ICC Profile Verification for Digital Printing

Allan Nengsheng Zhang[1,2], Andrew Y C Nee[3], Kamal Youcef-Toumi[4], Wen Feng Lu[1], Winson Lan[2], and Bin Ma[1,2]
[1]Singapore Institute of Manufacturing Technology, Singapore
[2]Kikuze Solutions Pte Ltd, Singapore
[3]National University of Singapore, Singapore
[4]Massachusetts Institute of Technology, Boston, USA

Abstract

Today, the ICC profile is a hot topic in the digital printing industry. However, it may not be as accurate as it should be due to insufficient data to verify that the current level of Color Management Modules (CMMs) compatibility will allow consistent processing of profiles provided by different vendors. ICC recommends a procedure for creation of an ICC profile for a particular printing system. But, it has not provided any standard method for verification of color outputs generated using the profile. This paper aims to address such problems encountered in the digital printing industry. It discusses the key issues for verification of ICC profiles, especially CMYK output profiles, in terms of accuracy and efficiency. The accuracy of an ICC profile can be improved by minimizing the error propagation in the color communication and transformation. A practical method for verification of ICC profiles for digital printing is finally introduced. It is critical for digital printing, especially for Print-On-Demand, due to the time pressure involved.

Introduction

The International Color Consortium (ICC) has published a standard defining the structure of ICC profiles. ICC profiles have been widely accepted in many color imaging software applications and systems. Today, ICC profiles and color management is a hot topic in the digital printing. But just as David McDowell, a standards consultant from a founding member of ICC, pointed out, that it is difficult to describe the role or benefits of color management for any specific user because there are so many different color reproduction workflows.[7] He also identified several key limitations of current ICC color management summarized as follows:

- Regarding CMM definition, there is insufficient data to verify that the current level of CMM compatibility will allow consistent processing of profiles by CMMs provided by different vendors.
- The ICC currently has no specifications or test procedures in place for CMMs.
- As for the reference printing conditions, CMYK output profiles require characterization data for the expected printing process.

Furthermore, ICC proposed a procedure for creation of an ICC profile for a particular printing system. But, it has not provided any standard method for ICC profile assessment. These limitations are the key barriers to greater uptake of ICC color management in the digital printing and publishing industry.

Currently, some manufacturers provide their own calibration functionalities for their digital printing machines, but they have not provided a practical method for verifying colors after calibration of the machines. By outputting several pages of images and color patches printouts after calibration, it is still doubtful if the colors are 'correct' because these outputs are difficult to verify.

The verification of ICC profiles is a complex area involving color science, psychophysics, stochastic process and image analysis. Most recent researches focus on tests and measurements of the accuracy of colorimetric transformation of ICC profiles.[9] The basic subset of an IT8.7/3 chart is printed and measured. A set of CIE Lab measuring values are provided for evaluation of the forward (AtoB tag) and reverse (BtoA tag) transformations of an ICC output profile. The Delta Es are usually calculated based on the two-way transformations. These values are used as metrics to differentiate "good" and "bad" profiles. Evaluation of ICC profiles based only on colorimetric transformation is not enough. The visual judge for appearance of final printouts is critical in most cases.

In this paper, we first briefly discuss color characterizations by emphasizing the nature of Negative Color Comparison, then discuss how to select test targets for evaluating profiles, the propagation of instrumental measuring errors in the profile verification process, and the effects of different color management systems. In the end, we propose a practical method for verifying ICC profiles for digital printing.

Color Characterization

According to Webster's Revised Unabridged Dictionary.[6] color is defined as "a property depending on the relation of light to the eye, by which individual and specific differences in the hues and tints of objects are apprehended in vision; as cool colors, warm colors etc." The sensation of color depends upon a peculiar function of the retina or optic nerve, in consequence of which rays of light produce different effects according to the length of their waves or undulations–waves of a certain length producing the sensation of red, shorter waves green, and those still shorter blue, etc. White, or ordinary, light consists of waves of various lengths so blended as to produce no effect of color, and the color of objects depends upon their power to absorb or reflect a greater or lesser proportion of the rays that fall upon them. Color is a perception of the human eye, it depends on the interaction of three types of cones in the retina - one especially sensitive to red light, another to green light, and a third to blue light.

