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Automated CtP Calibration for Offset Printing

– Dot gain compensation, register variation and trapping evaluation

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BIRGIT and DARIUSH

ABSTRACT

Although offset printing has been and still is the most common printing technology for color print productions, its print productions are subject to variations due to environmental and process parameters. Therefore, it is very important to frequently control the print production quality criteria in order to make the process predictable, reproducible and stable. One of the most important parts in a modern industrial offset printing is Computer to Plate (CtP), which exposes the printing plate.

One of the most important quality criteria for printing is to control the dot gain level. Dot gain refers to an important phenomenon that causes the printed elements to appear larger than their reference size sent to the CtP. It is crucial to have the dot gain level within an acceptable range, defined by ISO 12647-2 for offset printing. This is done by dot gain compensation methods in the Raster Image Processor (RIP). Dot gain compensation is however a complicated task in offset printing because of the huge number of parameters affecting dot gain. Another important quality criterion affecting the print quality in offset is the register variation caused by the misplacement of printing sheet in the printing unit. Register variation causes tone value variations, gray balance variation and blurred image details. Trapping is another important print quality criterion that should be measured in an offset printing process. Trapping occurs when the inks in different printing units are printed wet-on-wet in a multi-color offset printing machine. Trapping affects the gray balance and makes the resulting colors of overlapped inks pale.

In this dissertation three different dot gain compensation methods are discussed. The most accurate and efficient dot gain compensation method, which is non-iterative, has been tested, evaluated and applied using many offset printing workflows. To further increase the accuracy of this method, an approach to effectively select the correction points of a RIP with limited number of correction points, has also been proposed. Correction points are the tone values needed to be set in the RIP to define a dot gain compensation curve.

To fulfill the requirement of having the register variation within the allowed range, it has to be measured and quantified. There have been two novel models proposed in this dissertation that determine the register variation value. One of the models is based on spectrophotometry and the other one on densitometry. The proposed methods have been evaluated by comparison to the industrial image processing based register variation model, which is expensive and not available in most printing companies. The results of all models were

comparable, verifying that the proposed models are good alternatives to the image processing based model.

The existing models determining the trapping values are based on densitometric measurements and quantify the trapping effect by a percentage value. In this dissertation, a novel trapping model is proposed that quantifies the trapping effect by a color difference metric, i.e. ΔE_{ab}^* , which is more useful and understandable for print machine operators. The comparison between the proposed trapping model and the existing models has shown very good correlations and verified that the proposed model has a bigger dynamic range. The proposed trapping model has also been extended to take into account the effect of ink penetration and gloss. The extended model has been tested using a high glossy coated paper and the results have shown that the gloss and ink penetration can be neglected for this type of paper.

An automated CtP calibration system for offset printing workflow has been introduced and described in this dissertation. This method is a good solution to generate the needed huge numbers of dot gain compensation curves to have an accurate CtP calibration.

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Chapter 1

INTRODUCTION

Introduction

Background

Aim of the Study

Structure of the Dissertation

1.1 Introduction

This dissertation focuses on an automated CtP calibration system for offset printing workflow. In order to realize such a system a number of models have been introduced and explained in the present dissertation. The necessary concepts and existing models to understand the proposed novel methods are thoroughly described in the dissertation.

1.2 Background

The enormous influence that print had on every aspect of European and modern western culture is very evident. Most of the major shifts in science, politics, religion etc. have occurred after the invention of print. Johannes Gutenberg (~1400 - 1468) from Mainz in Germany known as the inventor of modern print technique invented the moveable lead letter types in the middle of the 15th century.

At the end of the 18th century, Alois Senefeder (1771-1834) invented a printing technique using stone as the image carrier (lithography). The offset printing is the modern and industrial sub-printing-process of lithography. In offset, a printing plate is used as the image carrier. The printing plate has two areas, one image free area uncovered aluminum oxide and one image area with a special coating layer. The image and image free areas are both at the same planographic level. The image free area, which is dampened before the plate is inked, repels the ink. In the offset printing, a compressible rubber blanket covers the so-called offset cylinder, which transfers the ink from the plate into the substrate. The rubber cover of the offset cylinder deforms the printed elements, called mechanical or physical dot gain.

