Updating ICC Profiles With Ink Cartridge Characterization Data For Color Inkjet Printers

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Abstract

A novel idea of color management per ink cartridge was previously proposed by us. This paper will describe the implementation details. Ink cartridges of color inkjet printers have been found accountable for the color variations from cartridge to cartridge under otherwise fixed printing conditions. It is not feasible to perform a color characterization and further build a printer profile at the user level for each ink cartridge by general users, due to the requirement of a color measuring instrument and extensive color science knowledge. However, characterizing cartridges at the manufacturing stage with simple procedure is quite achievable. It includes printing a set of simple CMY step wedges, measuring color with a digital camera, and storing away the characterization data associated with the cartridge identification number. The characterization data can be stored in a server and ready for access at the user level through the Internet. Upon installing a new ink cartridge at the user level, a dedicated application software, with minimal user intervention, will retrieve the characterization data, re-build the output LUT, and then update the printer profile, all transparent to the user. This paper will explain how the characterization is done, and how the ICC profile is updated reflecting the characterization of the cartridge.

Introduction

In dealing with the wide variations in the color rendered with different ink cartridges of color inkjet printers, we proposed an innovative idea on automatic color correction for the variations[1]. In the previous paper, we cited a variation as much as 20% peak-to-peak in terms of density measurement of each of the primary colors, i.e., cyan, magenta, and yellow (CMY). This amount of variations often resulted significant color shift from cartridge to cartridge and cannot be ignored.

This color variation is uncontrollable unless each ink cartridge is characterized and a printer profile is re-built. This requires a sophisticated color measuring equipment and extensive color science knowledge, and is not desired for the general users, unless it is for the high-end printers.

To provide a solution for low-end printers, we propose a bold idea to characterize all ink cartridges at the manufacturing floor and make the data available in a form such that when the ink cartridge is installed in a printer, the data can be retrieved and a resident software will re-build a printer profile on the fly to correct for the color variations of the cartridge.

In this paper, we will focus on the algorithms and the implementation details.

ICC Profile

The ideal solution for compensating the density variation of the cartridges is through the printer driver that has the direct control of CMY ink. However, given no direct control, we can only control the RGB levels and rely on the printer driver to render the corresponding changes in CMY. Nevertheless, this indirect approach is quite effective if all active color enhancement features in the driver are disabled.

The most accurate compensation is to re-build a complete printer profile for each ink cartridge. However, the long process for printing a complete test chart and measuring colors is not feasible either at the manufacturing stage or at the user level.

The ICC profile is a standardized Color Management System (CMS) specified by the International Color Consortium.[2] For each type of the color imaging devices in a system, there is a device color profile associated, e.g., monitor profile, scanner profile, printer profile, etc.

The major component in a printer profile is called BtoA0Tag. It is responsible for converting colors from the CIELAB color space to the printer color space. As shown in Figure 1, it includes a 3x3 matrix, a set of tone reproduction curves, a multidimensional lookup table, and a set of linearization curves. Where PCS, stands for Profile Connection Space, is typically CIELAB.

Examining the ICC profile for printers, we found the output LUT in the printer profile was the place that the update can be performed without touching other areas. These 1D LUTs can be used to linearize the RGB/CMY vs. CIELAB values for more efficient and accurate 3D LUT[3]. By updating the output LUTs with the density variations, the effective positions of the grid points in the preceding 3D LUT are modified and the desired color correction can thus be accomplished.

