The Optical Behaviour of Screened Images on Paper with Horizontal Light Diffusion

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Abstract

This paper presents a new physical model of the conditions of light radiation in screened prints. It gives an exact description of the Yule-Nielsen Effect. Whereby the extreme case of maximum horizontal light diffusion is in agreement with the Yule Nielsen approxiamation. It will be shown, that the Yule-Nielsen Effect has "it's own color", which is not only responsible for a density gain in the raster image but also for a real color shift.

Introduction

In different Non-Impact printing processes, just as in conventional off-set printing processes, there is a destinct necessity for screened representations of continous tone images. With the use of halftone cells, gray levels are achieved through the additive mixing of different shares of radiation remitted from their respective areas (all of which should be smaller than the resolution of the observer's eye). The light remission of the unprinted areas, or paperwhite, between these halftone cells combine with the remission of ink covered areas, or printed dots, to generate the image information through the modulation of the two.

In 1936 the inter-relationship between the paperwhite and the printed dot area was stated in a simple equation by Murray and Davies (1).

(1) $$R_R = 1 - \varphi + \varphi R_V$$

The equation is formulated so that the total light R_R out of the remission from the unprinted area is standardized to be within 1, and the remission of the printed area R_V is evaluated to be in accordance with the geometrical area φ, which is covered by ink. However, this equation does not describe the real behaviour of screened prints. The difference between the real behaviour, and the geometric Murray-Davies approach, is called light gathering or the Yule-Nielsen Effect.

Yule and Nielsen (2) found in 1951 that paper may not be the ideal mirror of light reflectance that Murray and Davies had proported it to be (this is a proper approxiamation with metallic printing substrates). The presence of a horizontal light scattering effect in the paper suggests that light falling on a particular area will not necessarily be remitted from that area but from another location (fig. 1).

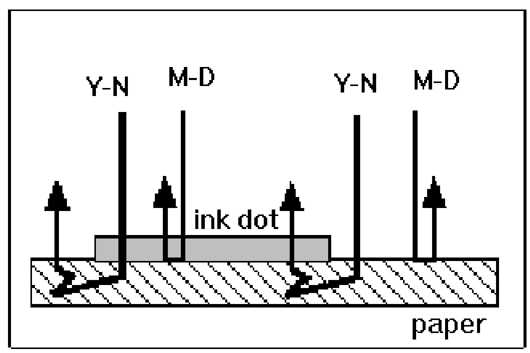

Figure 1. Light Pathes in a Screened Image: (M-D) signifies the light pathes assumed by Murray-Davies, while (Y-N) shows the horizontal light scattering in the paper discovered by Yule-Nielsen.

Yule and Nielsen assert that in the ideal extreme case of maximum horizontal light diffusion, the area where the light remission occurs is completely independent from the areas where the light hits the paper. In accordance with a statistical derivation they introduced the following equation:

(2) $$R_R = \left[1 - \varphi\left(1 - \sqrt[2]{R_V}\right)\right]^2$$

In this case the maximum horizontal light diffusion in the paper occurs simultaneously with minimal halftone screening.

In order to describe a real case between the maximun horizontal scattering length (Yule-Nielsen case) and the complete absense of horizontal scattering (Murray-Davies case), Yule and Nielsen have modified the equation (3) with an *n*-factor:

(3) $$R_R = \left[1 - \varphi\left(1 - \sqrt[n]{R_V}\right)\right]^n$$

There is no physical argument for this factor but only the analoguos conclusion from n=1 in the Murray-Davies case and $n = 2$ in the Yule-Nielsen case which leads to the asumption that $1 \leq n \leq 2$.

In different papers (e.g. [3,4]) it is pointed out that the *n*-factor in the Yule-Nielsen approximation is not an adequate description of the experimental findings. Several attempts at finding a better solution of the problem are known, so from Viggiano [5] with a spectral modification of the Yules-Nielsen approximation or from Arney, Engeldrum and Zeng [6] by a microphotographic histogram analysis with a modification of the Murray-Davies equation derived through an empirical approximation function. Another approach is to describe the effects of one or more dimensional point spread functions with in their microscopic scale. (e.g. [7,8,9])

In the following model, a new physical explanation of the the observed effects is described. Detailed citations to this investigation can be found in [10].

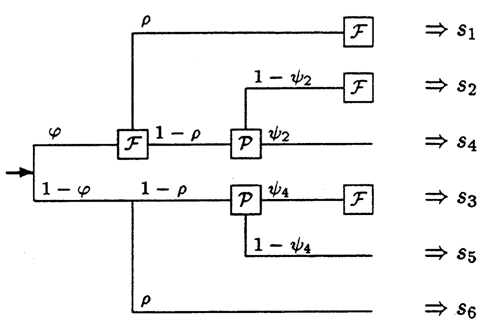

Figure 2. Structure of the Light Pathes: There are six fundamentally different pathes, each with its own shares φ,ψ,ρ.

