Automatic Color Correction for Ink Cartridge Variations

Chia-Lin (Charlie) Chu, Alp Bayramoglu, and Henry D'Souza
Compaq Computer Corporation
Houston, Texas

Abstract

Typical color management for ink jet printers includes a generic printer profile or a driver for each printer model. In addition to the profile of the specific printing process, it also addresses some parameters, such as printing media, ink types, and rendering intentions. However, it rarely deals with the variations of each individual ink cartridge, unless a profile is built for each ink cartridge at the user level. This is not quite feasible for general users because it requires expensive color measuring instruments and extensive knowledge of color science. The variations of ink cartridges affecting colors can be due to the hue and concentration variations in ink formulations, or the drop size variations in cartridge manufacturing. Test data indicates that the variations in color can be very noticeable from cartridge to cartridge. A novel idea of color management per ink cartridge, which is under investigation, involves characterization of individual ink cartridges at the manufacturing stage, storing condensed characterization data in certain media, retrieving the data upon the cartridge installation, and then building a color correction profile on the fly. This implementation is transparent to the user. The process will be explained in detail and the cartridge variations will be compared before and after the correction.

Introduction

Ever since the advent of ICM2.0 for Windows operation system, color management for color imaging devices has been widespread. These imaging devices include, but are not limited to, monitors, scanners, digital cameras, and printers. Through the implementation of Color Management, consistent color can be achieved among hardware and software components from various manufacturers.

In this paper, we will focus on color management for color ink jet printers. Typical color management for ink jet printers includes a printer profile for handling characteristics of ink colorants and the printing process. Perceptual, saturation, and absolute/relative colorimetric intents are selectable. In addition, a printer driver provides adjustment in color rendering for printing on different media, such as glossy, coated, and plain paper.

However, typical printer profiles and printer drivers provided by manufacturers are generic for each printer model and do not address the different characteristics of each printer, its printing process, and the ink cartridge. A specific printer profile can be built at the user level upon any changes in the printer condition if profiling tools are available and the user possesses a working knowledge of color science. For general users, these resources are beyond their reach and often result dissatisfactory prints.

Among other factors, we have found that the variations of each individual ink cartridge contribute significantly to deviations in print color quality. The variations of ink cartridges affecting colors can be due to variations in hue and concentration in ink formulations, or the drop size and nozzle alignment variations in cartridge manufacturing. From batch to batch, the variations of the colorant can cause hue shift and the variations of the concentration can result in saturation, or density changes. Our test data indicates that the variations in color can be very noticeable from cartridge to cartridge as will be explained in the next section.

We propose a novel idea of color management per ink cartridge, which involves characterizing the ink cartridges individually at the manufacturing level with a simple test target. This characterization data is condensed and stored in certain media. Upon installing a new cartridge by a user, the characterization data are retrieved and the color correction profile is then built on the fly[1]. This implementation is transparent to the user and requires no color measurement instruments.

Although this idea sounds like an overloaded solution, it is actually quite feasible because the characterization of the cartridges only involves a simple manufacturing process in measuring a simple target. The technology for storing and retrieving of small number of data in certain media are available[2], and the reconstruction of the printer profile on the fly is trivial on a modern high speed PC.

Cartridge Variations in Colors

A test was performed to determine if the ink cartridge variation is an important factor in color consistency for ink jet printers. A test chart with a step wedge of seven patches for each of CMY inks is printed with 10 new ink cartridges. All charts were printed, with Color Management turned off, on photo quality paper.

Each new cartridge was installed in the printer, aligned, nozzle cleaned and made sure that there was no blockage.

The test chart was then printed on a sheet of glossy paper. All prints were printed in the same afternoon to minimize variations in temperature and humidity. The prints were then allowed to dry overnight before measuring.