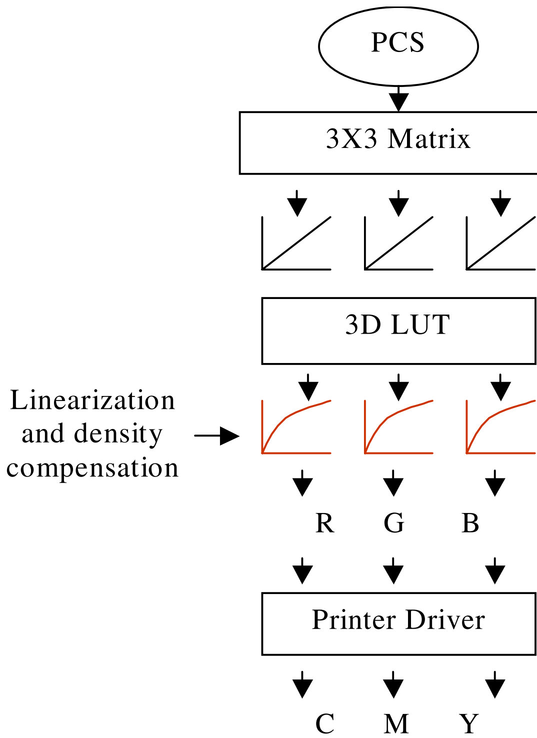

Figure 1. Overall output LUT compensation solution

Methodology

For characterizing the ink cartridges, a set of CMY step wedges as shown in Figure 2 is printed with the cartridge. This chart consists of a color wedge of 21 steps from 0% to 100% dots, 5% incremental for each of the CMY colors. One extra 100% patch at the left edge for each of the colors to clearly mark the boundary of the 0% patches.

Figure 2. CMY color wedges for ink cartridge characterization.

This chart is then placed under a digital camera for density measurement. The raw image is first gone through the following Image Processing steps: uniformity correction, linearity correction, edge detection, image rotation, image cropping, patch size calculation, noise reduction, and density calculation. Image rotation can be eliminated if there is no concern of more than 1° of rotation, which is the case in a manufacturing line.

Density is then calculated with the minus log of the reflectance for each of the primary RGB channel of each of the CMY patches, i.e., red channel for C patches, green for M, and blue for Y. The reflectance is the average value of the processed RGB values over each patch away from the borders. See the next section for the video camera calibration procedures.

The density measurements, or the characteristic data of the specimen cartridge are then compared to those of the reference cartridge, as shown in Figure 3. Where the marks are the density measurements of the primary channel densities for CMY colors at each dot percentage for the specimen cartridge. The curves are the 5th order polynomial curve fitting of the measurements for both of the specimen cartridge and the reference cartridge.

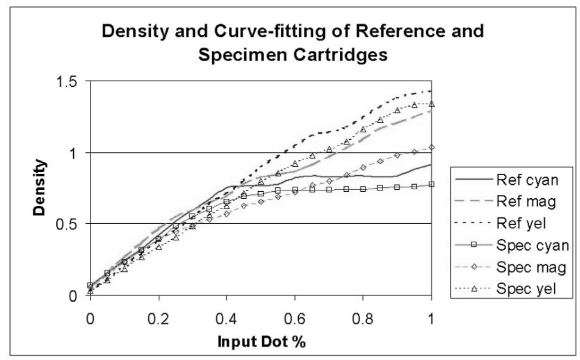

Figure 3. Density and curve-fitting of reference and specimen cartridges

A relationship of the dot percentage between the specimen cartridge and the reference cartridge can be derived as shown in Figure 4. This relationship determines how much ink needs to be compensated for the specimen cartridge in order to match the color of the reference cartridge.

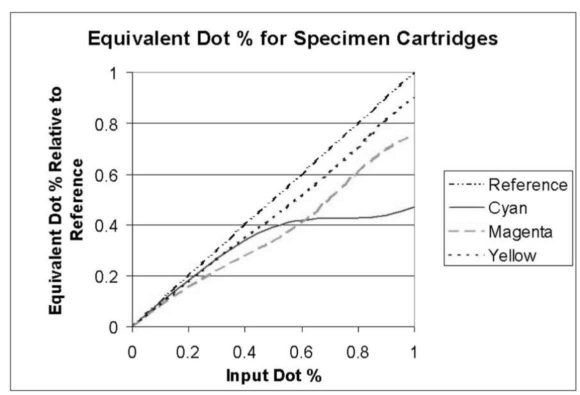

Figure 4. Equivalent dot % for specimen cartridges.

This full compensation, however, resulted a serious over-compensation. An empirical scale factor was then introduced to ease the problem and delivered a satisfactory result. A series of different scale factors ranging from 10% to 40% rendered a series of different degrees of compensation, from under-compensated to over-compensated, in a somewhat linear fashion. The optimal value of the scale factor is around 25%.

