ERROR PROPAGATION ANALYSIS IN PRINTING

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Abstract : With the advent of color management systems and the discussion about their accuracy, the knowledge about unavoidable fluctuations in the color signal produced by software and devices gain importance. This paper discusses contributions of different sources of color fluctuations in data generation and color printing. In the approach presented here, the influence of measurement devices, tone value variations and variations of dot gain are taken into consideration. The joint effect of these factors is described and the correlation between the types of fluctuations is addressed.

Introduction

Color differences between originals and their reproductions may not only occur due to color treatment by operators or systematic behaviors resulting of data processing in software or devices but also due to random errors on the signals. Those errors are unavoidable and, for printers, may have their origin in the physics of the materials and surfaces involved (1,2) or in the quantization characteristics of various software.

In the past, for users of color reproduction systems, the question of color accuracy of the individual device or software has been overlaid by the far more significant problem to communicate color doubtlessly which again caused proofing systems to concentrate on color reproducibility (rather than on system

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simulation). Now, since color communication is about to work accurately with color management systems, the color accuracy of the devices - or rather the color signal as it is produced by devices or software - need to be addressed with respect to reproducibility of color.

Following a brief review which addresses the accuracy of color measurement devices as they are used in prepress, the subsequent chapters deal with errors introduced by software and printers. As there is some characteristic on the noise of the color signals of offset presses this aspect is also highlighted.

1. Measurement devices for color

As partly reported earlier (3,4) devices for color measurement undergo different errors as there are:

1. variations in the color signal measured over time (3)
2. variations in the color signal measured when the devices are recalibrated (3)
3. differences between different measuring devices (4).

In our work we evaluated these findings reported and we could reproduce them - they can be summarized as follows: Looking at the individual apparatus, most of the devices for color measurement generate coherent data providing the device is used in stable conditions. Time dependent variations found range in the area of up to 0.2 dE and may, due to their low size, be neglected most of the time. Following a recalibration, the differences of the results generated by the same device before and after the calibration may, in certain cases and especially when using cheap devices range up to several units in dE. However, this only refers to the use of one and the same measuring device. The results generated with different measurement devices may vary significantly up to several dE depending e.g. on: which object (surface) has been measured, where in the color space the color of the target is located, the light source, the measurement geometry, and the sensors that have been used in the measurement device.

Of course the communication of color-related measurement results undergoes the same ambiguity. Subsequently the value of communicating measurement data versa color managed data and related ICC profiles should be regarded as safer when it comes to the unambiguous communication of image colors.

2. Scanners

2.1 Experimental Approach

The scanners examined (different devices have been used) in the experiments reported have been used to scan the Kodak IT8.7/2 target. ICC Profiles for the scanner have been generated using the profiling tools of ColorBlind™. The RGB data generated by the scanner have been read using the scanner profile and the appropriate ColorSync™ Module for absolute color rendering into Lab thus generating CIELab data. The reading of the data was made possible with the TIFF-Parser provided by LogoSoft ™. Five series with each 10 scans have been produced; the target as been moved on the screen following to every scan by some 1 cm.

2.2 Experimental Results

The scanners examined here were all in the sales price range of some $500 per device. Due to the relatively low quality of these devices errors encountered may thus be larger using these apparatus than if more expensive scanners will were under view. Results for the standard deviation (implicitly assuming a Gaussian distribution of the errors) were as follows (see also 3)

reflective target	ΔE_{94}	= 7
in ab-dimension:	ΔE_{94}	= 2
transmitting target	ΔE_{94}	= 9
in ab-dimension:	ΔE_{94}	= 4

Displaying the errors produced in histograms is somewhat misleading, of course, since signals in different segments of the color space may vary significantly. However, some insight in the distribution may be generated in such a plot as it is displayed in figure 1 for a reflective target.

