 6 female, was enrolled. Their experience in print mottle assessment ranged from little to extensive. All the judges had normal or corrected-to-normal vision.

Apparatus. The evaluation was conducted in a perception laboratory with a homogeneous overhead light source (1400lx, 5000K). A digitizing tablet (Summagrid V, 152 x 112 cm, resolution 1000 lines per cm) such as that commonly used in computer-aided design was used to record the visual assessments.

Procedure. The task of each judge was to position the 12 samples along the horizontal axis (x-axis) of the tablet. The x-axis of the tablet was considered to be a scale for assessing the magnitude of the general perceived level of disturbance in the samples. The judge was asked to use the whole scale of the tablet's x-axis for the evaluation, placing samples *without* any disturbances at the left-hand edge of the tablet and the sample with the *highest* disturbance level at the right edge of the tablet. The judge was then asked to place the other samples at proportional distances in between, i.e. so that, for example, a sample with half the perceived disturbance level of a second sample was positioned at half the distance from the left-hand edge of the tablet as the second sample. When the observer was satisfied with the ratings of all the samples, their positions on the tablet were recorded in a computer with a point-and click device. The device was pointed at the lower left edge of each sample and the coordinates of each sample on the tablet were saved in an Excel file.

Instrumental Evaluation

The printed samples were scanned in greyscale at 300ppi with an Epson 1680 Pro scanner, and analysed in accordance with all the models described in the Theoretical Analysis section of this paper, equations (1)-(15). All the models use a calibration process to adjust the reflectance values acquired by the scanner so that they match the values from a reflectometer.

Results

Visual Assessment

The inter-individual Pearson correlation coefficients were converted to the normally distributed variable 'z' using Fisher's z' transformation and the concordance among observers was calculated as the arithmetic mean of the transformed correlation coefficients (Fisher, 1924). The mean correlation coefficient between observers taken in pairs was 0.93.

Correlation between Visual Assessment and Instrumental Evaluation

The correspondence between the visual assessment and the different instrumental approaches is presented in Figure 1. The values given are the coefficients of determination, R^2. Neg indicates a negative correlation between visual assessment and the instrumental approach.

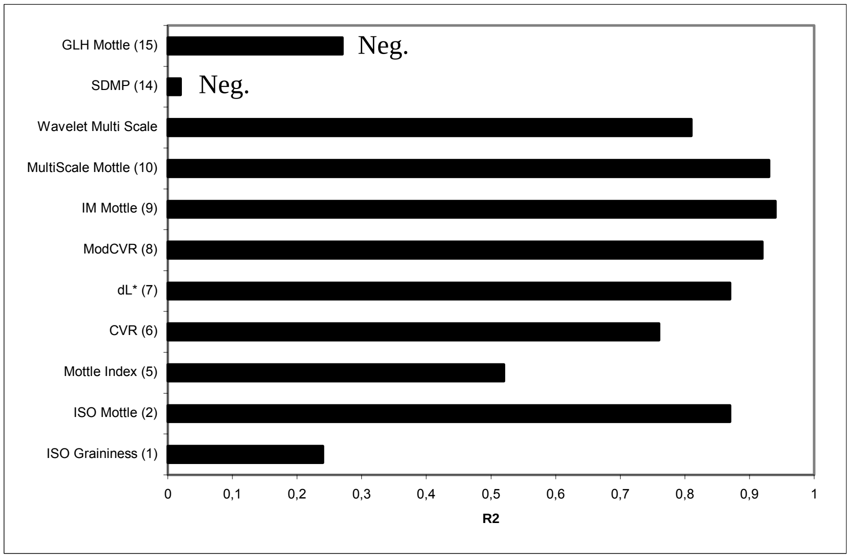

Figure 1. *Correlations between visual assessment and instrumental evaluation, coefficient of determination,* R^2*. Neg. indicates a negative correlation between the visual assessment and the instrumental approach. The numbers in brackets indicate the equation in the Theoretical Analysis section.*

Discussion

Twelve samples were created, visually assessed, and instrumentally evaluated by the various approaches described in the section Theoretical Analysis of this paper. The inter-individual correlation in the visual assessment was 0.93, suggesting that the observers agreed very well on how to assess the samples. The comparisons between the evaluated models and visual assessment show substantial performance differences. Two of the approaches did not, in fact, show any positive correlation with visual assessment at all.

The feature that unites the models that do correlate well and in some cases very well with the visual assessment is that they all take into consideration the three important aspects of stochastic monochrome print mottle, viz.: magnitude, coarseness, and mean reflectance level. Their degree of success depends chiefly on how this is carried out. The models that perform poorly all lack a proper consideration of at least one of these three important aspects.

The importance of the manner in which the magnitude of variation is estimated can be traced by comparing the results for *IM Mottle* (9) and *MultiScale Mottle* (10). Both models consider the same frequency range and normalise with respect to the square-root of the mean reflectance level. The fact that they both perform with the highest degree of satisfaction complies well with theory, i.e. that the magnitude of the variation can be estimated in either a spatial or a frequency domain. The Wavelet-based Multi-Scale model performs somewhat less well. It must however be said that the wavelet was not carefully chosen in this work, and it is quite conceivable that a better choice of base function might yield a better result than that presented here.

