USE OF IMAGE ANALYSIS AND COLORIMETRIC CALIBRATION FOR

AUTOMATIC SETTING OF SCANNER - AND REPRODUCTION-PARAMETERS

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Abstract

Improvements for high quality color reproduction systems by:
- optimizing the work flow with job preparation devices for scaling and layouting, mounting of originals, presetting and previewing and scanning with additional automatic correction of scan-focus values for optimal sharpness and for the preview station ChromaLight the use of image analyzing methods with histograms of colorimetric prescan-data for automatic setting of the most important separation parameters.
- scanning with well aligned and stable R,G,B-filters and use of three-dimensional colorimetric calibrations for transformation the RGB-color pixel data to device independent CIELAB-data or equivalent ones in order to get an exact color recognition at the scanner and then to use these optimal data for communication and color manipulation followed by separate transformations to separation signals dependent on the customers print-condition.
- automatic gradation adaptation for different print conditions, screen rulings, output-formats and original-density ranges in order to enhance the throughput of separation sets at a high quality level even for unskilled operators.
- offering different levels for input of job-parameters based on the individual operator-knowledge and in addition a new function for easy color-correction based on the sensational color coordinates Hue, Chroma and Luminance with selectable ranges and adjustable maximum effect on a selected color hue in the original.

1. Optimizing the work flow for reproduction

The prepress stage of the reproduction process needs furthermore to be simplified, but still at a high quality, or even improved level for the printed result. This is for the upcoming DTP or DTR (DeskTopReproduction) with a higher number of unskilled operators much more important. But instead of the proposals for HIFI-Color -Rendering and -Reproduction of Carli and Davis [3], we will describe high fidelity improvements for today used "normal" reproductions with only 4 inks (3 chromatic and black) and

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traditional electronic screening methods. We have to concentrate on enhancements for higher output at a high quality. For scanning systems, wether DTP or high end systems, considerable simplification is required not only of procedural sequences, but also in regards to color settings and printing process adaption.

Modem technologies in the form of expert systems, first steps are classification methods, and computer analysis of images are able to provide valuable support in image setting work. New forms of sensational color manipulation and Color Space Adaption are also possible to simplify the reproduction process.

In order to obtain a user-friendly man/machine-interface it is necessary to separate the input process, the sensational manipulations and the output process. Device independent color coding seems to be a prerequisite for such a man/machine-interface.

Fig. 1 shows the typical work flow for reproduction as offered with the DC3000 ChromaGraph Scanner and the recommended job preparation devices for scaling, mounting, job setting and color control and manipulation with the ChromaLight preview station.

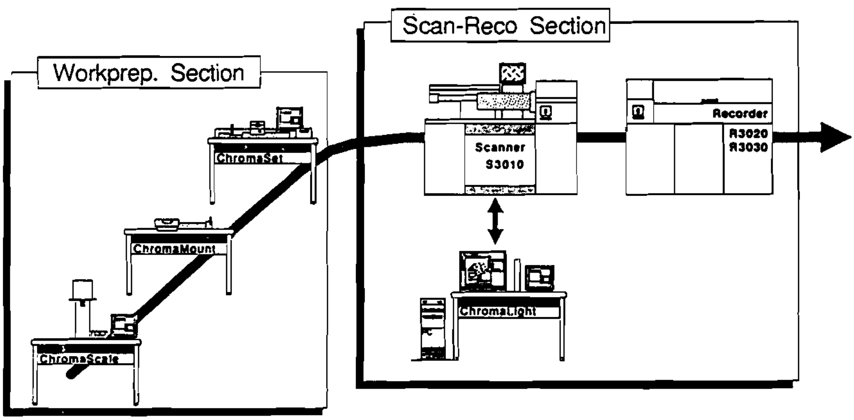


Figure 1: Typical work flow for reproduction

In order to get industrial like reproduction with optimized work flow we have to increase automation by use of more automatic features.

Automatic Scan Focus Correction

Automatic san focus correction is an additional function on the ChromaGraph Scanner S3010.
Automatic focus correction is done by scanning a certain line in the original with a small aperture for several focus values and dynamic evaluation of signal differences between

neighbour pixels. To get the right focus correction choose the focus value with the maximum of all differences (see Fig. 2).

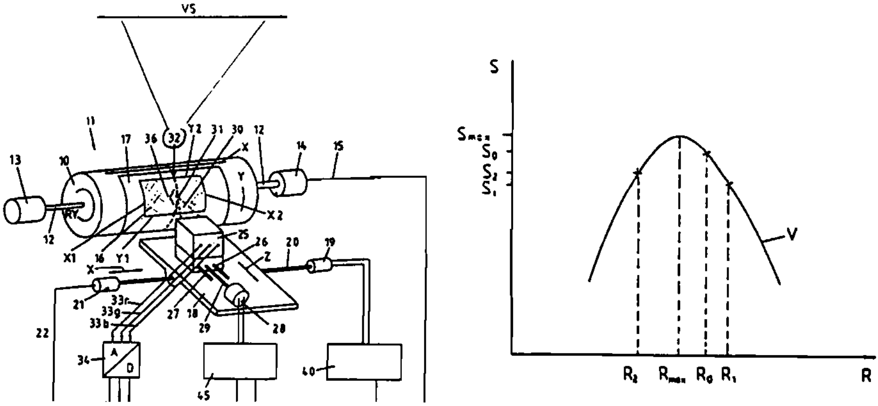


Figure 2: Automatic Scan Focus Correction

The advantages automatic san focus correction are:

- Standardized reproduction
- Independent of operator's subjective setting
- Uniformly high quality ensured

Today automatic sharpness setting is solved in our units, the calculations takes only some seconds.