Color has physical and physiological characteristics. It can be discussed from two perspectives: objective and subjective. In the objective perspective, the phenomenon of color results from the physical interaction of light energy with an object while in the subjective perspective, color is the experience of an individual observer.

The perception of color relies on three elements: the light source, object and observer. Color is the reflection of light. Without light, there is no color. Light is essential in viewing colors. It contains the wavelengths of the electromagnetic spectrum for all colors that are visible to human eyes.

From a scientific viewpoint, an object does not have inherent color. The perception of color is created solely by the reflection of light from an object. These physical characteristics can be established using a color measurement device.

A human observer sees color differently in the context of colors surrounding it. Different lighting conditions will generate different perceptions of colors. Individuals would perceive colors differently even under the same conditions. Light source, environment and experience would also influence color perception. Different observers may view a same color differently in the same environment.

The only way to describe colors clearly is by means of comparison. As a result, the way a particular color is perceived usually differs from the way it can be objectively measured. No matter what kind of measurement technologies used, the results should be consistent with visual assessment because the human eye is the final judge of color.

Choice of Test Targets

Test targets are used as references for verification of ICC profiles. It is desirable to have standard test targets for verification of profiles. Unfortunately, ICC hasn't provided any standard target yet. There are a lot of different designs of test targets used for evaluation of ICC profiles. Most of them are a subset of color patches selected from the IT8 7/3 targets that are shown in Fig. 1. The requirements for test targets for CMYK output profiles are recommended as follows:

1) The target should contain all combinations of solid colors.
2) At least half of the target patches should be different from those used for creating the profile.
3) The target should contain a neural gray ramp from white to black using fine increments. It should be replicated for GCR = none, low, medium, high and maximum.
4) The target should contain a ramp for the primary and secondary colors from white to maximum saturation using fine increments.
5) The target should contain a palette defined by a grid of N device values of 4 dimensions.

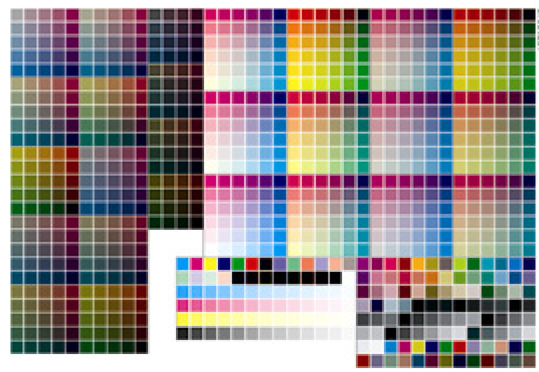

Figure 1. IT8 7/3 Target (ISO 12642)

There are several major issues related to those test targets.

1) Select color targets;
2) Measuring color patches;
3) Visual evaluation of the color patches;
4) Same targets for ICC profile verification from its creation.

Here, we introduce another design of the test target based on the Focoltone Color System (FCS) which is incorporated in most graphic design software like Adobe PhotoShop, Adobe Illustrator, Macromedia Free Hand, and QuarkXpress, CorelDRAW, etc. Figure 2 (a) shows the Calibration Chart which is a pre-printed chart. It has an array of color patches arranged in columns and rows. These are formed based on FCS which uses percentage of colorants C, M, Y and K to define each color patch. For example, color FCS1082 contains 0% of C, 100% of M, 100% of Y, and 25% of K. Thus, each color patch is a combination of the four base colorants to create different colors for each patch. In Fig. 2, there are one hundred and nine color patches on the calibration chart based on the FCS.

The color patches in each column have a single colorant, either C, M, Y or K but with different intensities to create different color effects. For example, the first color patch at the first column in the first row is created using 10% of cyan and no other base colorants. The intensity is increased along the same horizontal row with the next patch formed from 20% of cyan and so on until the 10th patch formed using 100% of cyan. Going down the first column, similarly, the

11th color patch is formed from 10% of magenta and so on until the 20th patch which is formed from 100% of magenta. The same methodology is used to create the different color effects for yellow and black colorants.