The importance of the second factor, coarseness, can be assessed by comparing *ISO Graininess* (1) with *ISO Mottle* (2), *ISO Mottle* (2) with CV_R (6), and $MODCV_R$ (8) with *IM Mottle* (9). The results here suggest that the choice of passband is important, but that an analysis of a wider range of frequencies does not necessarily improve the correlation. If a wide range of frequencies is considered, it is vital that they are weighted in accordance with the contrast sensitivity of the human visual system.

Perhaps most important is, however, the way in which the mean reflectance level of the print is taken into account. This is most easily demonstrated by comparing the correlations between the three different variants of the 1-8mm band passed Coefficient of Variation, (6), (7) and (8). Interestingly, the results suggest that the conclusions drawn by Fahlcrantz et al. (2003) are correct, i.e. that the variation should be normalised with respect to the square root of the mean reflectance level rather than merely to the mean reflectance level of the print.

In addition, the square-root model performs better than the dL^* model. In this study the visual assessment conditions, the sample character, and the scanner all differ from the earlier evaluation by Fahlcrantz et al. (2003). The calibration patches were however identical in both studies and this could be responsible for the deviation from the dL^* model.

An interesting and plausible explanation for why this result is replicated is the fact that the contrast sensitivity of the HVS differs under different illumination conditions. It is generally considered that the relevant conditions are the overall surrounding illumination conditions in the assessment environment, but to be precise, less light reaches the eye if a subject observes a dark sample than a light one, especially if the sample covers a significant part of the visual field, and thus the contrast sensitivity should theoretically decrease. This may, at least partially, be the reason why the variation should be normalised with a power function of the mean reflectance level in the denominator with a lower value than the one given by a differentiation of the L^* equation. It is however still very unclear whether, and if so to what extent, this is indeed the case.

As predicted in earlier reports, and also from theoretical considerations, *ISO Graininess* does not seem to be a predictor of print mottle to any reliable extent. The reason is that it considers variation in the print at frequencies outside the range within which the HVS is highly perceptive. This does not mean that graininess is irrelevant for print quality. It is in fact quite conceivable that there is a relationship between this parameter and visually assessed print sharpness. As mentioned in the conceptual analysis, *ISO Graininess* seems not to be mainly intended to be a measure of print mottle, but rather to measure graininess in high quality image reproduction such as photography.

The ISO Mottle model performs well in this evaluation. This is not however surprising since, although the frequency range regarded by *ISO Mottle* is not centred around the peak of the contrast sensitivity function of the HVS, the important low frequencies are nevertheless taken into account. It is far less certain whether the performance is as satisfying when mottle consists of noise with a different kind of frequency distribution, where the range of the band-pass filtration may play a more prominent role.

Nevertheless, the ISO standard model is outperformed by several approaches discussed in this paper. The natural question is therefore whether the current ISO Standard is a good choice or not? If not, with what should it be replaced or supplemented it with? Would a new, more sophisticated model be a better choice?

We think not. Print mottle is interesting because we attempt to create prints that present as good a quality as possible. Quality is a very subjective concept, which can never truly be evaluated by technical measurements. We therefore suggest that an ISO Standard on print mottle should perhaps be based on a rigorous visual assessment of a set of artificially created mottle samples, rather than on a mathematical definition. Technical models could then easily be assessed by their correlation with this standard visual evaluation. This would not only promote the development of better models for evaluating print mottle instrumentally, it would also make it much easier for the industry to choose which model to use. Whenever someone confronts you with a new, presumably better model, you would then just hand him, or her, the set of standard samples and say – please, show me how well your model correlates with the visual assessment of print mottle.

Despite the clear results presented in this paper, it is important to mention the weaknesses of the approach herein taken. Firstly, there is, of course, a choice-of-samples-bias in this case. We prepared the samples to simulate mottle and decided in what way they should differ from each other. Our assumption, that three aspects of print mottle influence the way in which stochastic monochrome print mottle is assessed, is nevertheless strongly supported by the results. All these three aspects, the amplitude of the variation, the coarseness of the variation and the mean reflectance level of the print must indeed be taken into consideration. Whether or not additional aspects need to be considered is not however explored in this paper.

The selection of models to examine can also be questioned. Our aim has merely been to demonstrate that these three aspects of print mottle are important, and not to say precisely in what way they should be considered. Conclusions need to be revised only: a) if it is proven that there exists a model that performs well without considering these three important aspects of print mottle, or b) if it is that there exists a model that is inadequate in spite the fact that it considers all three aspects properly.

Some models perform less well, and we have tried to give plausible explanations of this. By modifications it would probably be possible to improve the performance of those models. Agreement on the way to evaluate stochastic monochrome print mottle would be beneficial for everyone. If some kind of consensus could be reached, we could more easily move on to the more cumbersome problems of colour variation and systematic disturbances, which are still much less explored.

Conclusions

We have examined a number of instrumental print mottle evaluation models both conceptually, and empirically by comparing their correspondence with the results of a visual assessment. The results support the proposition that three factors are crucial to take into consideration when attempting to evaluate print mottle instrumentally viz.: a) the magnitude of the noise, b) the coarseness of the noise, and c) the mean reflectance of the print. The way in which this is carried out is however somewhat less crucial. We therefore question whether an ISO standard on print mottle really should be based on a specific model such as the one described in ISO 13660. A standard based on a rigorous visual assessment of artificially created mottle samples would perhaps serve a better purpose.

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