In the modern industrial offset printing, the printing plate has been made by Computer to Plate (CtP) since the end of the 20th century. Offset printing has been and still is the most common printing technology for the print productions. However, the offset print productions are subject to variations due to environmental and process parameters. Therefore, it is very important to frequently control the print production quality criteria in order to make the process predictable, reproducible and stable.

One of the most important quality criteria for printing is to control the dot gain level. Dot gain occurs partly because of the distortions in print and partly because of the diffusion of light in the printing substrate, making the printed elements larger than their reference size sent to the CtP. ISO 12647-2/13 defines the acceptable level of dot gain for standardized offset printing for different printing conditions. In order to print according to ISO recommended tone values, the dot gain has to be compensated, which is also called CtP calibration.

Another important quality criterion making the offset process instable is the register variation, which is caused by the misplacement of printing sheet in the printing unit of an offset printing machine. Register variation causes tone value variations, gray balance variation, blurred image details, etc.

Trapping is another important print quality criterion, occurring when the inks in different printing units are printed wet-on-wet in a multi-color offset printing machine. Trapping affects the gray balance and makes the resulting colors of overlapped inks pale.

Since there are many different parameters, such as printing substrates, inks, dampening solutions, plates, temperature, humidity, etc. affecting the quality of the offset print productions, the dot gain compensation is a complicated task. In practice, some of these parameters are grouped (for example printing substrates) to reduce the number of combinations. This might cause the dot gain to be out of the allowed range. A solution suggested in this dissertation is to use an automated CtP calibration system, which takes into account all combinations of parameters affecting dot gain.

1.3 Aim of the Study

The aim of this study is to develop an automated CtP calibration system for an offset printing workflow. To achieve this aim, first of all, the printing process has to be stable and reproducible, which can be ensured by the print quality control system. In this thesis, register variation and trapping are the two quality criteria that are evaluated and examined. The second important requirement for an automated CtP calibration is to have a non-iterative dot gain compensation method, because an iterative method is time and resource demanding and thereby cannot be included in an automated calibration. The third requirement for an automated CtP calibration system is a networked workflow for controlling and managing the printing process.

1.4 Structure of the Dissertation

This dissertation is written as a monograph composed of 9 chapters.

Chapter 2 introduces the common color fundamental and describes the measurement methods of ink value.

In Chapter 3 the reproduction techniques are briefly described. Furthermore, different printing technologies are introduced with the main focus on the offset printing process and a sheet-fed offset printing machine is briefly explained.

In Chapter 4 selected print quality criteria are described. All selected print quality criteria are important for a stable printing process, which have to be measured to control dot gain while generating a dot gain compensation curve

during a reproducible printing production. Furthermore, in Chapter 4 a summary of the most important part of ISO 12647-2/13 is given.

Chapter 5 presents two novel methods to determine register variation by using densitometry and spectrophotometry tools.

In Chapter 6 a novel spectral method is introduced to determine the ink trapping. Furthermore, the proposed spectral model is expanded to investigate the influences of ink penetration and gloss effect on trapping.

Chapter 7 describes the iterative and non-iterative methods for generating a dot gain compensation curve. Furthermore, a method is described and proposed for an efficient selection of a set of correction points needed to generate a dot gain compensation in a Raster Image Processor with a limited capacity of correction points.

In Chapter 8 a networked workflow is introduced for an automated CtP calibration in an offset printing process. All introduced and described methods and models in Chapter 5, 6, and 7 are required for realizing this automated CtP calibration system.

A summary for the entire thesis is given in Chapter 9. A few points for future work are also briefly suggested in this chapter.

Chapter 2

COLOR FUNDAMENTALS AND COLOR MEASUREMENTS

Color Vision

Additive and Subtractive Color Mixing

Color Matching Functions

Colorimetry and the CIE Color Spaces

Color Measuring Devices

Optical Density

Densitometry Devices

Summary

2.1 Color Vision

The color appearance of objects can occur in two ways: objects which are illuminated with an extraneous light and objects which are self-luminous. Without light no color is visible, hence the color vision is not a purely physical concept like weight or light velocity. Color vision is rather an optical phenomenon. The color vision is an outcome of an impression of interplay between a physical stimulus and the neural system and the brain. With other words the color vision is an impression of a light which the eye detects and the brain processes into the color impression. If the light illuminates a colored object then the object's surface absorbs a part of light, depending on its color. The absorbed light energies transform to the heat energy. The rest of the light will be reflected back from the colored object (Weber, 2006).