Since the printers we are dealing with are RGB printers, a transformation from CMY to RGB is needed. In addition, an inversion transformation, or swapping the x and y-axis needs to be done for an output profile. The final result is shown in Figure 5. This function is finally ready for building the output LUT of the B2A tags, by properly sampling and scaling per ICC's profile specifications.

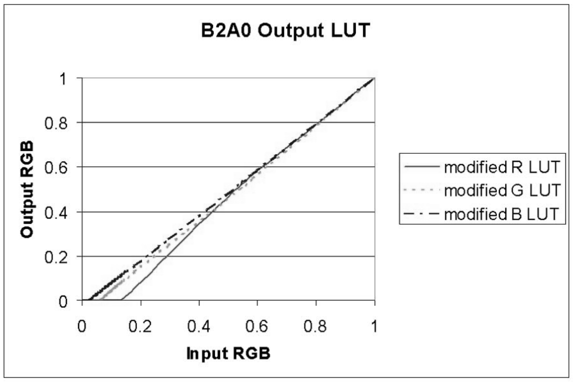

Figure 5. B2A0 output LUT.

Video Camera Setup and Calibration

In order to read consistent densities between the one in the laboratory and those in the field, a standard procedure for setting up the video camera needs to be established. In addition, a calibration procedure for density measurement with the video camera needs to be done to ensure the density consistency from camera to camera.

For the setups of a video camera, the video camera needs to be set for proper exposure, gain, brightness, contrast, white balance, hue, saturation, gamma, etc. for valid data. The rule of thumb is that there should be no pixel value clipped.

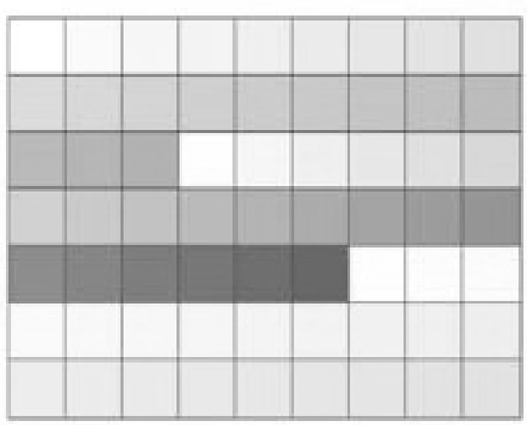

Figure 6. Calibration target.

In order to use the video camera as a densitometer, the video camera needs to be calibrated against a traceable densitometer to compensate for the spectral differences in RGB filter responses. A test target, shown in Figure 6, consists of 21 steps of each of the CMY patches at various dot percentages. This test target is measured by both the video camera and the densitometer for densities. The density values are corrected by calibrating against the Status T density measurements of the calibrated and treaceable densitometer through a low-order polynomial curve fitting.

Implementation

There are three stages in implementing the process: laboratory, manufacturing, and user level.

First of all, a reference cartridge needs to be selected and characterized and a generic printer profile needs to be built at the laboratory.

Then at the manufacturing stage, a set of CMY wedges needs to be printed with each ink cartridge and measured for characteristic densities. The data is stored in a server and then up-loaded to an Internet site in batch.

Then upon a new cartridge is installed at the user level, a resident program will access the Internet to retrieve the characteristic data and calculate for corrective 1D LUT and update the generic profile.

At the Laboratory

In the laboratory, the printing condition, the specifications of a reference cartridge, the setups of a video camera for density measurement, and a generic ICC profile need to be established.

For printing conditions, the photographic paper is chosen as the media for most significant impact; the vivid mode is chosen, as the gamut is larger and more uniform; normal quality is chosen for testing speed.

For the specifications of the reference cartridge, a number of new ink cartridges are used to print a cyan wedge, a magenta wedge, a yellow wedge, and a CMY gray wedge. The candidate cartridge is the one with most neutral gray wedge and well-behaved CMY wedges in terms of density measurement.

The camera is set and calibrated according to the standard procedures described above.

