On-line Measurement of Color - Densitometer or Spectrophotometer?

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Keywords: On-line, densitometry, spectrophotometry, measurement, color

Abstract: Discussions about the on-line color measurement of a print often deal with the question of whether a densitometer or a spectrophotometer should be used. The question relates to the number of channels needed to measure the reflectance properties of a print, arising from the fact that the reproduction of color in printing is not only affected by the light absorption properties and the amount of the inks but also by a number of other factors. Consequently, in four-color printing the four channels of a densitometer might not be sufficient to measure the reflectance properties of the print.

In this study, the question is viewed against two newspapers whose production is followed for two months. Tens of reflectance spectra of the printed colors are measured daily. The colors are selected randomly. The resulting huge databases are analyzed in order to find out how many channels are needed to measure the spectral reflectance properties of the colors in the two newspapers. According to the results, allowing an average measuring error of 1 ΔE, three channels are needed to measure the gray test marks and, correspondingly, five channels to measure all the colors in the newspaper.

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Introduction

The reproduction of color in printing is not only affected by the light absorption properties and the amount of the inks but also by a number of other factors. These include the absorption of light into the paper, scattering, reflections from the interfaces, and sometimes also emission through fluorescence. Over the years, their importance to the print quality has been discussed in the literature extensively. The different types of interaction are summarized in Figures 1, 2 and 3.

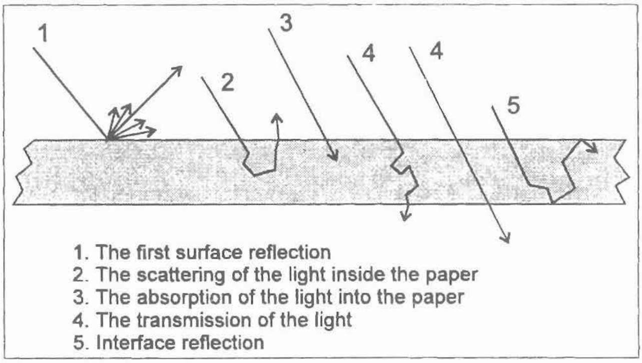


Figure 1. Examples of interactions between the light and the paper.

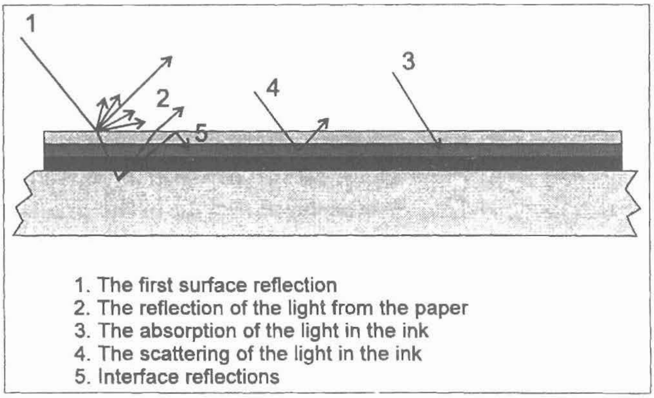
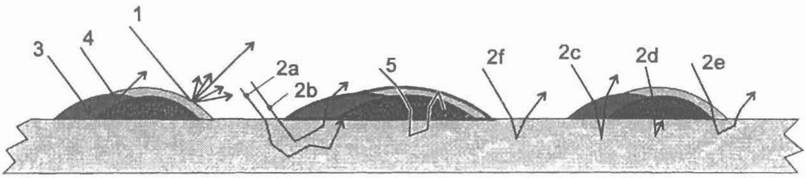


Figure 2. Examples of reflections from the interfaces.



1 The first surface reflection
2 The reflection of the light from the paper
   a The falling of the light on the paper in an area with no ink, the reflection from the paper and finally the absorption into the ink
   b The falling of the light on the paper in an area with no ink and the reflection from the paper back to the air through the ink
   c The falling of the light on the paper and the reflection back to the air through the ink
   d The falling of the light on the paper through the ink, the reflection and finally the absorption into the ink
   e The falling of the light on the paper through the ink, the reflection and the return back to the air from an area with no ink
   f The falling of the light on the paper and the reflection from the unprinted paper
3 The absorption of the light into the ink
4 The scattering of the light in the ink
5 Surface reflections

Figure 3. Examples of interactions between the light and the print in halftone image areas.