Figure 2.1 shows an object illuminated with white light. The colored surface reflects only a part of the light back. The reflections stimulate the light sensitive area of the eye and the brain processes this stimulus to a color sensation.

Figure 2.1: Color perception.

In 1676, Isaac Newton used a prism to decompose the sun light. He believed that the light is a composite of different particles. Figure 2.2 demonstrates a triangular prism which disperses the white light. Longer wavelengths components of light (such as the red light) are diffracted more (a), but refracted less (b) than shorter wavelengths components of the light (such as the violet light). Light is electromagnetic radiation and the human eye can perceive a spectrum of light with a wavelength between about 360 nm and 830 nm. Human color vision can be described in three categories, namely spectral reflectance from an object (physics), color stimulus (eye) and color perception (brain). The reflectance is the light reflected back from an illuminated object. In the human eye there are two kinds of photoreceptors namely rods and cones. The rods are not involved in color vision but cones are. There are three kinds of cones which perceive the red, green and blue light (Sharma, 2003).

Figure 2.2 A triangular prism disperses the white light.

2.2 Additive and Subtractive Color Mixing

There are two color mixing principles. The first one is a system to mix the spectral primary lights found out by Thomas Young in 1827. The primary lights are usually red, green and blue. In this color mixing principle, two or more primary lights are mixed (added) together and the result is a brighter light than any one of the primaries. All three color lights together add up to white light, see Figure 2.3(a). Hence this system is referred to as the additive color mixing system.

Figure 2.3: (a) The additive color mixing system including the primary colors and their mixtures. (b) The subtractive mixing system including the primary colors and their mixtures.

For example, computer monitors or TV screens use additive color mixing for displaying color images. The other color mixing system is subtractive, which is primarily used for the printing of color images. Usually a printing machine prints color images using primary colors (i.e. the printing inks) of the subtractive

color mixing system. The primary colors of subtractive color mixing are cyan, magenta and yellow, which are complementary colors of Red, Green and Blue, respectively. In this system the mixture of two or more primary inks result into a darker color than anyone of the primaries. If all of the primary colors of the subtractive color mixing system are mixed together, then the result will theoretically be black, see Figure 2.3(b).

2.2.1 Color Circle and the Complementary Color

The mixture of two primary colors is a secondary color and the mixture of three primary colors results into a tertiary color. The mixture of two primary colors of a color mixing system results into a primary color of the other color mixing system, see Figure 2.4.

Figure 2.4: (up) The subtractive color mixing of magenta ink and yellow ink results in red which is a primary color for the additive color mixing system. (down) The additive color mixing of the blue and green light results in cyan.

Figure 2.5 shows a color circle containing the primary and secondary colors of both color mixing systems.

Figure 2.5: The color circle and the complementary colors. The symbols (a), (b) and (c) demonstrate the subtractive primary colors, the additive primary colors and the complementary axis, respectively.

In the color circle the counterpart colors are complementary. A color and its complementary part add to white in the additive and to black in the subtractive color mixing system.

2.3 Color Matching Functions

The human visual system is needed to define perception of color, color as stimuli, or the psychophysics of color. As mentioned in Section 2.1, in the human visual system there exist three different types of cones. The cones detect the red, green and blue spectra of the light. Hence the human color vision is based on the perception of these three spectra (red, green and blue). Also the spectrophotometry uses a triple-chromatic system (Schanda, 2007).

Wright (1929) and Guild (1931) investigated methods for specifying the colors at the end of the 1920s. Their investigations were mainly based on experiments and the result was the color matching functions. In 1931, the Commission Internationale d'Eclairage (CIE) conducted experiments to find the color matching functions representing the response from the cones and thereby being able to specify colors based on these functions. The experiment was done by using a test light incident on the half of a bipartite white screen as the sample color. The observers (average observers with normal vision) were asked to match the three visual attributes hue, brightness and saturation of the test light by adjusting three additive primaries R, G and B, which were illuminated on the other half of the screen. The amounts of three additive primaries R, G, B, which determine a color light, are called stimulus values (Klein, 2004). The CIE test was done with different samples for the wavelength band from 380 nm to 780 nm. Figure 2.6 shows the graph of the color matching functions (CMF), i.e. the tri-stimulus functions of $\bar{r}(\lambda)$, $\bar{g}(\lambda)$ and $\bar{b}(\lambda)$.

