# Paper related Color Reproduction Models in Ink Jet Printing

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Abstract: The interaction of ink and paper requires better models to be fully understood. Multi spectral analysis of the interaction using Kubelka-Munk-based theory reveals that the color reproduction in its simplest form, full-tone printing, is very complex in its behavior. The problem to understand what happens in a normal situation with reproduction of natural color images involves dot-gain that makes the problem even more difficult to understand. This paper discusses the problems of color reproduction with emphasis on the complex dot gain process that occurs in mixed halftones.

The color reproduction properties of a printing process and its attainable color gamut are in many ways more dependant on the paper quality than on other factors. The surface properties of the paper, gloss for example, and the degree to which color penetrates into the paper through the pores are of fundamental importance. In ink-jet printing models have been proposed that describes some of these phenomena quite closely in the situation of full-tone color printing assumptions. Taking a further step requires the models to encompass also the dot-gain behavior of the process when halftones are used.

## Introduction

The reproduction of color on scattering substrates is difficult to master. The turbid media, the physical dot enlargement and optical dot gain are all factors that make the problem a quite complex one. The simple problem of full tone in a one process ink becomes much more intricate if the tone level is intermediate. There have been proposed a large number of models for this case in recent years. A still more complex problem arises when there are more than on process color. In four-color printing there are few fundamental models. The point of this paper is not really to propose new models but rather to show a few important things about reproduction that already existing models can reveal if properly applied.

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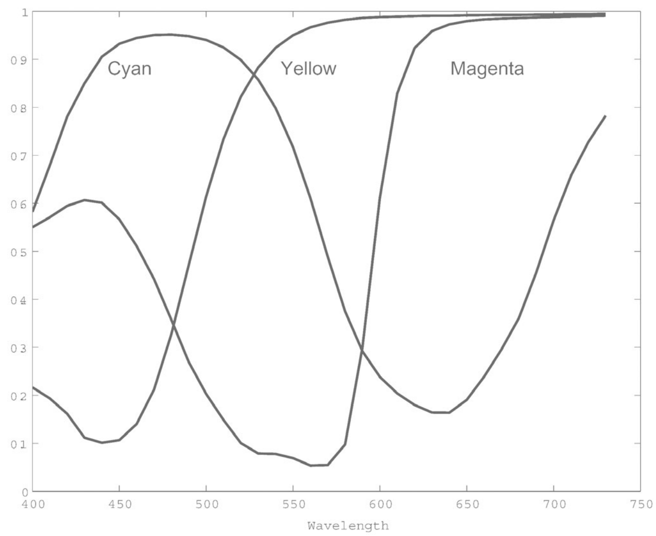



Figure 1. The transmission curves of typical dye-based ink jet inks used in commercial printers.

## Assumptions and Simulation

The properties of different paper grades vary a great deal. The differences between coated and non-coated substrates are obviously larger than the differences within the categories. In this paper we will study some reproduction properties of paper grades that have in common that they both exhibit physical dot gain in the printing process and also show a significant optical dot gain. We will use the properties of dye-based inks such as in ink jet printing in our simulations. The figure below shows the spectral transmission of such inks in a typical commercial printer.

We will study the effects of both physical and optical dot gain. The dot gain is illustrated in the figure below. If a drop of ink is placed on the substrate a dot will form. The size of the drop will increase as the ink is spreading on the surface. Due to the scattering induced optical dot gain the dot will appear even larger, the Yule-Nielsen effect. The effects have recently been modeled by several authors (Wedin M., Kruse B., 1995, Gustavsson S. 1995 and 1996, Rogers G.L. 1997, Emmel P. 1998, Yang L. and Kruse B., 2000, Mourad M.S. 2002). The ink will also penetrate into the paper complicating matters further (Yang L. 2003b). The penetration effect will not be taken into account in this paper however.