All the interactions between the light and the matter are dependent on the wavelength of light. This suggests that in four-color printing the four channels of a densitometer might not be sufficient to measure the reflectance properties of the print. If the sampling interval of a spectrophotometer is 10 nm and the measured wavelength range is 380-730 nm, the resulting spectrum is composed of 36 channels. On the other hand, according to some literature references all of the 36 channels are not needed to define print reflectance properties (Johnson A. 1997, Seymour J. 1997, Vrhel M. J. and Trussell H. J. 1992). In this study, we analyze the number of channels needed to define the reflectance properties of newspaper prints.

Objectives

The objective is to establish the number of spectral bands needed to estimate the print reflectance spectra for a three-color gray and a color area of a newspaper. The criteria were set in ΔE-values. The first criterion was the number of bands needed to make estimations which differ less than 1 ΔE-value in average from the measured spectra. The second criterion was the number of bands needed to make estimations where the maximum values differ less than 1 ΔE-value from the measured spectra.

Methods

Overview

The issue of "*How many channels are needed to estimate the print reflectance spectra*? " is viewed here against an estimation of the print reflectance spectra with a model based on a multiple linear regression model. The model contains:

- *Dependent variables*. The estimated reflectance spectrum composed of 36 bands is the dependent variable of the model.
- *Independent variables*. The single spectral reflectance values of a print are independent values for the model. The number of independent variables, and thus the number of channels, may be varied.
- *Parameters*. The spectra of cyan, magenta, yellow, black and paper are the parameters of the model.

For this study, newspaper production was monitored for two months. The resulting huge databases are used in the analysis as follows:

- *Calibration of the model*. The model is first calibrated to find the regression coefficients. The first fifty measurements of the database are used in the calibration; they were taken during the first two days of the long-term measurements.
- *Employment of the model*. After the calibration, the model is used for all the other measurements during the two months.

The model was used to establish the number of channels needed to estimate the print reflectance spectra. The analysis was first made by using three independent variables, i.e. three spectral channels. If the deviation between the estimated and the measured spectra was too large, one channel was added, and the calibration and the analysis were made again. Channels were added as long as the difference between the estimated and the measured spectra was within the above defined criteria.

Data collection

The measurements were made with a Gretag SPM100 spectrophotometer. The essential technical information of the device is in Table 1.

Table 1. The measuring conditions.

Device	Geometry	Illumination	Viewing angle	Polarisation filter	Sampling interval
Gretag SPM100	45/0	D50	2°	No filter	10 nm

During the two months, the color pictures and the three-colour gray test marks of the newspaper were measured daily. This means that a representative sample of spectra was collected from the newspaper. The color measurements were made in random locations within the color images. The idea was to include in the color measurements as different colors as possible in the database. The three-colour gray test marks were measured in another database. The measured spectra are in Table 2.

Table 2. The number of spectra measured during two months.

Color pictures	Three-color gray
2,028	344

Model

A mathematical model was developed, based on a multiple linear regression analysis, to estimate the print reflectance spectra from the reflection measurements. The basic principle of the model is in Figure 4.

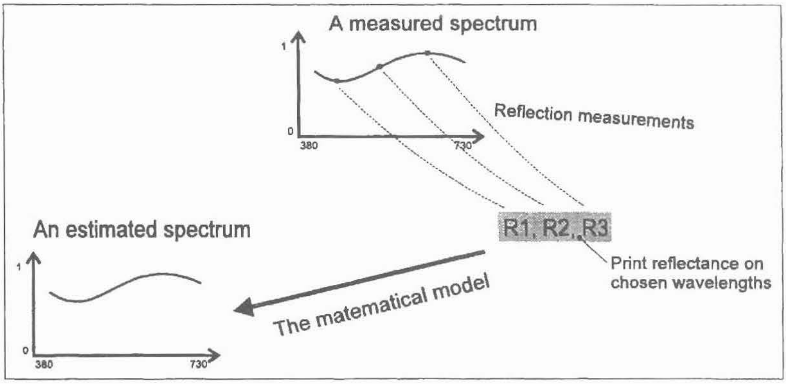


Figure 4. The basic principle of the model.