Measurements were made with GretagMacbeth's iProfile system, with a spectrophotometer, Spectrolino on an x-y table, Spectroscan. Spectrolino measures spectral samples from 380nm to 730nm, at every 10nm, with 4.5mm aperture. It checks a calibration white tile every minute or so to compensate for any drifting and achieves 0.03 ΔE and ±0.01D repeatability. Spectral reflectance was recorded and Status T densities were calculated for each of the patches.

The repeatability was verified by measuring the same chart three times and comparing the results to see how consistent the instrument and method is. The result was satisfactory within ±0.01D, confirming the instrument's specifications. For visual evaluation, a few prints containing images were also produced for comparison.

As shown in Figure 1, the density responses of the ten cartridges are quite different. Table 1 summarizes the maximum differences of the densities among the ten cartridges. Density variation among cartridges is up to 0.2D or 22% of the solid ink density and is a significant amount.

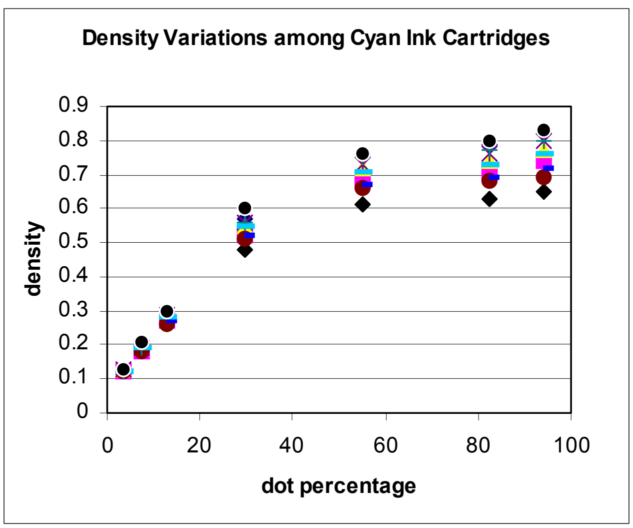

Figure 1. Density variations of the cyan step-wedges among 10 ink cartridges.

Table 1. Density variations among 10 cartridges.

	C	M	Y
Max. density (Dmax)	0.83	1.16	1.44
Max. difference (ΔD)	0.18	0.20	0.18
ΔD / Dmax	22%	17%	13%

Analysis in CIELAB space shows the color variations are mainly in chroma than hue. The maximum hue and chroma differences among the cartridges are 2.28 and 8.14 respectively, indicating that the hue difference is less a problem than that of the chroma, and thus density.

Testing images are printed with each cartridge for visual evaluations. The prints with the extreme cartridges are clearly color imbalanced upon visual inspection by a casual observer. The color imbalance was characterized by neutral patches shifted to brownish hues, red patches shifted to orangish, or the green patches shifted to yellowish. This information indicates that color correction for individual cartridges can be of merit.

Automatic Color Correction

Based on what we have found, we assert that the color variation of ink cartridges is a significant contributing factor to the color variations in printing and should be addressed. Cartridge variations can come from the ink or the printing process. The former can contribute to both hue shift and solid ink density from batch to batch depending on how tight the quality control on mixing inks is in the manufactur-ing stage. The latter can contribute to the density response for various dot percentages, depending on different elements and the process, such as the heater and the nozzles.

However, building printer profile for each ink cartridge installed in the user level is not quite feasible for general users. It requires at an expensive colorimeter, enough knowledge on Color Management and some foundation in Color Science, and at least a few hours' work.

Our proposal is to automate the process by characterizing each ink cartridge at the manufacturing stage. The characterization data can be stored in a certain medium and can be retrieved at the user level. When a new cartridge is installed to the printer, the serial number of the cartridge is fetched from the cartridge memory and the characterization data is then retrieved from certain media, can be the cartridge memory, Internet, or other media. A complete ICC printer profile is then rebuilt or modified depending on the algorithm. The whole process is transparent to the user and requires no color science knowledge or color measuring instrument.