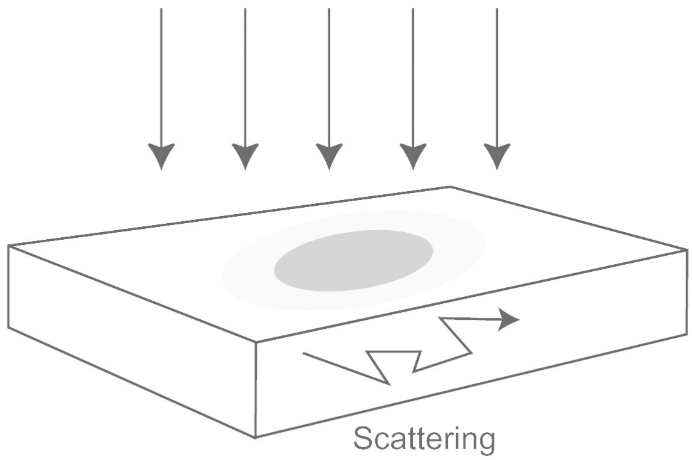



Figure 2. The spreading of the ink together with the scattering induced optical dot gain changes the resulting reflection image that is observed.

The first experiment is aimed at studying what will happen when we print with two inks and the separations are translated relative to each other. We will assume that the separations are equal in size and that they are printed on top of each other in the first place. This means that there is initially only one color, a secondary color equal to the mix of the two primaries. Due to the dot gain there are also intermediate colors between the background white and the mix. We will now study the effects when the translation occurs. In the Figure 3 below it is graphically illustrated what happens. When the two separations are shifted relative to each other there will be different parts of the paper that are covered by no ink, a single ink and of course two inks. We no longer have a single dot. Instead there are intricate patterns of paper, ink and ink on ink. Had we used additional inks the patterns would have been even more intricate.

The optical dot gain is visible at every border where there is a change in ink coverage. Therefore the different sub patterns each produces their own dot gain. The resulting reflection image is composed of all these effects. In order to compute the resulting reflection image we will use the simple rule of addition for the secondary colors. This simplification means that we add the effects of the inks as if they were acting alone and we will not take into account effect due to ink penetration. It has been shown in Yang L. 2003b that this holds under the circumstances. We will not however make the simplification of Neugebauer that there is a random distribution of the primary, secondary and tertiary colors generated by the halftones through rotation for example.

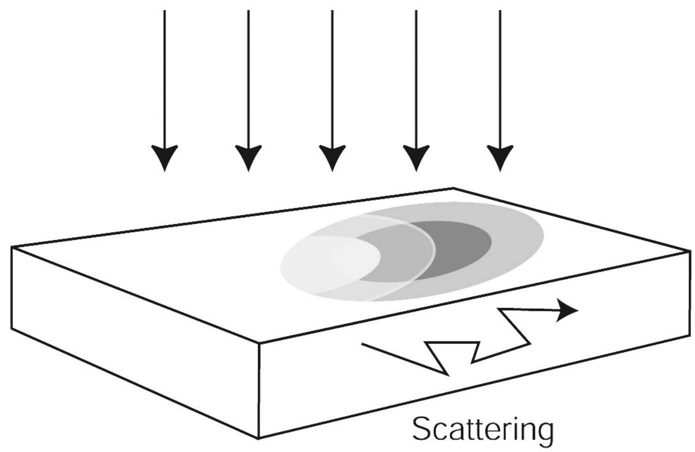
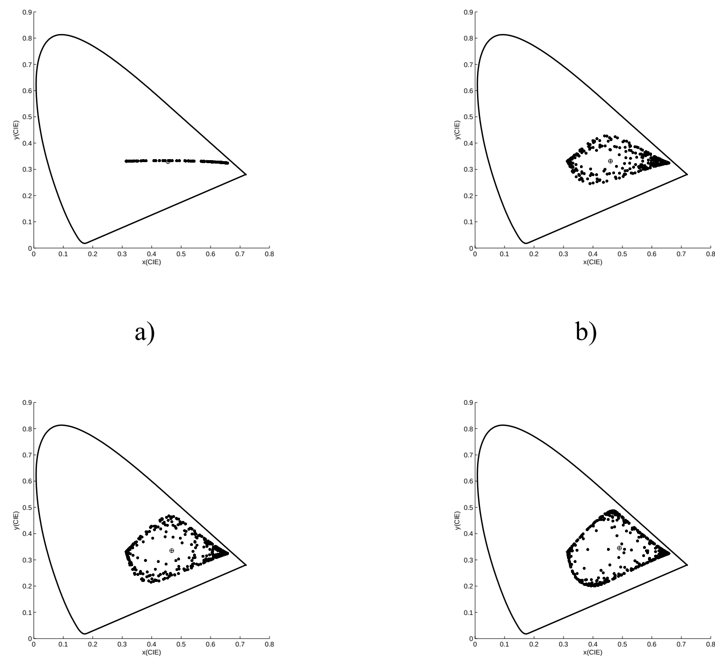