Figure 2.6: The first set of CIE color matching functions for $\bar{r}(\lambda)$, $\bar{g}(\lambda)$ and $\bar{b}(\lambda)$.

The test was carried out using the monochromatic RGB primaries at 700.0 nm, 546.1 nm and 435.8 nm and was repeated by different observers (Schanda, 2007).

As one can see in Figure 2.6 the color matching of $\bar{r}(\lambda)$ is partly negative, which is not physically correct for definition of colors. Hence the CIE

commission decided to transform the color matching functions to obtain the positive color matching functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ across the visible spectrum, see Figure 2.7 (DIN 5033-2, 1992).

Figure 2.7: CIE second set of color matching functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$.

The relationship between $\bar{r}(\lambda)$, $\bar{g}(\lambda)$, $\bar{b}(\lambda)$ and $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ is given in the CIE publication No. 15 (CIE, 1971; Kang, 1996) and is shown in Equation 2.1 (Hunt, 1998).

$$\begin{bmatrix} \bar{x}(\lambda) \\ \bar{y}(\lambda) \\ \bar{z}(\lambda) \end{bmatrix} = 5.6508 \cdot \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00 & 0.010 & 0.99 \end{bmatrix} \cdot \begin{bmatrix} \bar{r}(\lambda) \\ \bar{g}(\lambda) \\ \bar{b}(\lambda) \end{bmatrix} \quad (2.1)$$

In 1931 the CIE system was introduced based on the 2° standard observer, which means that during the color matching experiment the subjects looked through a hole that allowed them a 2° field of view. In 1931 the CIE believed that all the color-sensing cones of the eye were located within a 2° arc of the fovea, located directly behind the retina in the eye. Figure 2.8 shows the human eye with its fovea region behind the retina in a 2° angle.

Figure 2.8: 2° angle of sight and the observed area at 50 cm distance.

At a distance of 50 cm the viewing field of the fovea is about 1.8 cm in diameter (Klein, 2004). In 1964 the CIE published a set of data for color matching functions with 10° standard observer. The graphic industry always refers to the 2° standard observer, which is also used in this dissertation.

2.4 Colorimetry and the CIE Color Spaces

Spectrophotometry gives a quantitative spectral measurement of the reflection of an illuminated object as a function of wavelength. The measured spectra are a physical description, but colorimetry also implies the human observer and therefore is a science of psychophysics. Colorimetry uses the results of spectrophotometry for the further computation. Furthermore, colorimetry offers solutions to map the colors in a color space to another color space. A color space is a three-dimensional coordinate system in which the color of an object can be specified by its position in the space. An example of a color space is the R, G, B color system. Further examples are the CIEXYZ and CIELAB which are described in the following sections.

2.4.1 CIEXYZ

In 1931, along with the color matching functions, CIE also introduced the CIEXYZ color space. The color matching functions describe the relative sensitivity of light for a standard observer, which results in the XYZ tri-stimulus values.

For describing the color of an object, besides the color matching functions, the object's spectral reflectance and the spectral power distribution (SPD) of the used illuminant are also needed. Figure 2.9 shows the SPD of two CIE standard illuminants A and D₆₅.

Figure 2.9: Spectral power distribution of CIE illuminants A and D₆₅.