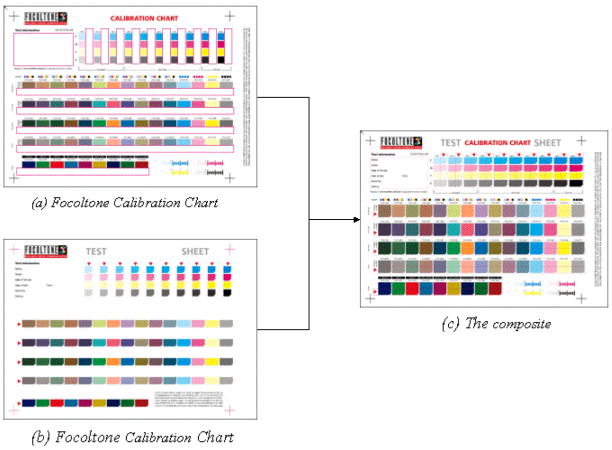

Figure 2. Focoltone Calibration Chart, Focoltone Test Sheet and the Composite

Coming to the five rows in the calibration chart, the intensity of each colorant is fixed but each colorant is turned ON or OFF to create the different color effects along the entire row. For example, the 41st patch is created with 15% cyan, 30% magenta, 50% yellow and 25% black. However, for the 42nd patch, the black colorant is turned off and thus this color patch is formed from 15% cyan, 30% magenta, 50% yellow and 0% of black. These create the fifteen different color patches along the same row with some color patches having two colorants being turned off.

The same principle is used for the subsequent rows to create different color effects for each color patch, for example, the row of color patches from the 56th patch to 70th is formed from permutations of colorants comprising 55% cyan, 65% magenta, 25% yellow and 35% black. The last row contains 9 selected solid colors from the combination of R,G,B,C,M,Y and 25%K.

The calibration chart has a plurality of die-cut rectangular openings arranged beside each column and row. For each column of "single-component" color patches on the calibration chart, a vertical opening is formed beside it. Similarly, for the color patches arranged in a row, there is an elongated opening arranged below it.

The test sheet shown in Fig. (b) is printed on demand by a printer. This has an array of color patches arranged as columns and rows similar to the layout of the calibration chart but the array is offset from the array of color patches in the calibration chart such that when the calibration chart is placed and aligned on the test sheet, the array of color patches on the test sheet can be seen through the respective openings. When the calibration chart and the test sheet are so arranged, a composite shown in Fig. 2 (c) is formed. By viewing the composite, it is easy to detect a set of colors on the test sheet differing from their respective reference colors on Focoltone Color Calibration Chart.

The main advantage of the Focoltone color target is that it can be used both as a test target and for visual evaluation of patches against a reference easily.

Delta E - Color Difference

After test targets have been selected, the next issue is how to quantify the color differences against its reference data. Since the CIELAB color difference model was introduced in 1976, it has been refined many times. The new formulae, which are in widespread use, include CMC, CIE94 and CIEDE2000. They are used for calculating color difference, or Delta E, between two colors L_M a_M b_M and L_R a_R b_R in the CIE Lab color space.

Delta E – CIELAB (or CIE1976): This is the standard CIE color difference based on Euclidean distance in the three-dimensional CIE Lab color space. CIEL*a*b* color space provides a 3-dimentional representation for the perception of color stimuli. If two points in the space, representing two color stimuli, are coincident, then the color difference between the two stimuli is zero. As the distance in space increases, it is reasonable to assume that the perceive color difference between two stimuli represented by the two points increases accordingly. The formula is described as follows:

$$\Delta E = \sqrt{(L_M - L_R)^2 + (a_M - a_R)^2 + (b_M - b_R)^2} \qquad (1)$$

Delta E - CIE94: This is a refined formula based on the above model. The CIE has defined reference conditions under which the new metric with default parameters can be expected to perform well.

Delta E - CMC: This is the method of the color Measurement Committee (CMC). It is a model represented as CMC(l:c) using two parameters l and c. Usually, CMC(1:1) is used for perceptibility and CMC(2:1) for acceptability.

Delta E - CIE DE2000: This is the latest formula for color difference based on CIELAB. It includes not only lightness, chroma and hue weighting functions, but also an interactive term between chroma and hue differences for improving the performance for blue colors and a scaling factor for CIELAB a* scale for improving the performance for gray colors.

It is important to know the differences between Delta E values outputted using the above formulas. The following table (see table 1) shows the different results of Delta E using the above formulas.

Table 1. Different Delta E Values Using CIELAB, CIE94, CMC and CIE DE 2000 Formulae.