Figure 3. Translation of two dots with respect to each other creates a complicated pattern of ink and ink on ink. Each of the sub areas exhibits their own optical dot gain.

Instead we will use the outcome of the actual dot placements and their overlap in the simulation. We will also carry out the computations with full spectral resolution. In the first simulation it is assumed that there is a constant optical dot gain and also a constant physical dot gain. The only difference between the following diagrams in Figure 4 is the relative translation between the separations.

In the diagrams a) through d) in Figure 4 a simple model for physical dot gain has been used. A linear filter with unit gain for slow spatial variations has been used. The average ink level is thereby conserved but the dot is somewhat spread out. For the optical dot gain we assume that the model from Wedin M. and Kruse B. 1995 and Gustavsson S. 1995 hold. This results in a non-linear effect in combination with another linear filter that model the scattering behavior of the turbid media.

The figure below shows the actual resulting CIExy colors from the reflection image projected into the chromaticity diagram. In Figure 4 a) it is clearly seen that the actual colors lie on an approximate straight line between the secondary color coordinate (in this case red) and the white point. If it hadn't been for the dot gain there would only have been two visible points corresponding to the white and the secondary color. As the separations are translated more colors appear and the effect of the primary colors begin to show. In all diagrams there




a) b) c) d)

Figure 4. Two separations, yellow and magenta, have been printed on top of each other. The viewing distance color average is shown with a marker. The two separations have been translated a small distance relative each other in a) through d). The secondary color (red) and the unprinted substrate (white) are shown in a). Notice how the gamut changes as more colors appear. The primary colors are beginning to show in c) and they are clearly visible as well as the secondary color and the paper white background. Notice the shift of the viewing average color.

is also a marker that denotes the observable color viewed from a long distance (viewing distance).

Although the actual color distribution becomes dramatically different as the relative translation progress the reflected color hue as viewed from a distance stays approximately the same. However there is a substancial change towards more saturation that can be observed. A local variation in physical point spread will therefore produce a varying reflection image.