A is the SPD of a tungsten filament bulb. The D_{65} demonstrates the SPD of the daily light illuminant with 6,500 Kelvin color temperature. The color temperature is defined as the closest point on the Planckian-locus in a chromaticity diagram. As noticed in Figure 2.9 the illuminant A has a higher level of red than the illuminant D_{65} . Illuminants and light sources are different and should not to be confused. Contrary to an illuminant the SPD of a light source is not defined. For example the sunlight is a light source and its SPD varies during the day. The light sources are not reliably mathematically described and hence not suited for colorimetric characterization. (Konica Minolta, 2011)

Using the color matching functions and a standard illuminant, the CIE tri-stimulus values X, Y and Z can be calculated according to Equations 2.2 to 2.4 (Loos, 1989).

$$X = k \int_{380}^{780} \bar{x}(\lambda) \cdot R(\lambda) \cdot S(\lambda) d\lambda \quad (2.2)$$

$$Y = k \int_{380}^{780} \bar{y}(\lambda) \cdot R(\lambda) \cdot S(\lambda) d\lambda \quad (2.3)$$

$$Z = k \int_{380}^{780} \bar{z}(\lambda) \cdot R(\lambda) \cdot S(\lambda) d\lambda, \quad (2.4)$$

where $R(\lambda)$ and $S(\lambda)$ are the spectral reflectance of the object and the SPD of the illuminant, respectively. $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ are the color matching functions and k is a normalizing factor.

The stimulus value Y is a measure of the luminance or brightness of a color. The factor k is to fit the stimulus Y value to be equal to 100 for a completely white surface (an area that completely reflects all incoming light at different wavelengths), see Equation 2.5.

$$k = \frac{100}{\int_{380}^{780} \bar{y}(\lambda) \cdot S(\lambda) d\lambda} \quad (2.5)$$

A color can be defined by its three tri-stimulus values. The CIE recommended a chromaticity diagram with the chromaticity coordinates x, y and z. The chromaticity coordinates are described in Equations 2.6 to 2.8.

$$x = \frac{X}{X+Y+Z} \quad (2.6)$$

$$y = \frac{Y}{X+Y+Z} \quad (2.7)$$

$$z = \frac{Z}{X+Y+Z} \quad (2.8)$$

Since $x + y + z = 1$, the x and the y values are enough for describing the chromaticity.

Figure 2.10 shows the CIE x - y chromaticity diagram¹. The white area (white point or the achromatic point) shows the area in which the tri-stimulus x and y both equal $1/3$ if the norm light E (equal-energy spectrum) is used. The diagram is curved and looks like a horseshoe, hence sometimes called "horseshoe diagram". All visible and real colors are demonstrated on and inside this curve.

Figure 2.10: CIE x - y chromaticity diagram.

Outside of the curve there are all the radiations with a wavelength outside the human visible wavelength interval like ultraviolet (UV) or infrared (IR). The curved line in the diagram represents the spectral locus. The line between the end of the spectra (connecting $\lambda = 380$ nm to $\lambda = 780$ nm) is known as the purple boundary. The colors at this purple boundary do not appear in monochromatic light. The CIE x - y diagram and CIEXYZ allow to check whether two colors are identical or different. If the colors are different, it is not possible to precisely conclude how different they are perceived by an observer. The reason is that in this system the geometrical distance of colors are not proportional to their visually equidistant (Weber, 2006). Hence the CIEXYZ and the CIE x - y diagram are not really useful for a practical application in the production at a print machine. Therefore different color spaces have been developed to better represent the visually equidistant of human color vision. These types of color

¹ Figure 2.10. is kindly taken from Daniel Nyström's thesis. (Nyström, 2008)

systems are called uniform color systems. The CIELAB is one of the uniform color systems, which is briefly explained in the following subsections.

2.4.2 CIE 1976 $L^*a^*b^*$ (CIELAB)

In 1976, the CIE recommended two perceptually uniform color spaces. The first one was the CIE 1976 $L^*u^*v^*$ (CIELUV) and the second one was the CIE 1976 $L^*a^*b^*$ (CIELAB). Figure 2.11 shows a scheme of the CIELAB color space. There is a lightness axis (L^*) which is scaled from zero (dark) to 100 (bright), a red-green axis (a^*) and a yellow-blue axis (b^*).

Figure 2.11: CIE 1976 $L^*a^*b^*$ (CIELAB) color space.