The next step for automation is a very basic and more complicated one: automatic analysis of images.

Automatic Image Analysis

Originals which are used for reproduction work are generally not standardized and cannot be reproduced satisfactorily using only one standard scanner setting. It will be necessary, as a minimum, to adapt the density range (highlight and shadow). A finer setting must take into account the color range of the original, correct color casts, and, important for a good modulation, provide the proper gradation change.

Originals can also show deficiencies through incorrect exposure, unsuitable illumination, faulty film material or incorrect development. These deficiencies result in the form of color casts in the highlight, midtone and shadow areas or contrast changes, which have to be corrected.

During the last years there have been different approaches to solve this problem with automatic image analysis and to get results more independent from the individual

operators opinion and knowledge (first published papers see Ovchinnikov [10] or Hradezky [9]). Newer solutions you have seen on Imprinta '92 (see [1] [5]).
I want to explain our approach to automatic image analysis, we name it "ColorAssistant", that is available to customers since autumn '91.

The analysis of images has the task of measuring the color information of an image and of employing certain objective criteria to decide, wether there is a color deficiencies present or not. Since the analysis has no information at its disposal on the content of the image, statistical properties of images have to be taken as criteria.

For an image analysis it is necessary to make a prescan of the images and with the prescan data a computer program can analyse the images. Therefore we offer ColorAssistant with our preview station ChromaLight, which is directly connected to the ChromaGraph Scanner S3010 for making the prescans (see Fig. 1).

As a result of automatic image analysis proposals will be provided for setting the right values for image gammut, color cast correction and image gradation.

Normal setting of an image gammut is done via RGB-density values for maximum and minimum that correspond to the image highlight and image shadow of the original respectively.
By means of the lightness histogramm of an image it is possible to find the highlight and shadow values of the image dependent on the extend of the histogram in the highlight and shadow region.
(The histogram in Fig. 3 shows on the x-axis the density levels of an image and on the y-axis the relative number of pixels for a certain density level.)

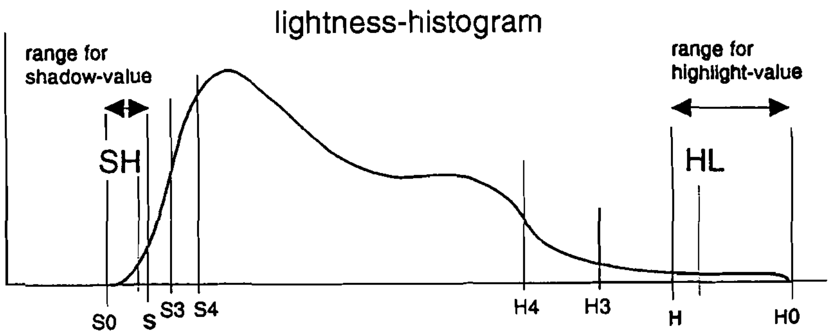


Figure 3: Lightness histogram of an image for determination of highlight and shadow value

Information on the color cast of an image is obtained by averaging the color components of weakly saturated original colors in the highlight and shadow region (see Fig. 4).
But instead of using RGB-values to do these calculations, the image data are transformed into the CIELAB color space [4], which is much better adapted to the visual sensation than RGB-densities or even CMYK-data.

The color cast could be obtained separately for highlight and shadow.