In the laboratory, a generic printer profile is established from the average profiling data of a number of selected "normal behavior" ink cartridges. This generic printer profile will serve as the base profile and will then be updated with the characteristics of each individual cartridge for corrected printer profile without going through the full profiling process.

Then on the manufacturing floor, each cartridge would be used to print a simple linearization chart containing only CMY or even with K and RGB step wedges for cartridge characterization while the cartridges are still on the conveyer. Color patches would then be measured for tri-stimulus values as the cartridge specific color character-istics. These characteristic data would then be used to update the base profile and generate the updated profile for the individual cartridge.

Figure 2 and Table 2 depict the improvement of such updated profile comparing to using the generic profile and without profile at all. The updated profile is indeed showing the promising results. The improvement could be more phenomenal if the cartridge is one of the out of specifications.

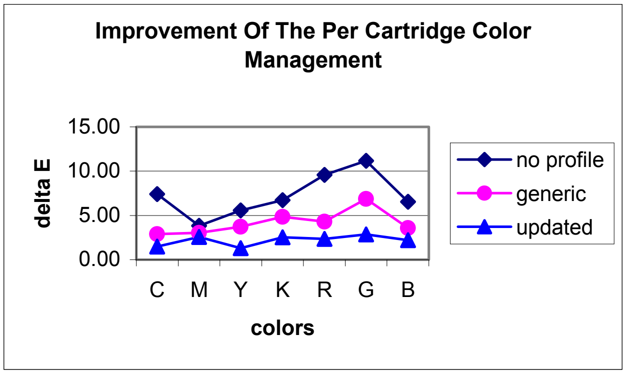

Figure 2. Improvement of the per cartridge color management. The improvement of the updated profile compared to using the generic profile and without a profile. All ΔE are reference to the complete profile for the ink cartridge in question.

Table 2. Improvement of the updated profile. The maximum CIELAB color difference ΔE compared between No profile, Generic profile, Updated profile, and the Complete profile for various patches.

	No profile	Generic	Updated
C	7.40	2.90	1.48
M	3.82	3.02	2.55
Y	5.57	3.73	1.29
K	6.74	4.85	2.52
R	9.58	4.29	2.34
G	11.17	6.87	2.85
B	6.54	3.57	2.22

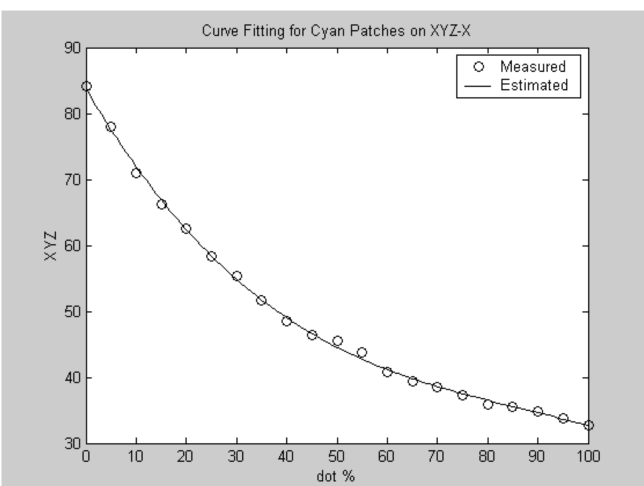

Figure 3. An example of least square curve fitting with third order polynomial.

Table 3. Comparison and calculation of the amount of memory required for various order of least square curve fitting.

order	# coeff	# colors	# channel (XYZ)	# bytes (float)	Memory required	Max. error
3rd	4	7	3	4	336 B	4.32
4th	5	7	3	4	420 B	2.82
5th	6	7	3	4	504 B	1.7

The measured cartridge tri-stimulus data for each cartridge can be compressed and stored in certain media to be fetched at the user level when a new cartridge is installed.

These data can be modeled with a polynomial curve fitting and result coefficients as shown in Figure 3. These coefficients can then be reconstructed to an equation and sampled to the appropriate resolution for the ICC profile.