Reference			Measured			Delta E			
L	a	b	L	a	B	CIELAB	CIE 94	CMC(1:1)	DE2000
59	-24	-41	47	-20	35	77.05	45.89	44.77	47.53
54	55	-1	50	53	1	4.90	4.19	3.77	4.11
89	-7	71	92	3	67	11.18	5.73	5.90	6.35
39	1	3	45	-1	4	6.40	6.36	7.00	6.21
53	52	22	51	45	29	10.10	5.56	6.45	6.00
53	-44	12	50	-41	11	4.36	3.18	2.97	3.16
37	7	-28	34	5	-20	8.77	4.68	5.31	4.64
72	-16	-26	67	10	12	46.31	30.94	31.84	35.27
68	35	-4	73	28	1	9.95	6.50	5.98	5.64

Color Measurement

Measure Color Itself

ICC profile relies on the Profile Connection Space (PCS), the reference color space in which colors are encoded in order to provide an interface for connecting source and destination transforms. The PCS values constitute an encoding of a CIE colorimetric specification. PCS is based on CIE Lab or CIE XYZ color space. CIE Lab (or CIE XYZ) is determined for a specific observer, relative to a specific illuminant, and measured with a specified measurement geometry, for reflecting media. The simple CIE system does not accommodate the effect of surrounding stimuli to the sample being measured or the level of illumination. Both of these affect appearance so that the PCS values do not by themselves specify appearance. The coordinates in CIE Lab or CIE XYZ are based on the spectral data measured using a color measuring device. The accuracy and reproducibility of measurement values using such devices are very important when building a profile.

Spectrophotometers are widely used for measuring colors. Figure 3 shows a summary of an experiment using three different spectrophotometers to measure five solid colors: White(W), Cyan (C), Magenta (M), Yellow (Y) and Black (K) for three times.[1] The measured values are different using different spectrophotometers. They are also different in different measurements even using the same device.

In general, the measuring value of a color C_i using a device can be represented as follow:

$$C_t = C_i + \varepsilon_{D(i)} + \varepsilon_{E(t)} \qquad (2)$$

where C_t is the measured value for Color C_i, at time t, $\varepsilon_{D(i)}$ represents the systematic error of the device D for the color i in consideration of the sensibility of the device for different colors. And $\varepsilon_{E(t)}$ is the random error caused by environment factors at time t.

Let t = 0 denote the reference measurement of the color C_i, the color distance between the measured value C_t and its reference value is as follow:

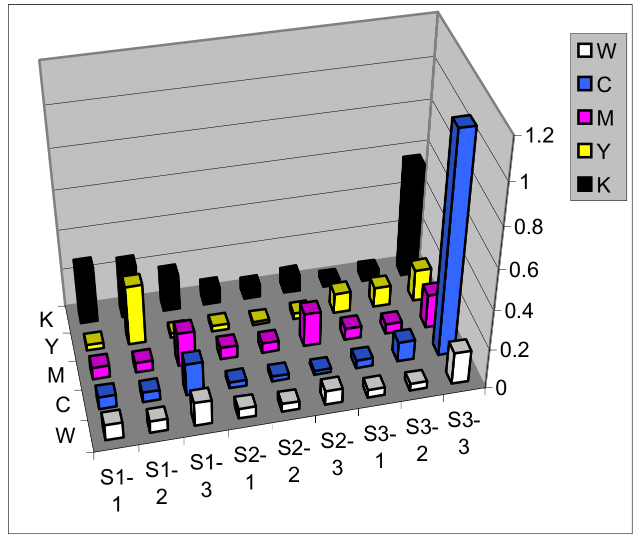

Figure 3. The different measurement values using 3 different spectrophotometers S1,S2 and S3 to measure same solid colors white (W), Cyan (C), Magenta (M), Yellow (Y) and Black (K) in three times. Si-j denotes the jth measurement test using spectrophotometer Si , where i,j =1,2,3.

$$\Delta(C_t^i, C_0^i) = \sqrt{\sum((\varepsilon_{D(t)} - \varepsilon_{D(0)}) + (\varepsilon_{E(t)} - \varepsilon_{E(0)}))^2} \qquad (3)$$

$\varepsilon_{D(i)}$ and $\varepsilon_{E(t)}$ are important factors for such color measurement devices if they are not small enough to be ignored. How to reduce their impact to the results of color measurement is also a challenge.