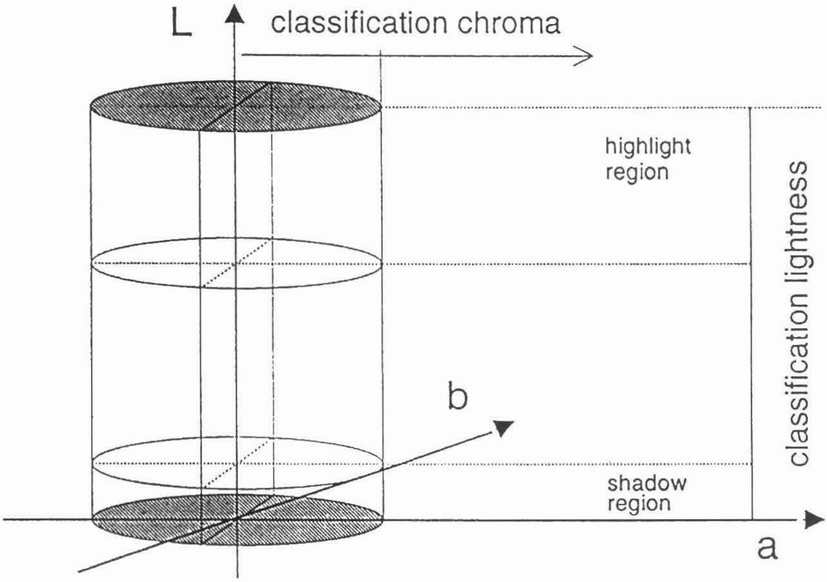


Figure 4: Color space with regions for color cast analysis

For obtaining information on image gradation the image data are analysed in divided sub-areas and these sub-images are classified in respect to modulation. All sub-images with only small data variations from pixel to pixel are taken out of consideration or have small influence for the statistical evaluation. From all sub-images with large data variations is calculated the lightness histogram (see Fig. 5). Based on this histogramm the optimal gradation will be calculated ([6] [7] [11]) and provided as a neutral gradation change to the operator.

The automatic image analysis reaches the limits of its capabilities, if an original exhibits marked color or contrast flaws or if the originals are in order but the motif of the original is judged. Critical originals of this type, e.g. sunsets, nighttime shots or weakly saturated bright motifs cannot be analyzed correctly unless a classification has been conducted first. Nevertheless we are expecting significant benefits for our customers using image analysis. This technology might also help the professional operator to increase productivity.

With the image analysis even an automatic scanning without operator interaction is possible. Then all precalculated values by ColorAssistant (or only some selected parameters) are automatically taken for the individual job.

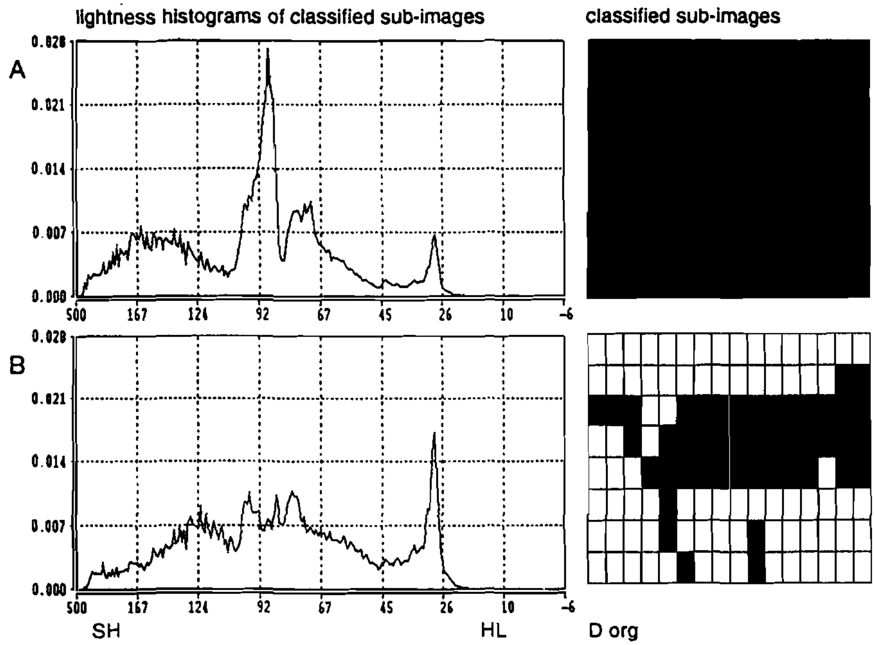


Figure 5: Lightness histograms of an image without (A) and with (B) classification of sub-images

The work flow with ColorAssistant can be described as follows (see Fig. 6):

- Job preparation

The image is parameterized as a prescan in the job preparation stage.

- Prescan

A prescan with a low resolution is performed on the ChromaGraph Scanner S3010. The prescan image data are transfered to and stored in the ChromaLight. A series of originals can be combined in so called "subqueues" for automatic scanning.

- Image analysis

ColorAssistant employs mathematical and statistical methods to analyse the prescan image data as mentioned above and calculates the presetting values.

- Image Setup

ColorAssistant parameterizes the gammut- and contrast- related setting parameters of jobs. It also allows the user to take further corrective actions, when the analysis results are diplayed on the ChromaLight-Monitor (see Fig. 7).

- Fine scan

The setting parameters are then transfered to the ChromaGraph Scanner S3010 by queueing the fine scan on the ChromaLight. Then the fine scan is performed on the Scanner S3010 with the prespecified parameters.

For most part ColorAssistant runs without any intervention by the operator, the latter merely having to queue the jobs for the prescan and fine scan.