For the huge quantity of cartridge characteristic data, amount of the memory required is huge, any reduction or compression of the data is desired. Table 3 depicts the memory required and their corresponding errors for three different orders of least-square curve fitting. The higher the order, the less the error will be, but would require more memory. In addition, higher orders would result interpolation than curve fitting eventually!

Comparing to the curve fitting approach, storing the tri-stimulus data point by point with reduced precision as shown in Table 4 can reach an error of 0.3 out of 100 with only 315 bytes when the data is recorded as an unsigned byte. Here the calculation is based on that there are 21 steps for CMYK, and 7 steps for RGB.

Further more, if only the differences of the tri-stimulus compared to the generic tri-stimulus are stored, the memory can be halved, by using a merely 4 bits, with the compromise of 0.5 in error. The only catch is that we are assuming the maximum difference among any cartridge and its generic is within ±7.

Table 4. Comparison and calculation of the amount of memory required for storing characterization data with various data type.

Data type	# bit	#patch	Memory required	Max. error
Floating	32	315	1260 B	0.0
Short	16	315	630 B	0.0
Byte	8	315	315 B	0.3
Delta	4	315	158 B	0.5

Ultimately, The amount of memory can be drastically reduced to 32 bytes per cartridge. After all, only CMY inks are used for all test charts. Density of the primary channel of each ink, rather than all three XYZ values needs to be stored. The tri-stimulus values of the CMY, and even those of the RGB and K patches can then be estimated from the CMY density data with a reasonable inking model.

The characterization data for each cartridge can be stored in a certain media associated with the serial number of the cartridge. The storage can be the memory in the cartridge[2], in the database of the Internet, or other media.

Upon installing a new cartridge in the printer, the serial number can be manually typed in by the user or automatically retrieved by the printer driver if the model of cartridge supports build-in memory on the cartridge. The corresponding characterization data are then retrieved from the designated media. The data would be uncompressed and tri-stimulus data would be reconstructed. The ICC printer profile reflecting the characteristics of the ink cartridge will then be build for better color reproduction.

Discussion

Although the idea of automatic color correction for ink cartridge variations has been presented as in the above section, the actual implementation has not been completed yet. There are many issues that need to be addressed and resolved. These issues include:

- Printing and measuring linearization chart without increasing too much manufacturing processing time,
- Minimal memory size required for each cartridge,
- Good inking model for color estimation,
- Storage of the serial number to each ink cartridge,
- The access to the huge database of cartridge characteristic data

In addition, the characterization data should be collected on at least three most distinctive media types, glossy, coated, and plain paper, since the density responses on these media can be quite different.

Acknowledgement

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References

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Biography

Chia-Lin (Charlie) Chu received his B.S. degree in Physics from National Taiwan Normal University in 1972, M.S. degree in Geophysics from National Central University in 1977, both were in Taiwan, Republic of China, and Ph.D. in Biomedical Engineering from Drexel University, Philadelphia, in 1984. He has worked in various fields, and has been more focused on Color Imaging in recent years. He is a member of IS&T and TAGA.

Alp Bayramoglu received his B.S. degree in Electrical Engineering from Turkish Naval Academy in 1978, M.S. degree in Electrical Engineering from Naval Postgraduate School in 1984 and a Ph.D. in Electrical and Computer Engineering from University of Houston in 1999. Since 1989 he has worked for Compaq managing the development of Display Devices, Color Management and Graphics Cards. He is a member of the IS&T. His research interests are, Color Management, Neural Networks, Motion Detection and Vision Research.

Henry D'Souza received his B.S. degree in Electrical Engineering from Western Michigan University in 1982 and a Masters Degree in Electrical Engineering from Rice University in 1986. Since 1983 he has worked at Texas Instruments, EyeSys Technologies and Compaq Computer Corporation. His work has focused on Digital System Design, Optical Instrumentation and most recently Color Management in Computer Displays. He is a member of the IS&T and SID.