Measuring the Difference of Colors

Viewing a color involves making comparison from the nature of human vision. Color comparison is a critical step in the color management process. It is a fact that the human eye cannot measure colors accurately but can compare between colors. Two individuals looking at a single color will see it differently. These two individuals looking at two different colors will still see each of them differently but they will see the difference between the two colors with about the same degree of accuracy. In a typical case, the nature of the color is not important. What is important is that the difference between two colors can be seen as identical by the two individuals.

Measuring the color difference emphasizes how to reduce the impact of the color measuring device and the environment factors to the measured values. Based on the Focoltone Test Sheet and Calibration Chart, it is possible to measure color patch and its reference using same device like a scanner at same time to minimize the error propagation of systematic error of a measuring device and the random error caused by different environmental factors. A sample result of color difference is shown in Fig. 4.

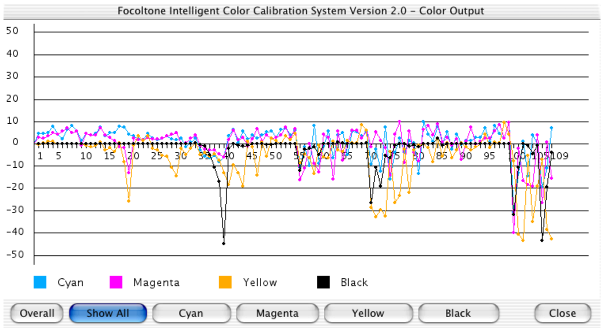

Figure 4. Color differences measured using a scanner

Understanding of Color Transformation

According to ICC profile specification, color devices are broadly divided into three classifications: input, display and output devices. For each color device, there is an ICC profile. Device profiles provide color management systems with the information necessary to convert color data between native device color spaces and device independent color spaces. For each device class, a series of base algorithmic models are described which perform the transformation between color spaces. Each of the base models provides different trade-offs in memory footprint, performance and image quality. The necessary parameter data to implement these models is described in the appropriate tag type descriptions. This required data provides the information for color management module (CMM) to transform color information between native device color spaces. In the paper, we focus on the output profiles, especially, the CMYK printer profiles, which is an N-component LUT Based output profile. A CMYK output profile records the color characteristics of a particular printing machine. The following tags are required for a CMYK output profile.

i) profileDescriptionTag
ii) copyrightTag
iii) mediaWhitePointTag
iv) chromaticAdaptationTag
v) AToB0Tag
vi) AToB1Tag
vii) AToB2Tag
viii) BToA0Tag
ix) BToA1Tag
x) BToA2Tag
xi) gamutTag
xii) colorantTableTag

The first four tags are common for all device profiles while the rest are specially required for output profiles. The AToB and BToA tags are the fundamental elements of the ICC profiles. Each of them contains information that is needed for a color transformation. The "A" denotes the device dependent color space, while the "B" denotes the PCS. The rendering intent is designated by the 0,1,or 2 representing perceptual, related colorimetric or saturation, respectively. For example, the AToB0 tag should be used for A-to-B transformation with the perceptual rendering intent. Profiles generally offer more than one transformation, each of which is applicable to a specific rendering intent. When the intent is selected the appropriate transformation is selected by the color management application. The choice of rendering intent is highly dependent upon the intended use. In general, the perceptual rendering intent is most applicable for the rendering of natural images, though not always. The colorimetric rendering intents operate directly on measured colorimetric values, though possibly with correction for chromatic adaptation when the measured values were not calculated for the D50 PCS illuminant.

In order to investigate the effects of different CMMs to an ICC profile, several CMMs have been tested. Some results shown in table 2. In this experiment, we chose Adobe ACE and Microsoft ICM for comparison. There are two CMYK profiles were used, US. Web Uncoated V2 as source profile and HP Color Laser Jet 9500 CMYK 05/29/03 as the destination

Table 2. Different CMYK Values Generated from Adobe ACE and Microsoft ICM from the Same CMYK Input Values (Cyan and Magenta Ramps).