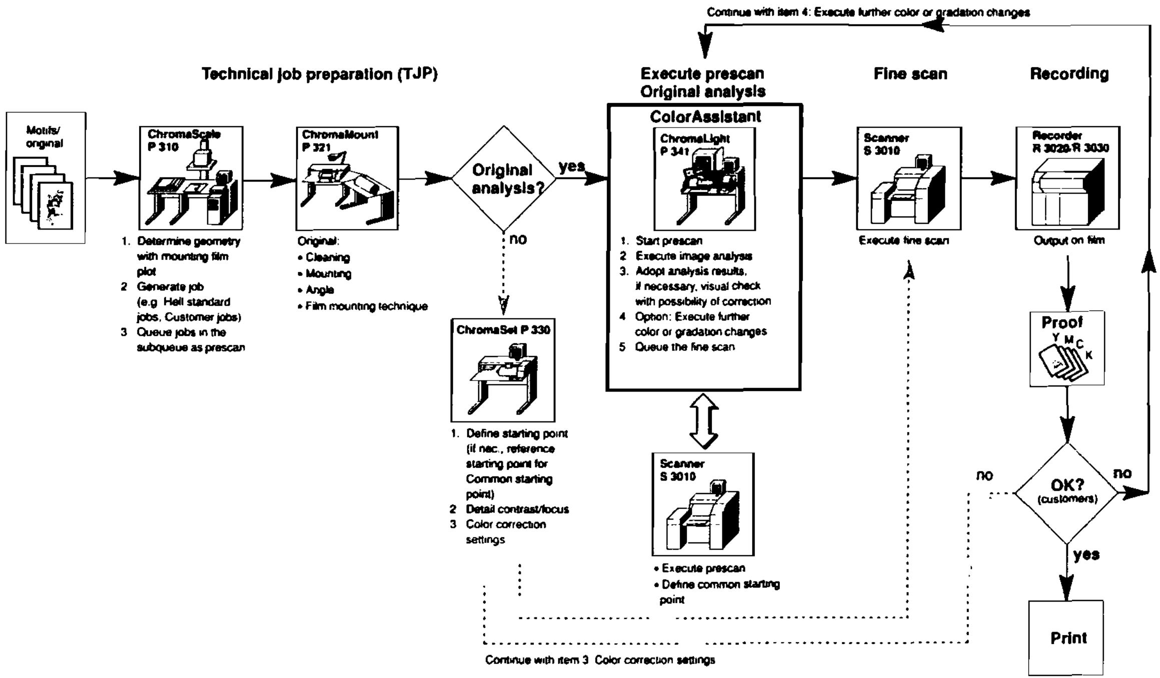


Figure 6: Work flow with ColorAssistant

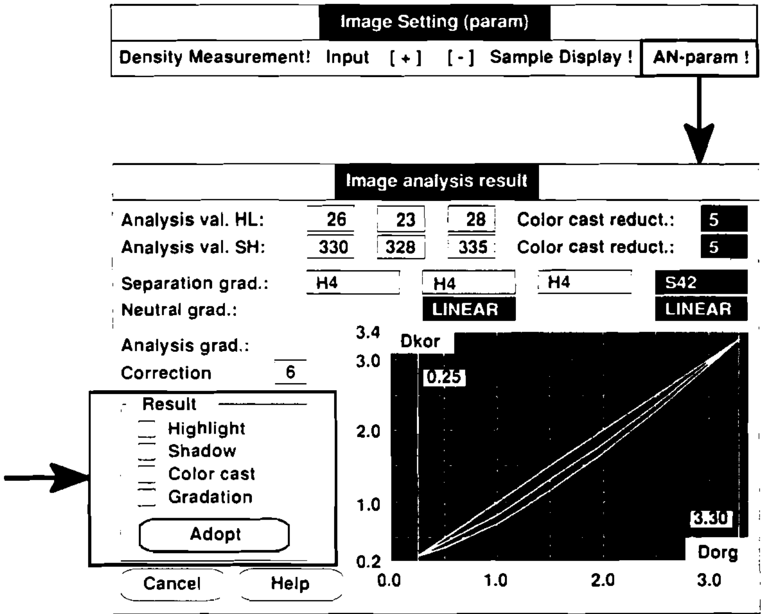


Figure 7: Display of analysis results with ColorAssistant

Features / advantages of ColorAssistant:

- standardized reproductions, independent of individual ratings
- automated determination of optimal image adjustment
  - image highlight / image shadow
  - color shift correction
  - gradation change for contrast enhancement
- profi-operators are relieved from routine work
- support of less trained operators by preset image adjustment
- productivity increase by process simplification

2. Scanner Calibration

Todays solutions in color communication are device dependend. In the field of High End Reproduction we communicate with printing process dependend CMYK values. In the Desktop Publishing area on the other hand, we communicate with scanning device dependend RGB values. Future solutions should be based on a division between color input, color adjustment and communication and color output by use of well defined and standardized color spaces. It is in such an environment not necessary to define the output process during scanning and it is not necessary to correct scanning deficiencies during data output to an recording device. The user interface of an Electronic Color Publishing System will in general be independend of the properties of the input and output devices.