A generic printer profile is then constructed with a typical ICC profiling process, i.e., printing a 9x9x9 CMY mixing test target with the above printer and cartridge, measuring the patches with a x-y colorimeter, launching a profiling software to construct a printer profile. This profile will serve as the generic printer profile for the same model printer.

At the Manufacturing Stage

At the manufacturing stage, all ink cartridges need to be characterized with a simple CMY step wedge. (Fig. 2) This simple and small sample needs to be printed with each cartridge and measured with a video camera for densities.

In order to avoid being a bottleneck, the time for the process should be very short. The pattern and the size of the step wedges are designed to be optimized with the print head, such that a minimum time is required to print such a pattern.

Prior to the characterization, the camera needs to be properly set up and calibrated. The setup and calibration procedures are the same as in the laboratory. The camera is housed in a covered housing for better lighting control. It can be either an analog or digital video camera.

The density data or each patch on the characterization chart is then saved indexing with the serial number of the cartridge and stored in a server. The serial number can be scanned in from the barcode on the cartridge. The characterization data files can then be uploaded to an Internet site periodically for future access.

The overall time for printing, picture taking, data processing, and storage should be no more than two seconds, which should not be a bottleneck in the manufacturing line.

At the User Level

Upon installing a new ink cartridge in the printer, a resident software will be launched to assist the profile updating process. The user will be asked for the type of printer and cartridge, and the serial number. The characterization data will then be retrieved from the Internet, the output 1D LUT of the generic printer profile will be modified based on the characterization data of both of the new cartridge and the reference cartridge. Finally, the printer profile is updated and installed and ready to deliver correct colors.

Discussions

To save the data storage, the characterization data can also be modeled with a polynomial curve-fitting and result coefficients. Further more, these compressed data can be storaged in the memory on the cartridge to simplify the process at the user lever. These coefficients can then be reconstructed to an equation and sampled to the appropriate resolution for the ICC profile.

The same characterization data have been applied to different printer models using the same type ink cartridges and had satisfactory results. A different generic profile needs to be built for each of the different printers, of course, since the printer drivers are different from printer model to printer model.

We also noticed that the density of a given dot percentage patch somewhat depends on the image content. Apparently a color enhancement depending on the image content is controlling the actual dot percentage printed. To achieve a better color correction, this mechanism should be disabled through user selections or even through the driver. If the printer driver is at the disposal, then the color correction should be placed at the last stage to reflect the compensated dot percentage and with no need to disable all the feature functions in the printer driver.

Conclusion

The implementation of a novel idea of color management per ink cartridge was described above. The implementation are in three stages: laboratory, manufacturing, and user. At the laboratory stage, a reference cartridge is established and a generic printer profile is built. At the manufacturing stage, each ink cartridge is characterized for ink density and the data are stored in the server and later uploaded to the Internet. At the user stage, the characterization data of the cartridge is retrieved from the Internet and a new 1D LUT is reconstructed, and an updated printer profile is then completed for satisfactory color rendering.

References

1. Chia-Lin Chu, et. al., Automatic Color Correction For Ink Cartridge Variations, Proc. CIC9, IS&T/SID, pg. 205. (2001)
2. ICC Specifications ICC.1:2001-12, ICC, Reston, VA, 2001.
3. Henry R. Kang, *Color Technology For Electronic Imaging Devices,* SPIE Press, Bellingham, WA, 1997, pg. 87.

Biography

Chia-Lin (Charlie) Chu received his Ph.D. in Biomedical Engineering in 1984 and has since dedicated his career in Image Processing and Color Imaging. He is currently working for Hewlett-Packard Company as a Color Imaging Scientist. Prior to his current job, he was with Quad Tech International in Wisconsin for eight years in the area of color measurement and color control of the printing press. Dr. Chu 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.

Tam Duong received his B.S. degree in Electrical Engineering from Virginia Tech University in 1984. Since 1984 he has worked at IBM and Compaq Computer Corporation as a Software Engineer. He researched, designed, implemented, packaged for all graphic controllers diagnosis, Graphic applications, Coloreal products and tools. He is the main software architect behind the Coloreal Project of Compaq Computer Corporation.