The model is based on two steps, the calibration and the employment of the model. The regression coefficients were found in the calibration step. The calibration step is shown in Figure 5.

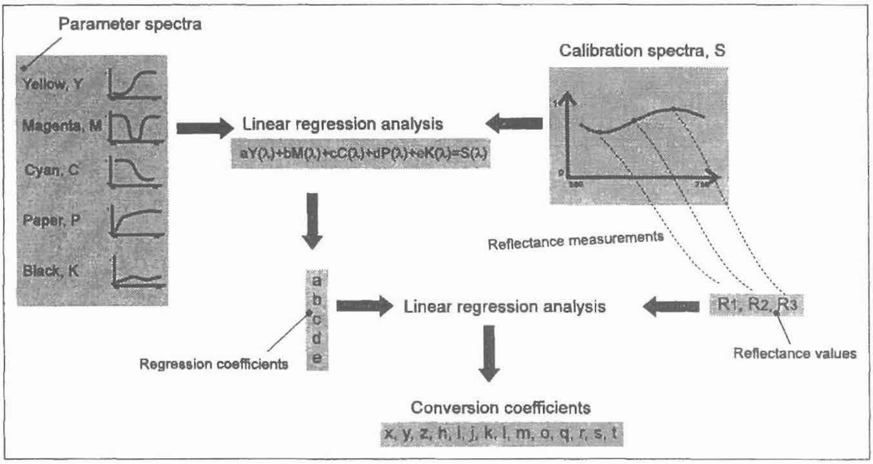


Figure 5. The calibration of the model.

In the calibration step, the reflectance values are first calculated from the calibration spectra with reflection filters. The choice of the reflection filters and the calibration spectra used in the model is not limited. In this study, the first fifty measurements during the two months' period were used as the calibration spectra in both the three-color grey and the color analysis.

The second step in the calibration is the calculation of the regression coefficients between the calibration spectra and the parameter spectra using linear regression analysis. The spectral absorption properties of the inks, the reflectance filters and the paper were used as the parameter spectra.

The final step in the calibration is the calculation of the conversion coefficients. The coefficients were calculated with a linear regression analysis between the regression coefficients and the reflection values. The conversion coefficients are needed to use the model shown in Figure 6.

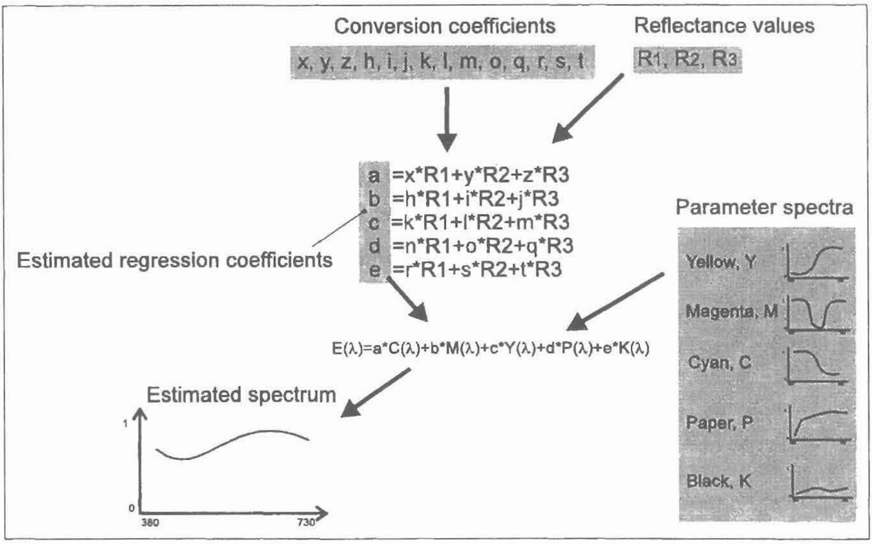


Figure 6. The application of the model.