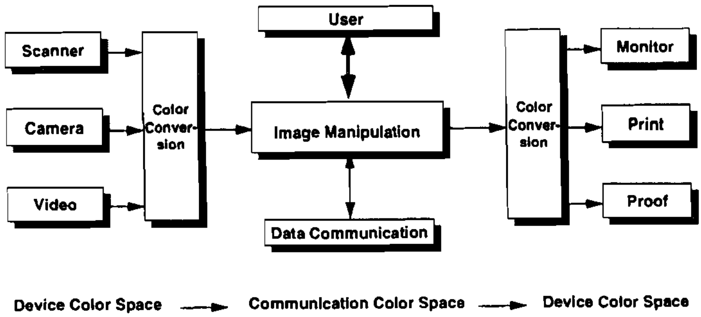


Figure 8: Electronic Color Publishing System

Fig. 8 shows in principle the data flow in an Electronic Color Publishing System. Scanner, Camera and Video are examples of input devices with their specific device color spaces. Monitor, Print and Proof are examples of output devices, again with their specific device color spaces. Data Communication and Image Manipulation are done in a device independent color space. The reference system or communication model is based on the CIE 1931 XYZ colorimetric system.

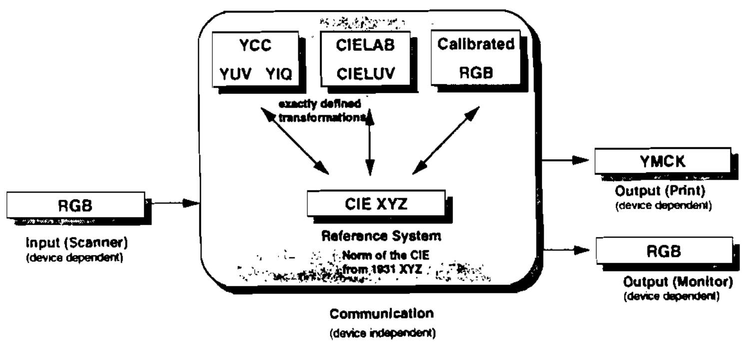


Figure 9: Color Communication Model

Fig. 9 shows the Color Communication Model. The input RGB-signals are transformed into an application specific color space such as for example the CIE 1976 L*a*b* or a Calibrated RGB color space. All these transformations of the XYZ colorimetric system are well defined. The input RGB scanning devices have to be calibrated to these color spaces. This calibration process is described in some detail next.

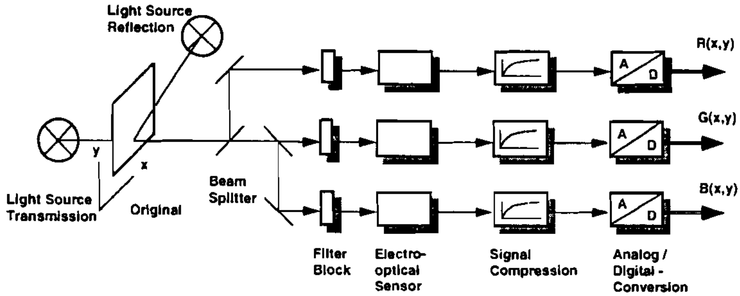


Figure 10: Structural Principle of Scanning Devices

Fig. 10 shows in a schematic way the building blocks of a scanning device. The reflected or transmitted light from the original was splitted into its RGB-components by beam splitters and filters. This signal was received and transformed into a voltage signal by an electro-optical sensor. The dynamic range of the analog signal was compressed and finally converted into a digital signal by an analog to digital converter. The output signal of the electro-optical sensor was given by a convolution of the spectral responses of the components of the optical system as show in Fig. 11.

$$R,G,B = f\left(\sum_{380\,nm}^{780\,nm} \left(S(\lambda) \times \Phi(\lambda) \times \tau_{R,G,B}(\lambda) \times R(\lambda) \times c_{R,G,B} \times \Delta\lambda \right) \right)$$

Spectral responces of Lightsource Image Color Filter Sensor Gain

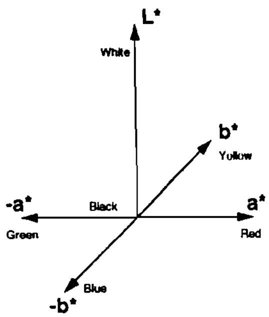
$$f() = \left\{ \begin{array}{l} \text{Dynamic Range Compression} \\ \text{fitted to the visual sensation of} \\ \text{the human eye} \end{array} \right\} = \left\{ \begin{array}{ll} 1.16 \times R^{1/3} - 0.16; & R > 0.008856 \\ 9.033 \times R; & R <= 0.008856 \\ & \text{G and B corresponding} \end{array} \right.$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{D65} = \begin{bmatrix} a11 & a12 & a13 \\ a21 & a22 & a23 \\ a31 & a32 & a33 \end{bmatrix} \times \begin{bmatrix} f^{-1}(R) \\ f^{-1}(G) \\ f^{-1}(B) \end{bmatrix}$$