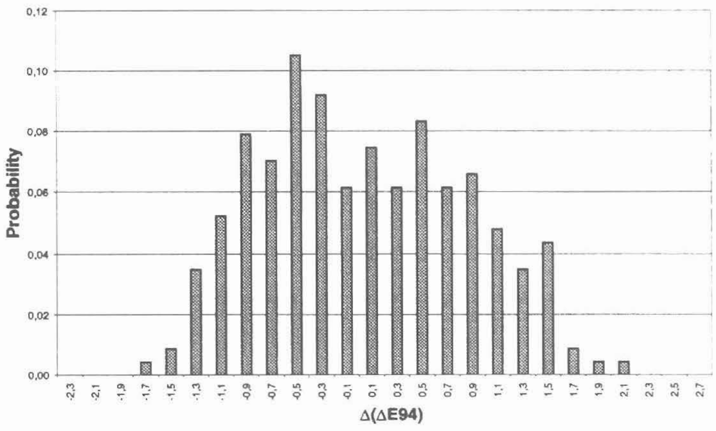

Figure 1: Error distribution for scanner signals (reflective target, in ab-dimension of the CIELab-space)

The process to make this graph is as follows :
First, we calculate the colorimetric difference in terms of ΔE_{94} between the original and the output data for each patch of the target.
Then, we calculate the average of ΔE_{94} of the 228 patches.
And to derive the $\Delta(\Delta E_{94})$, we subtract the difference between the original and the output data for each patch to the mean value.

3. Software

3.1 Experimental Approach

In the evaluation of the errors introduced by software for a first approach, compression and decompression of data was chosen. For that purpose each file generated by the scanner as described above was read into Photoshop™, turned to a certain angle to avoid the same artifacts to be generated in different subsequent experiments, compressed in JPEG (highest compression-level), then opened as compressed data, and then turned around in the negative angel. As described above for scanner the reading of the data was made possible with the TIFF-Parser provided by LogoSoft™ ColorLab 1.3.

3.2 Experimental Results

Examinations of the errors introduced into the color signal by lossy compression methods may be found in the literature (e.g. 5). For the experiments reported here and in order to generate some insight into error propagation throughout the process, the signals generated with the scanner, as they are displayed in figure 1, were treated as described in 3.1. The resulting distribution of signals is shown in figure 2.

As can be seen by comparing figure 1 and 2, the errors introduced by lossy compression contributes mainly to the likelihood of errors occurring and slightly to the distribution of errors.

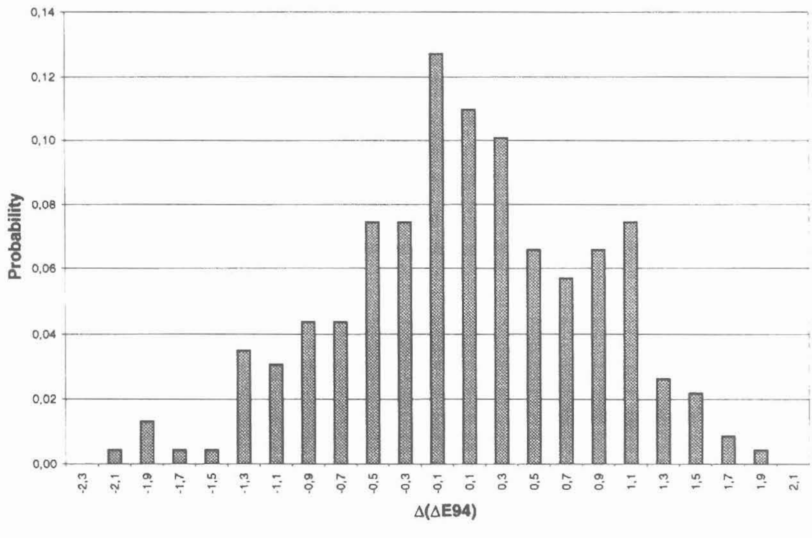

Figure 2: Errors introduced to the signals represented in figure 1 by processing through lossy JPEG data compression and decompression. Data processing using the software contributes to the width and height of the error distribution.

4. Rip and Printer

4.1 Experimental Approach

In order to evaluate the noise on the color signal on the paper we have undergone different experiments:

For the experimental investigations a test chart with 1088 color patches was used. The printing experiments were carried out on a four-color sheet-fed offset press, a photocopier (Xerox 5790 mit Splash 5.08 RIP (Software- RIP)) and a printer (Lexmark Color Laser Writer Optra C). Because of the large number of color measurements a system for automatic measurement and data acquisition was developed (see also 6). The color measurements were made using an industrial color measurement instrument (Gretag, SPM 100 II) with an interface which enables a computer to trigger the measurement and collect the data. Samples were measured over a white backing with a measurement aperture of 4mm. The color measurement conditions were: 45 /0 geometry, no polarization. The color density values were computed in the measurement device (status DIN E), and color coordinates were expressed in the CIELAB system with D50 illuminant and 2° standard observer. This system made fast and reliable data acquisition possible. Runs of up to 5000 sheets on three different types of paper were printed, and 50 sheets of each type of paper were used for color measurements.