In the application of the model, the estimated regression coefficients are calculated according to the conversion coefficients and the reflectance values. The reflectance values are independent variables of the model, and they correspond to the spectral reflectance of the print on single wavelengths. With the estimated regression coefficients, it is possible to estimate the spectrum by multiplying the coefficients by the parameters of the model, i.e. the spectra of the inks and the paper. Figure 7 shows a spectrum measured from a three-color grey test mark and a spectrum estimated with the model.

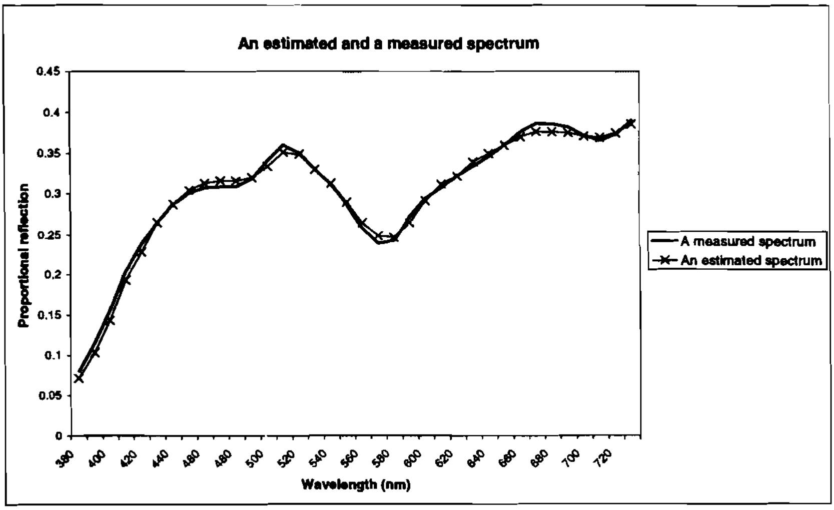


Figure 7. A spectrum measured from a three-color grey test mark and an estimated spectrum calculated with the model.

Selection of channels

The number of the required channels was estimated with a set of tests. In the beginning, calibration was carried out by using three independent variables, with reflectance values of 430, 530 and 620 nm according to the DIN standard for density measurements. After that, the model was used to estimate all the other spectra in the database. If the estimated spectra were not good enough, a spectral channel was added, the model was recalibrated, and the analysis was repeated. The added spectral channel represented the wavelength with the biggest deviation between the estimated and the measured spectra. The tests were continued and independent variables were added until the deviation between the estimated and the measured spectra reached the agreed maximum limit.

The principle of the band selection is shown in Figures 8 and 9. Figure 8 gives the ratios of the measured and the estimated spectra in 255 three-color grey measurements. Figure 9 presents the ΔE-values of the analyzed spectra.

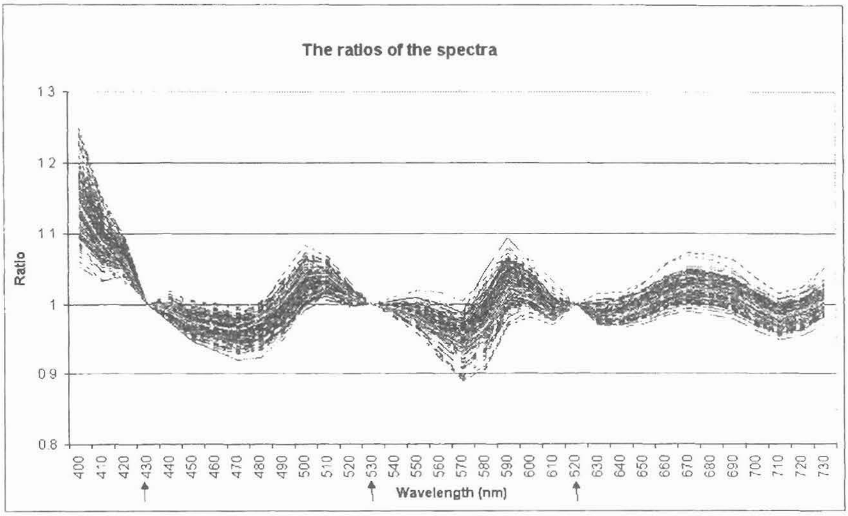


Figure 8. The ratios of the measured and the estimated spectra on different wavelengths when RGB filters (430, 530, 620 nm) are used in the model.