Color Values CIE 1931 XYZ — Device Dependent Transformation Matrix — Scanner Image Color Values

Figure 11: Scanner Image Color Values

The dynamic range compression function has to be fitted to the visual sensation of the human eye for a signal transmission with an optimal resolution between scanner and color publishing system. Before transforming the compressed RGB values into the XYZ reference system the signals must be decompressed.



$$L^* = 116 \times f(Y/Yn) - 16$$

$$a^* = 500 \times (f(X/Xn) - f(Y/Yn))$$

$$b^* = 200 \times (f(Y/Yn) - f(Z/Zn))$$

with

$$f(X/Xn) = \begin{cases} (X/Xn)^{1/3} & X/Xn >= 0.008856 \\ 7.787 \times (X/Xn) + 16/116 & X/Xn < 0.008856 \end{cases}$$

f (Y/Yn) and f (Z/Zn) corresponding, Index n = White Referenca

Color Difference Formula

$$\Delta E_{ab} = \sqrt{\left((L^*_1 - L^*_2)^2 + (a^*_1 - a^*_2)^2 + (b^*_1 - b^*_2)^2 \right)}$$

Chroma and Hue

$$c^*_{ab} = \sqrt{(a^2 + b^2)} \qquad h_{ab} = \arctan(b / a)$$

Figure 12: Color Space Transformation CIE 1976 L*a*b*

Fig. 12 shows the formula for the color space transformation into the uniform color space CIE 1976 L*a*b* (CIELAB). This color space was choosen because of its sensational uniformity and because of its wide acceptance in the printing industry. The color space transformation from device dependend RGB values into CIELAB values was done by 3-dimensional look-up-tables (LUT) and interpolation.

For a correct transformation into the CIELAB color space the spectral responce functions of the scanning device must be a linear combination of the CIE xyz spectral responce functions. Normally this is not true. Therefore a device specific calibration of the input signal is nessecary. This is shown in Fig. 13.

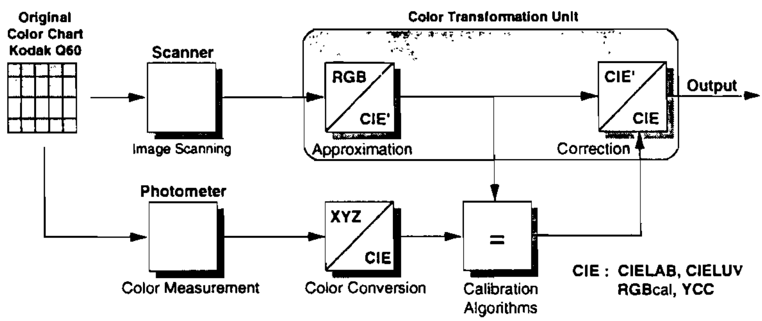


Figure 13: Workflow of the Color Calibration Process

A test image with a lot of colored patches like the KODAK Q60 testform was measured by a scanner as well as by a spectrophotometer. Both measurements are transformed into CIELAB color values. The RGB values are transformed by a more or less rough approximation depending on the input device characteristics. The differences between these two sets of values will then be calculated. To correct all entries of the 3-dimensional LUT an error vector for each entry has to be calculated from the much smaller number of differences. This was done by an error diffusion method, that means, weighting differences near the entry into the LUT higher than those far away. The error vector was added to the approximation values giving a new corrected LUT. This process was repeated several times until the overall error for all patches was less than a given value. Because there is a close relation between the filter curves and the dye pigments of the image, this calculation has to be repeated for all original materials of the different vendors.

3. Automatic Gradation Adaption

The 'Automatic Gradation Control' Software adapts the gradation of the separation in respect to

a) density range of the original
b) print gradation
c) separation size
d) screen ruling

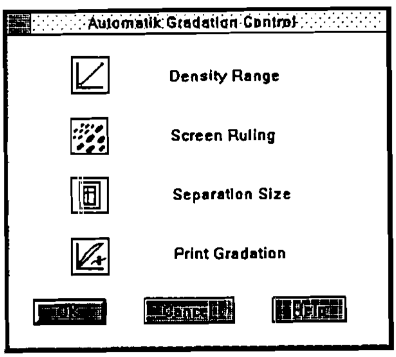


Figure 14: Dialog Box 'Automatic Gradation Control'

Fig 14 shows the dialog box of the scanner control software. The different automatic functions are visualized by icons. By 'clicking' on these icons the user aktivates or disactivates the different functions.

a) Density Range

This function duplicates some of the functionality of the 'Color Assistant' Software and is used if the 'Color Assistant' Software is not installed.

b) Print Gradation

This functions takes the dot gain curve of different printing machines and processes into consideration. The user has to find out the dot gain curve, for instance by using the Linotype-Hell CALI 2 testform or the proposed IT 8.7-3 print calibration form and input the values into the Software. After that the user can select the dot gain curve by inputting a name in a separate Dialog Box 'Printing Conditions'.