4.2 Experimental Results

4.2.1 Noise on signal in different areas of the color space

In the experiments it turned out that the shapes, sizes and alignments of the ellipsoids in the color space - they are the factors which characterize the fluctuations between different colors - vary markedly as can be seen in figure 3. Considerable differences are seen, both in the size and in the shape and alignment of the ellipsoids. The fluctuations in primary colors mainly tend towards varying chroma, whereas fluctuations in mixed colors appear more evenly distributed in chroma, in hue and in lightness. The way in which primary colors fluctuate can be plausibly explained by fluctuations in the ink layer thickness and in the dot gain. Fluctuations, therefore, are mainly to be expected between the solid tone and paper white. This can be seen very clearly in the case of yellow, where the ellipses are particularly elongated. However, this shape is also caused by a distortion in the CIELAB color system. The human eye does not perceive differences in chroma in the yellow range as weighted in the CIELAB color system.

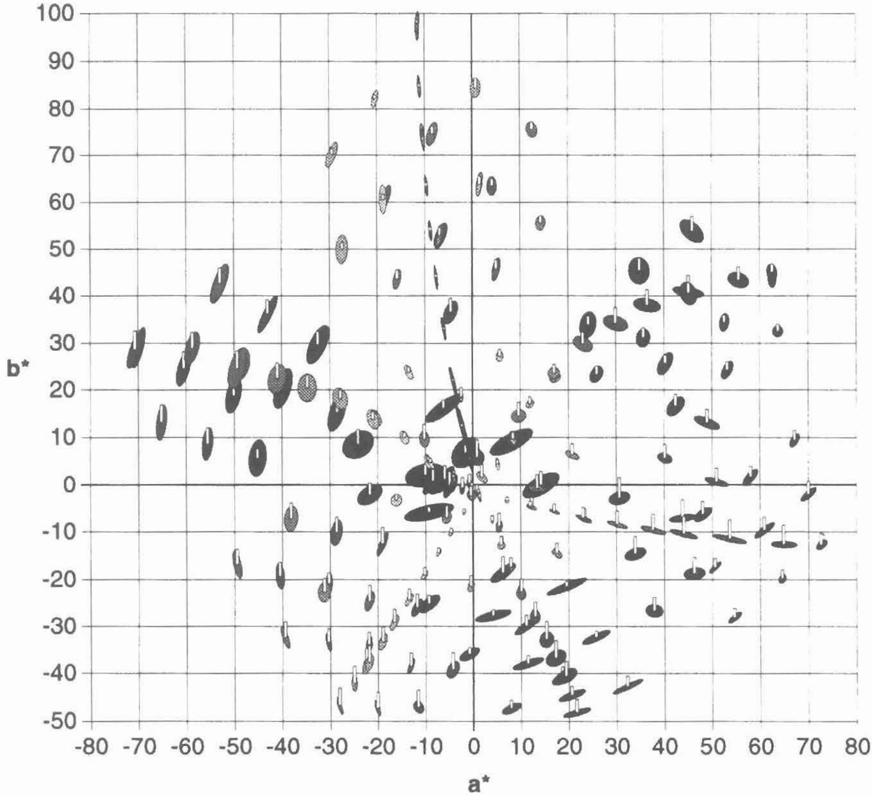

Figure 3: Fluctuation ellipses of color fluctuations in offset print. The largest fluctuation ellipsoid occurs with green when the yellow and cyan dot percentages are 80%. The little columns in the ellipsoids indicate the noise as it is found in the L-direction.

The fluctuation ellipses grow larger as the dot percentage increases. It is clearly apparent that the fluctuations are greater at a dot percentage of 80% than they are in the case of solids. The reason is, that in three-quarter tones, fluctuations in ink-layer thickness occur as well as fluctuations in dot gain.

The primary colors can fluctuate independent of one another. This is why, in the case of secondary colors, the fluctuations do not perform in such a dominant way. As is to be expected, the overall fluctuation of the secondary colors are markedly greater than with the primary colors. The fluctuation ellipses in the ranges of the three secondary colors red, green, and blue show that particularly strong fluctuations in the hue are to be expected here. Between these three secondary colors considerable differences also occur in the shape and alignment of the ellipses. In the case of blue, the ellipses are relatively small and elongated. They show that in the case of blue the fluctuations in hue are mainly to be expected. The largest fluctuation ellipsoid occurs with green when the yellow and cyan dot percentages are 80%.