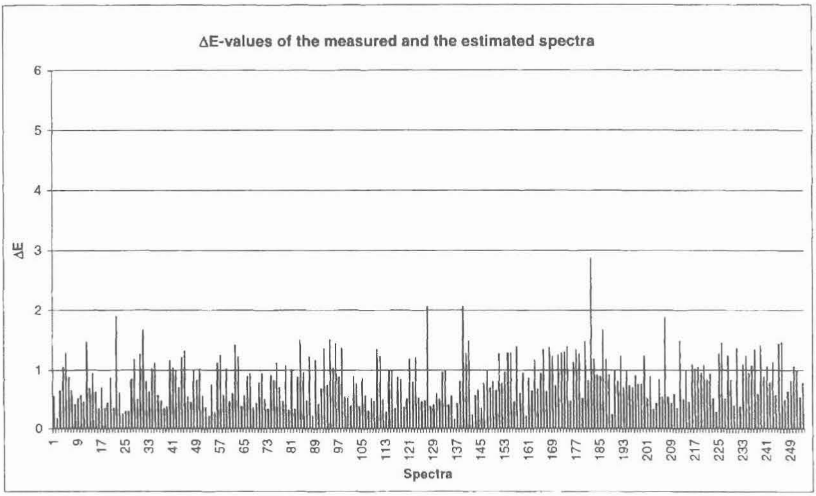


Figure 9. The ΔE-values of the measured and the estimated spectra when RGB filters (430, 530, 620 nm) are used in the model.

In the analysis shown in Figures 8 and 9, the maximum ΔE-values are between 1 and 3 while the average ΔE-value is 0.84. The purpose of the average ΔE-value has then been reached, but the maximum ΔE-values are still too high.

Filters were added, one by one, to the wavelengths with the biggest error until the maximum ΔE-values are below 1. Two additional filters were needed in that case. The results are shown in Figures 10 and 11.

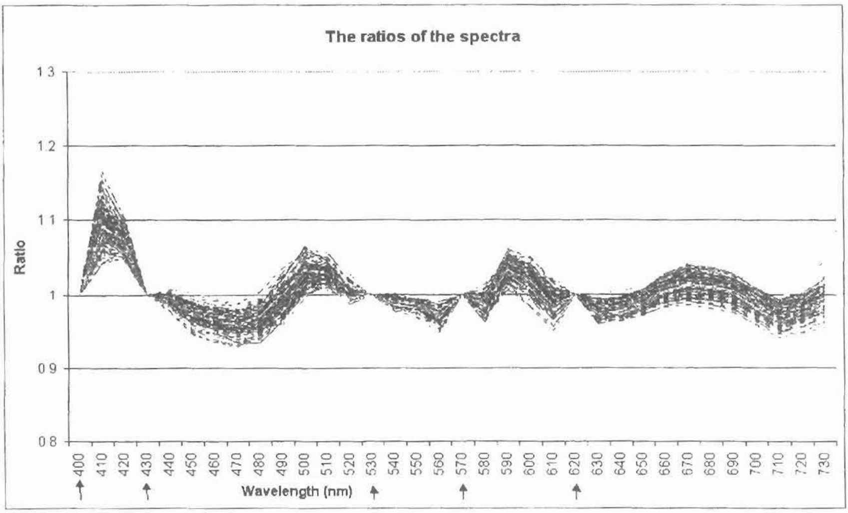


Figure 10. The ratios of the measured and the estimated spectra with different bands when filters of 570 nm and 400 nm are used in the model in addision to RGB filters (430, 530, 620 nm).