The Model

In a screened single color area the light radiation conditions could be devided in six fundamentally different shares (fig 2). Each different radiation share integrates over all possible light pathes and optical influences. Which can be put into the equation:

(4) $$B_R = \rho F\ \varphi F + (1-\psi_2)F\ (1-\rho)P\ \varphi F +$$
$$+\psi_2(1-\rho)P\ \varphi F\ + \psi_4 F\ (1-\rho)P(1-\varphi) +$$
$$+ (1-\psi_4)(1-\rho)P\ (1-\varphi) + \rho(1-\varphi)$$

The remitted, macroscopic measurable radiation of the screened area is described with the operator function B_R. The Operator P comprehends all optical changes to the radiation during the transit through the paper, F descibes all optical influences which occur in the ink layer.The scalar values φ, ρ, ψ determinate the shares of the different pathes, where by, φ gives the geometrical dot area. The equation described the macroscopic structure of the raster, the microscopic effects are collected in the operator functions. The pathes s_4 and s_3 in fig. 2 represent the pathes where the light is not remitted from the same incoming areas.

For further determination of equation (4) the case of a homogenious solid tint B_V and of plain paper B_U could be investigated. Using specific suppositions for φ, ρ, ψ regarding the isotropic behaviour of light transmission, the definition of the surface layers, and the interdependence between φ, leads to a simplified equation:

(5) $$B = \nu\, B_U \left[\sqrt{\frac{B_V}{B_U}} - 1\right]^2$$

with the scalar value

(6) $$\nu = (1-\varphi)\,\varphi\ \omega\ g\ h'_0$$

where φ is the geometrical dot area, ϖ is the screen resolution and g is a relative value proportional to the length of circumference of the dots (or other raster elements). h'_0 is a specific material constant which describes the strength of the horizontal light diffusion for each paper stock. h'_0 is normalized, in the Murray-Davies case it is h'_0 =0, in the Yule-Nielsen case h'_0=1.
B_Δ is defined as:

(7) $$B_R + B_\Delta = \varphi\, B_V + (1-\varphi)\, B_U$$
$$B_\Delta = \left[\varphi\, B_V + (1-\varphi) B_U\right] - B_R$$

B_Δ is the additional figure to describe the divergence of the Murray-Davies equation and shows the magnitude of the Yule-Nielsen effect, in spectral form.

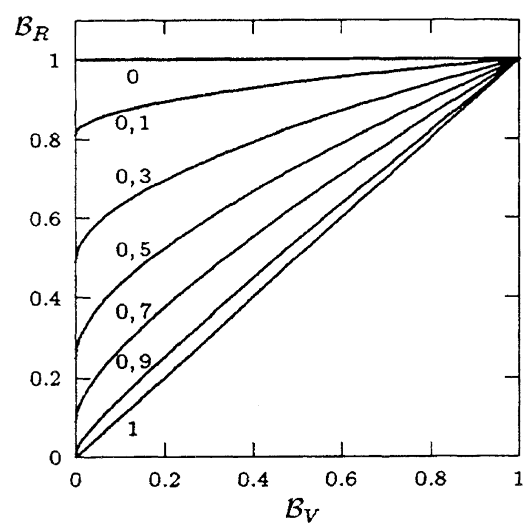

Figure 3. The Spectral Influence: Solution of Equation (8) for different φ at h'$_0$=1. Apart from the simple cases φ=0 and φ=1 the function is not linear.

Experimental Examination Conclusions

With this formulation of the remission of screened prints some experimental expiriences could be explained.

1. The influence of Yule-Nielsen effect is spectral

If equation (6) and (5) are fitted together and if it is normalized for "paper white" (B_U =1), the light remission is

$$B_R = \varphi B_V + (1-\varphi) - v\left[\sqrt{B_V} - 1\right]^2 \qquad (8)$$

It is clear that the part of Yule-Nielsen effect B_Δ in the equation takes an other, not linear result by it´s square damping than the pure solid tint B_V . In fig 3 equation (8) is shown by an example. It can be seen that the spectrum of solid tint values ($0 \le B_V \le 1$) can not be transformed linearly to the raster spectrum B_R. This effect can be shown by experiments. Fig. 4 gives a remission spectrum of a Cyan raster, once by measurement, the other as a computed sum of solid tint spectrum and the the plain paper spectrum, weigthed by area shares. The difference in the "red" parts of the spectrum shows the spectral influence of the Yule-Nielsen effect and in result the color is shifted (fig 5). The conclusion that the Yule-Nielsen effect has "it's own color" is identical to the expiriences found in off set press practices. For this reason, it is not enough to describe remissions with horizontal light diffusion by optical density but more accurately by spectral function.