Input CMYK	Printer CMYK	
	ACE (Adobe)	ICM (Microsoft)
0,0,0,0	0,0,0,0	1,1,1,0
10,0,0,0	12,3,2,0	11,3,2,0
20,0,0,0	19,3,1,0	19,3,1,0
30,0,0,0	28,5,1,0	29,4,1,0
40,0,0,0	36,5,1,0	37,5,1,0
50,0,0,0	45,6,1,0	46,6,0,0
60,0,0,0	54,7,1,0	55,7,1,0
70,0,0,0	63,8,1,0	64,8,0,0
80,0,0,0	73,8,1,0	73,8,1,0
90,0,0,0	83,8,1,0	83,9,0,0
100,0,0,0	94,8,1,0	94,9,1,0
0,10,0,0	0,10,2,0	2,11,2,0
0,20,0,0	4,19,4,0	4,19,4,0
0,30,0,0	4,27,6,0	5,27,5,0
0,40,0,0	5,35,7,0	5,36,7,0
0,50,0,0	6,45,10,0	7,45,10,0
0,60,0,0	7,53,13,0	7,53,13,1
0,70,0,0	8,61,16,0	9,61,17,1
0,80,0,0	9,69,19,1	9,69,20,1
0,90,0,0	9,77,22,1	10,77,23,1
0,100,0,0	10,86,25,1	11,86,26,1

Discussion

The main objective of ICC profile verification is not only to provide an objective benchmark of the profile accuracy, but also to understand the profiles' behavior, and to identify problem areas in order to help edit the profile later. There are two criteria for judging usage of ICC profiles in digital printing: accuracy and efficiency. The accuracy is related to the quality of the profile while the efficiency is related to the verification process. A practical method should balance these two criteria. Here, we propose a method of verification of ICC profiles for digital printing, which can be typically described as follows:

1) Understand your customer's quality preference, different customer may have different color quality demands;
2) Select a set of test targets in addition to Focoltone Test Sheet based on customer's preference;
3) Print the test targets (including Focoltone Test sheet) using a profile under the same conditions used for production;
4) Conduct visual evaluation of colors on the Test Sheet against their reference colors on the Calibration Chart;
5) Scan the composite by placing the calibration chart on the top of test sheet properly. The printed test targets can be measured with a measurement device, if necessary;
6) Analyze color differences in terms of the measured color values and their reference values using the software tools provided by vendors;
7) Evaluate the ICC profile quality based on the metric recommended;
8) Edit/refine the ICC profile and repeat the process, if necessary.

The above method has been implemented in a printing company. The company applied it successfully in the color proofing process to verify ICC profiles for a collaborative project with Hewlett-Packard and a leading design house to print 300 copies of personalized, full-color, offset-quality, 36-page books for journalists who attended the MTV Asia Awards 2004 within 12 hours in the event on 14 Feb 2004.

Conclusion

In general, an ICC profile is a structured record of color characterization data for a color device to communicate color with other devices through PCS. The characterization data are generated based on the measured values of color patches provided. A color management system uses it to predict color outputs. Verification of the ICC profile for a digital printing machining is critical in a digital printing process, especially in Print-On-Demand. A practical repeatable and reliable ICC profile verification methodology is very important in digital printing. Unfortunately, there is not a standard method for verification of ICC profiles now.

In this paper, several issues related to verification of ICC profiles, especially, CMYK output profiles have been discussed. Selection of a test target is important for verifying an ICC profile. Some requirements it should satisfy. Using the same test patches for verification and creation of a profile provides misleading to the users. Different Delta E formula comes out different values for the same inputs. How to interpret those results is also a tough task. The accuracy of an ICC profile depends on error propagation of the measuring device. The systematic and random errors are important for judging the performance of the profile. It is possible to minimize those errors through adoption to measure the differences of colors instead of measuring color itself. While verifying an ICC profile, the different implementation of CMM should be also considered. A practical method for verification of ICC profiles for digital printing is finally discussed. It is critical for digital printing, especially for Print-On-Demand, due to the pressure of time-to-market.

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Biography

Dr. Zhang is Chief Scientist with KiKUZE Solutions Pte. Ltd. He is also a Research Scientist with Singapore Institute of Manufacturing Technology. His research interests include knowledge management, data mining, machine learning, artificial intelligence, computer security, software engineering, software development methodology and standard, intelligent control systems and enterprise information systems. His current research interest focuses on intelligent colour print quality control methodology and applications. He has over 20 years of experience in the research and development of software and has developed many enterprise-wide software solutions for many industries, notably, the financial, engineering, and printing sectors. He is currently leading several collaborative R&D projects with MIT, a local university and a local research institute on color quality control for digital printing. He is a corporate representative of ICC (International Color Consortium) and PODI (Print On Demand Initiative), and a member of IS&T, and ACM.