c) Separation Size

This function changes the midton values of the separation gradation in respect to different separation sizes.
The calculation is based on a picture size of 12x18 cm² (5"x7"). For each change of the picture size by the factor of 2 (1/2) the midton values are increased (decreased) by 3.5%.

d) Screen Ruling

This function takes the change of the dot gain curve for different screen rulings into consideration. The calculation is based on new results from the FOGRA/ BVD [see Lit. 2]. The diagram Fig. 15 shows how the dot gain changes with different screen ruling. The diagram is to be used as follows. If your current screen ruling is 60l/cm and the dot gain is 16% find the curve which goes through the point of intersection of the values 60l/cm an 16% (see arrow 1). If you want to determine the dot gain at 100 l/cm go along the curve until the intersection with 100 l/cm (arrow 2). Read out the dot gain value 22% on the left side of the diagram (arrow 3) or the printed area size 62% on the right side of the diagram. Figures 16 and 17 show the relationship for typical offset printing conditions at a dot size of 40% and 80%.
Figure 18 compares the curves for offset printing and 'CROMALIN' proof. This figure shows that the dot gain simulation of the CROMALIN proof is only correct in the range between 60l/cm and 70l/cm. This is also true for other proof processes.

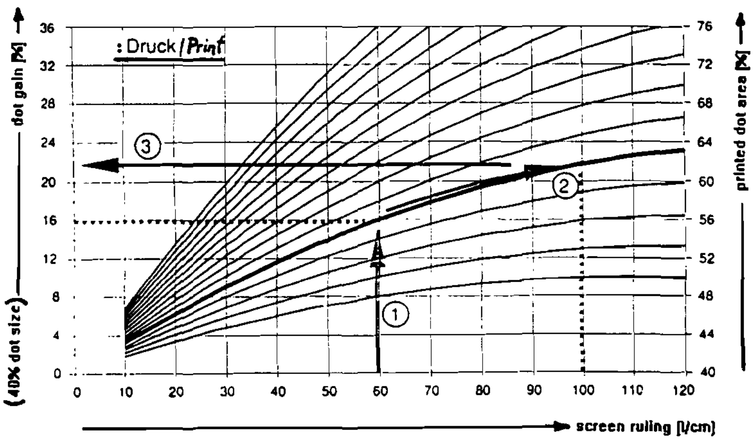


Figure 15: Using The Dot Gain and Screen Ruling Diagram

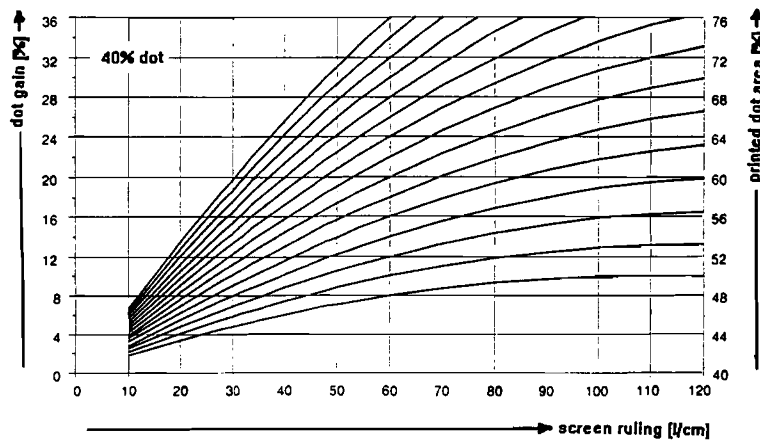


Figure 16: Dot Gain and Screen Ruling at 40%

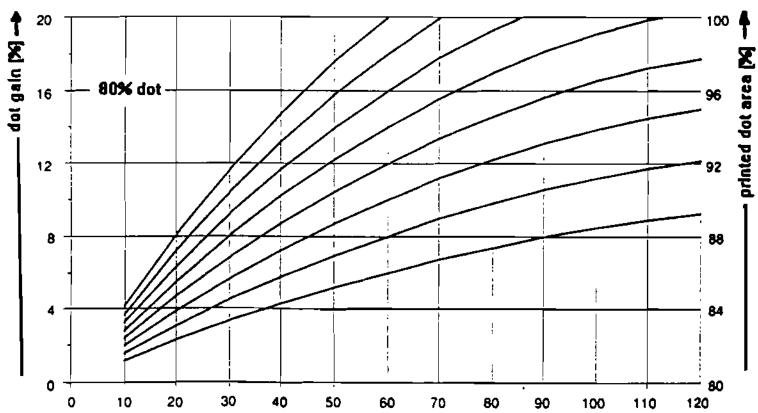


Figure 17: Dot Gain and Screen Ruling at 80%

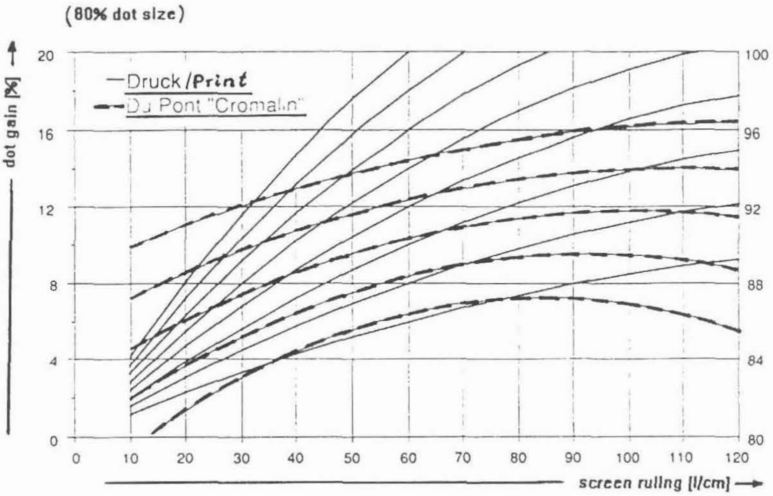


Figure 18: Comparison Dot Gain and Screen Ruling of Offset Printing and CROMALIN

Basic Settings

The software offers several different basic settings of Job parameters for different kinds of originals (Fig. 19 and 20) and different output transformation tables (PCT) for adaption to different printing conditons (Fig 21) for easy preparation of scanner settings.

HELL Master Jobs

H010-COLOR DIA
H015-KODACHROME
H020-COLOR DIA B/W
H030-COLOR NEGATIVE
H050-COLORPRINT
H065-WATER COLOR
H071-DUPLEX/DIA
H999-TEST DIA

Figure 19: HELL Master Jobs

Customer Jobs

C001-DIA/VERYDARK	:	Specifically for very dark transpar.
C002-DIA/DARK	:	Specifically for dark transparencies
C003-DIA/NORMAL	:	Specifically for normal transpar.
C004-DIA/BRIGHT	:	Specifically for light transparencies
C005-DIA/VERY BRIGHT		Specifically for very light transpar.
C010-RED COLORS	:	For transparencies to increase the definition in red tones
C011-LANDSCAPE	:	For landscapes whose spatial features and modulation improve because of the use of a special gradation (CO3).

Figure 20: Customer Jobs