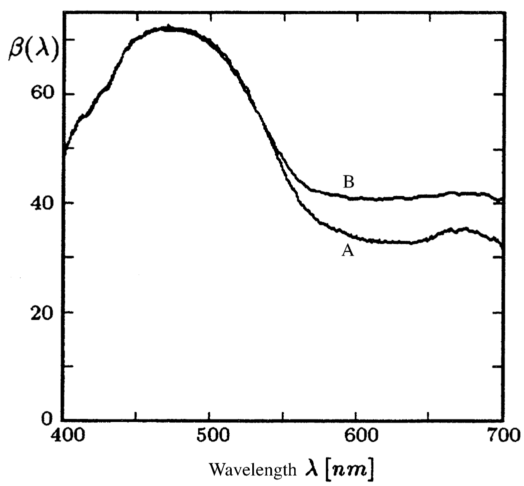

Figure 4. Spectral Deviations by the Yule-Nielsen Effect: The measured spectrum A is different to the predicted spectrum B which is calculated as the sum of the plain paper spectum and the solid tint spectrum without correction for the Yule-Nielsen effect (Cyan raster with φ = 0,53).

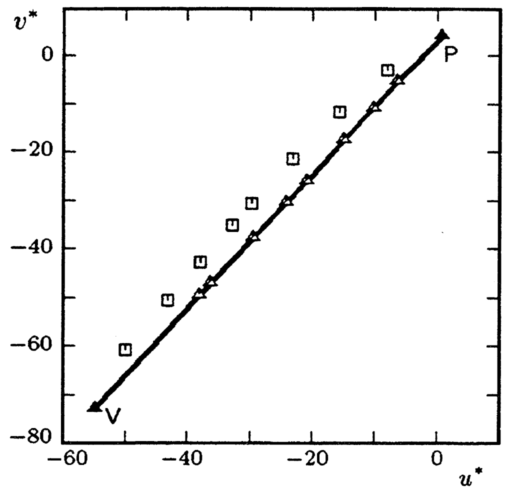

*Figure 5. Plot of the color coordinates for different geometrical area coverages in the L*u*v* color space. The direct line between plain paper (P) and the solid tint (V) is the uncorrected prediction, the measured curve shows the influence of the Yule-Nielsen effect.*

2. The new equation gives an exact prediction of the experiment

Equation (6) gives the exact definition of the Yule-Nielsen effect which has to be added to the simple geometric situation of the screen (as noted in equation 8).The Murray-Davies case and the Yule-Nielsen case (equation 8) could be reduced to equation [1] and equation [2]. For the cases between it is possible to calculate the remission spectrum with great exactitude [8]. Fig. 6 is an example of this.

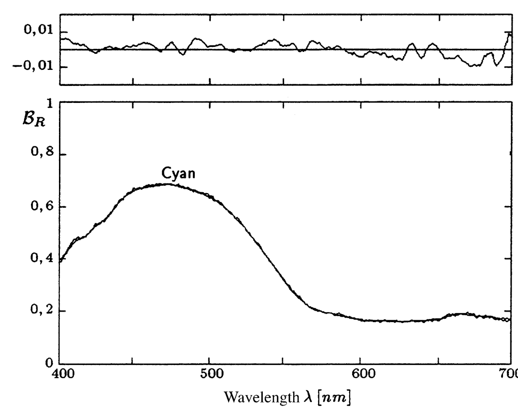

Figure 6: Measured and Calculated Spectrum: The two spectra in the bottom plot overlay each other as near equivalents. In the upper plot the difference between the measured and calculated curve is shown on an enlarged scale.

3. The effects of screen geometry

A well known phenomenon is the increasing Yule-Nielsen effect at higher screen resolution. It can be shown that this influence is well described by ⌊ in equation (6). Because of (φ-1) φ becomes a maximum at φ= 0.5, all density functions and plots in the color space have a typical bulgy shape (see fig. 5). However the circumference length g of each raster element also is important. For example, with circular dots this length is given by $g = \sqrt{\pi\varphi}$ (normalized to a line raster structure) with the result that the maximum Yule Nielsen effect shifts are shown in fig. 7, another well known phenomenon of screened printing. These geometrical influences explain the larger Yule-Nielsen effect in FM screening.

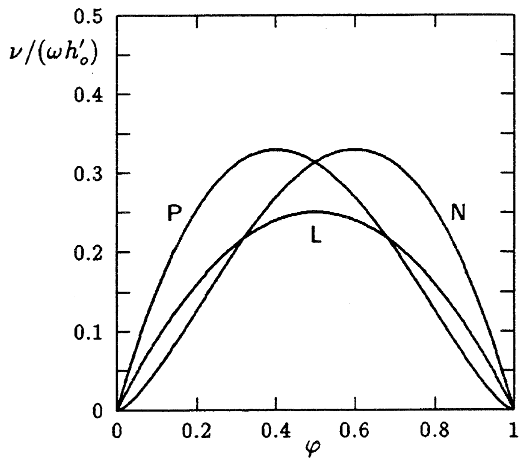

Figure 7: The shift of the Maximum Yule-Nielsen Effect: For linescreens (L) a centered curve with a apex of 0,5 is calculated, for negative (N) and positive (P) cylindric dots with shifting apex's.

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