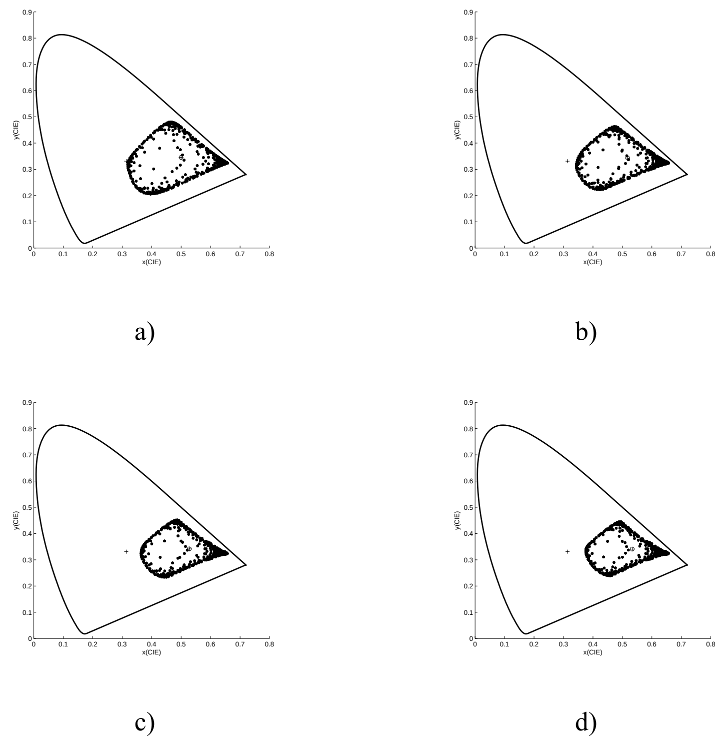
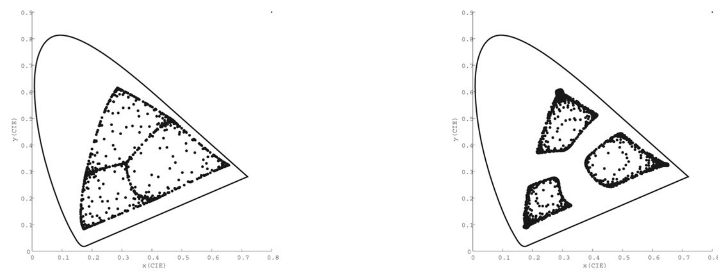



Figure 5. The colors of two translated separations with moderate dot gain projected on the chromaticity diagram. In a) through d) the effect of higher optical dot gain is shown. The more optical dot gain the les pure paper white and the saturation of the reflected viewing image is increased. The marker shows how the increased optical dot gain has increased the saturation.

The second experiment shows the effect of increasing the optical dot gain. This is obviously something that is very difficult to illustrate practically because the paper itself has to be modified. In the simulation however it is very easy. We chose a set of separations with a certain relative translation from the previous study and apply an increasing amount of optical dot gain.

In the Figure5 a) the primaries and secondary colors can be seen together with the white as clusters. The following Figures 5 b) through d) show how the white is changed due to the scattering of light that has passed the color layer once on its way into the paper and emerges from the unprinted paper surface (the optical dot gain effect). What is more interesting is that the series of figures also show how the reflection average is shifted towards more saturated colors. In the limit with a very large dot gain the colors in the chromaticity diagram would all be in



a) b)

Figure 6. The distribution of colors in a set of separations with all pairs of primary inks translated relative each other are shown in a). The same set of separations but printed on a substrate with high optical dot gain is shown in b).

the same position as the average marker. There would not any longer be any discernible dots. This fact has already been shown in Gustavsson S. 1997.

The most interesting observation that the simulation shows is how important the optical dot gain is. There is a substantial increase in the saturation of the resulting reflection image color with increasing optical dot gain. This fact is of course interesting for the paper manufacturers. If a substrate can be changed so that the internal scattering is increased the substrate is known to appear whiter and the potential for printing more saturated colors increase. From the Figure 5 below it can be observed that the effect is large.

The same characteristic changes appear for all of the three different combinations of two inks. In Figure 6 above the three combinations are shown together in the same chromaticity diagram. It is interesting to see how the distributions of the gamut colors of the different combination of primary colors are formed. In the literature the chromaticity gamut diagram is usually drawn as a triangle with the primaries on the vertices. This is of course true for optical mixing of the primaries. However, in printing this is not true. The difference is a consequence of the neglect to take the dot gain into account. As can be seen from the figure the boundary is not exactly a triangle.

## Summary

It has been demonstrated through simulation using known models for physical and optical dot gain that the color reproduction of halftones is very dependant on these effects. This has been practically known for a long time and many models have been devised to increase the knowledge base in this area. Even the simple models that have been used in this paper show one thing that is of great importance to the paper manufacturer. A paper with large optical dot gain has a greater potential for printing highly saturated colors. That the effect is so large in halftone color printing is new although similar results have been shown before for full tone printing situations.

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