PCT (Programmed Color Transformation) Data Records
(Option Package, Version A3K0)

Print. Proc. = Destination printing process, source printing process: sheet-fed offset
Print. Stock : 48.8 g newsprint, machine coated paper, polypropylene
Intens. Incr. = Intensity increase for 50%
FDS = Total ink coverage
Gr. Range = Gray range
Min. Limit. = Minimum limitation for Y, M, C
K Grad. = Black (K) Gradation

Data Record	Print. Proc.	Print. Stock	Intens. Incr.	FDS	Gr. Range	Min. Limit.	K Grad.
09 PCT Z	Newsp.	48.8 g	25%	290%	4	0%	K-100
10 PCT Z	Newsp.	48.8 g	20%	300%	4	0%	K-95
11 PCT Z	Newsp.	52 g	30%	280%	1	0%	K-100
12 PCTOT	O/G proc.	mc 70 g	10%	350%	4	0%	K-80
13 PCTOT	O/G proc.	mc 70 g	20%	330%	2	0%	K-90
14 PCTOT	O/G proc.	mc 70 g	+8%	360%	1	0%	K-100
15 PCT F	Flexo	Polymer	25%	320%	4	0%	K-80
16 PCT F	Flexo	Polymer	35%	300%	0	0%	K-80
17 PCT F	Flexo	Polymer	20%	320%	5	3%	K-80

Figure 21: PCT Data Records

Sensational Color Manipulations

Descriptions of color definitions or changes, which are orianteted to printing processes and which use ink componenets (C,M,Y,K) measured in halftone dot aerea sizes are heavily dependent on the selected printing process and require a high level of abstraction or a good skilled user. Color manipulations should therefore be described by lightness, chroma and hue, the sensational color coordinates. Such kind of description or user definable ranges in these values will simplify the manipulation process and is also a prereqesite for a user friendly man/machine interface.

Methods of Color Manipulation

Color manipulations represent modifications to color values of an original with the aim of enhancing the reproduction, correcting deficiencies, making autohor corrections and performing adaption to the printing process or in general to the output conditions. In relationship to a special printing process it is neccessary to show and correct the separation values (separation dot sizes of the CMYK inks).
With a new software function it will be possible to calibrate the correcting function to a certain hue of the original color pixel, define a broad or narrow range in all of the three color coordinates lightness, chroma and hue in order to get a optimal and easy understandable correction range (f.i. for pastell colors or skin tones).

Conclusion:

All of these previously decribed functions support the user at different levels of skill (the beginner, the advanced, or skilled user) in routine applications and tasks, help to minimize errors but they cannot replace an expert. The practical benefit for the user is reducing what is still a high number of repetitive tasks, further shortening the setting time required to obtain the correct parameterization of the scanner and so getting a better productivity.

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