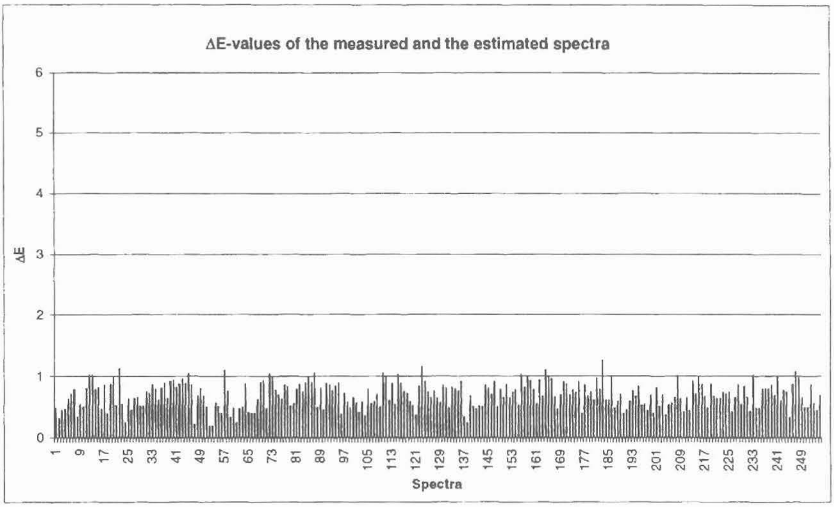


Figure 11. The ΔE-values of the measured and the estimated spectra when filters of 570 and 400 nm are used in addition to RGB filters (430, 530, 620 nm).

In the analysis shown in Figures 10 and 11, the maximum ΔE-values are about 1 and the average ΔE-value 0.70. The purposes of the maximum and the average ΔE-values are reached with the five filters.

Results

The measurements made during two months were analyzed by using the model. The filters needed to reach the objectives are in Table 3 for three-color grey measurements and in Table 4 for color measurements.

Table 3. The results of the analysis of the grey test marks.

Number of filters	Wavelength (nm)	ΔE_{max}	$\Delta E_{average}$
3	430, 530, 620	2-3	0.84
5	430, 530, 620, 570, 400	about 1	0.70

Table 4. The results of the analysis of the color areas.

Number of filters	Wavelength (nm)	ΔE_{max}	$\Delta E_{average}$
4	430, 530, 620, 570	3-5	0.74
6	430, 530, 620, 570, 420, 490	about 1	0.57

The number of channels required for another newspaper

The same analysis was made of a second newspaper. A large database was collected also for that newspaper by making daily measurements during two months. The measured spectra are in Table 5.

Table 5. The number of the spectra measured in the second newspaper.

Color images	Three-color gray
1,756	345

The results of the 2nd newpaper are very similar to those of the 1st newspaper as shown in Tables 6 and 7.

Table 6. The results of the analysis of the grey test marks in the second newspaper.

Number of filters	Wavelength (nm)	ΔE_{max}	$\Delta E_{average}$
3	430, 530, 620	1-2	0.59
5	430, 530, 620, 570, 400	about 1	0.48

Table 7. The results of the analysis of the color areas of the second newspaper.

Number of filters	Wavelength (nm)	ΔE_{max}	$\Delta E_{average}$
4	430, 530, 620, 570	1-3	0.74
6	430, 530, 620, 570, 420, 490	about 1	0.61

Conclusions

The objective of this study was to establish the number of channels needed to measure print reflectance. The question is essential for the on-line control of the print quality because in that application lots of data must be processed in a short time. In this study, the issue was viewed against the quality control of newspaper printing. The results showed clearly that all of the 36 channels of a spectrophotometer are not needed to measure the print reflectance spectra.

According to the results of the two newspapers, three channels are enough for the measurements of the gray test marks, if the average error has to be less than 1 ΔE, compared with the spectral measurements. Correspondingly five channels are needed, if the maximum error must be less than 1 ΔE. Four and six channels are respectively needed to measure print reflectance from color images.

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