4.2.2 Random Noise and error propagation

It is known that the density measured in solid and midtones on sheets in offset and rotogravure printing is not constant but varies significantly. Analyzing the data it can be seen that the noise is of random character (7,8) despite there is some structure as to how large the occurring errors are in the different parts of the color space. Analyzing the size of the noise in solid and 80% tones published data indicate that the accuracy depends on the printing method under view and that the noise on the printing signal performs standard deviations of several dE:

Method	Noise
Rotogravure	dE*ab = 3.0
Offset	dE*ab = 5.5

Differentiating between colors may be useful - the solid tone color densities and the dot gains of the four process colors are often used to control production print run. Table 1 shows data for color densities and dot gains at 50 % tonal value, printed on glossy paper, together with the standard deviations which indicate the degree of fluctuation.

Table1: Color densities (D) of solids, dot gains (T) at 50% tonal value and their standard deviations in prints on gloss coated paper (SD).

Color	DMean	T	SD
Cyan	1.41	0.150	0.0102
Magenta	1.29	0.108	0.0120
Yellow	1.34	0.165	0.0100
Black	1.51	0.182	0.0112

The fluctuations in ink density values were lower on matte-coated and uncoated paper than on gloss-coated paper. It is assumed that the lower fluctuation in color density
is related to the fact that, on matte-coated and uncoated papers, ink density is less dependent on ink layer thickness. There is also a greater ink flow on these papers, and this leads to smaller variations.

In order to generate some insight into error propagation throughout the process the signals generated with the scanner, forwarded in a compression and then

were output after the required RIP process. The resulting data are displayed in figure 4.
As can be seen by comparing figure 1,2, and 4 the errors introduced by the output device including the RIP contributes largely to a spreading of the signals and also to the likelihood of errors.

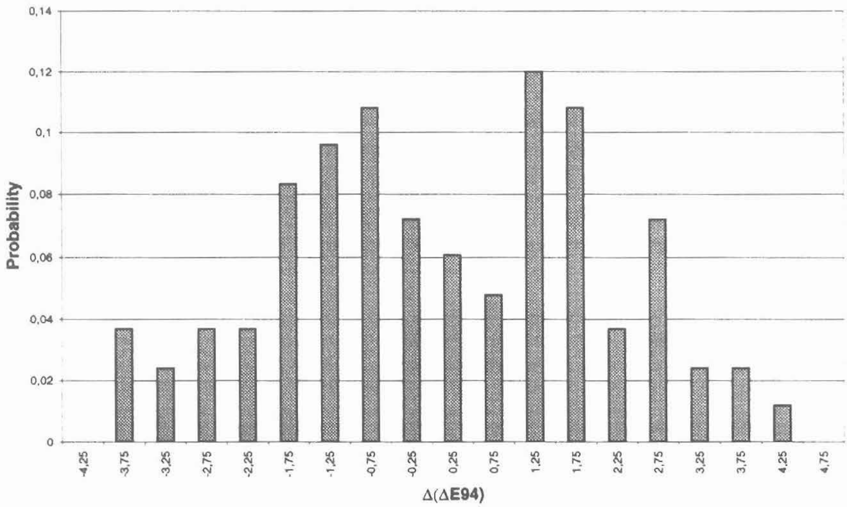

Figure 4: Signal distribution in print (Docucolor 5790 and Splash RIP) following the forwarding of the signal displayed in figures 1 and 2.

If one subtracts the distribution displayed in figure 4 from the one displayed in figure 2 the contribution of the RIP and the printer to the all over error becomes visible. However, as the bitmap produced by the RIP was not accessible a subdivision of the errors introduced by RIP and printers has not been possible.
It may be worthwhile to point out that any discussion on the accuracy of color management systems should consider the influence of unavoidable random color fluctuations which may not be attributed to the color management system but to other process characteristics. (T. Newman (9) recently reported that errors introduced while performing identity-operations using ICC profiles and CMMs (device-pcs-device) in a correct manner depend on the combination of profiles and software and the average error exceeded $\Delta E = 0.5$.)

5. Summary

In this study we evaluate the accuracy of devices and the propagation of errors introduced into the process. It turns out that the change in signals introduced by scanners, software and printers may significantly alter the signal processed. The structure of this alteration is dependent on the area in color space under view. Furthermore the inaccuracy introduced by measuring devices contributes to the ambiguity in color communication.

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