In the following the CIELAB color space is briefly explained. In the CIE recommendation for CIELAB, there exists a set of mathematically nonlinear functions for the transformation of CIE XYZ tri-stimulus to a uniform-chromaticity-scale color space (Hunt, 1998). Equations 2.9 and 2.10 demonstrate the transformation formula from the CIEXYZ tri-stimulus values to CIELAB.

$$\begin{cases} L^* = 116 \cdot f\left(\frac{Y}{Y_n}\right) - 16 \\ a^* = 500 \cdot \left[f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right) \right] , \\ b^* = 200 \cdot \left[f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right) \right] \end{cases} \quad (2.9)$$

where X_n , Y_n and Z_n are the tri-stimulus values for the reference white point of the illuminant. Function f in Equation 2.9 is defined in Equation 2.10.

$$f(x) = \begin{cases} x^{\frac{1}{3}} & x > 0.008856 \\ 7.787x + \frac{16}{116} & x \leq 0.008856 \end{cases} \quad (2.10)$$

2.4.3 CIE 1976 Color Difference Formula

As mentioned earlier one of the most important reasons for the CIE to create CIELAB was to develop a uniform color space. That means the difference of the $L^*a^*b^*$ values of two different colors correlates to the perceived color difference by a human visual observer. It is worth emphasizing that the CIE 1976 target "to present an absolutely uniform diagram" is not perfectly fulfilled (Simon, 2007).

In 1976, the CIE recommended an equation for computing the color difference between two colors based on their CIELAB values. Equation 2.11 shows the CIE 1976 ΔE_{ab}^* color difference formula.

$$\Delta E_{ab}^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}, \quad (2.11)$$

where ΔE_{ab}^* , ΔL^* , Δa^* and Δb^* denote the color difference value, the difference of the lightness, the difference of red-green value and the difference of the yellow-blue value of two different colors, respectively. As mentioned before, the aim of CIELAB for developing a visually equidistant color space based on human color vision was not completely achieved, especially in the yellow area of this color system (Simon, 2007). However, it is not easy to create a new and perfectly uniform color space. The problem is that the CIELAB color space from 1976 is used in many applications in computer graphics, printing industry, color, ink and pigment formulation, etc., so a change of this color space is almost not practically possible (Simon, 2007). Hence there are a number of other color difference formulas. The target of creating these color difference formulas is to compensate this "little" error. In ISO12647-2/13, besides the CIE 1976 color difference values, the CIE 2000 color difference values are also proposed (just for information and not as a necessary recommendation). The results of this CIE color difference formula correlate more to the human visual perception. However the computation of the CIE 2000 color difference formula is complicated for people working at a printing machine compared to the CIE 1976 color difference formula. All color difference formulas have their pros and cons. The CIE 1976 color difference formula is still the most used model in practice.

Another value for comparing the colors (without taking into account the luminance of their color) is ΔC_{ab}^* , the so-called delta chroma or chroma saturation difference. ΔC_{ab}^* is the distance on the a^*b^* of two colors in the CIELAB color space, see Equation 2.12.

$$\Delta C_{ab}^* = \sqrt{a_1^{*2} + b_1^{*2}} - \sqrt{a_2^{*2} + b_2^{*2}}, \quad (2.12)$$

where the ΔC_{ab}^* is the difference in chroma between two colors and a_1^* , b_1^* , a_2^* , and b_2^* are the CIE a^*b^* values of the first and second color (Kurabo Electronics Division, 2014).

The hue difference is also used to indicate the color difference between two colors. As Equation 2.13 demonstrates the differences in brightness are ignored in this color difference formula.

$$\Delta H_{ab}^* = \sqrt{\Delta a^{*2} + \Delta b^{*2} - \Delta C_{ab}^{*2}}, \quad (2.13)$$

where ΔH_{ab}^* is the hue difference and Δa^* and Δb^* have the same meaning as in Equation 2.11.

2.5 Color Measuring Devices

Color measurement means the measurement of the spectral reflectance and the computation of the tri-stimulus color values. That can be done in two different ways. The first way is using a tri-stimulus colorimeter and the second way is using a spectrophotometer which is more universal and more precise. In the graphic industry using a spectrophotometer is much more common than a tri-stimulus colorimeter. Here the principle of a simple handheld spectrophotometer will be described. A spectrophotometer optically measures the quantity of the spectral radiation. A spectrophotometer involves in principle five components: the light source, the measuring spot and the collecting optic for focusing the light flux, the dispersing system or monochromator, a detector for detection of spectrum and a calculator combined with a display for the presentation of the measuring data (Weber, 2006). In Figure 2.12, (1), (2), (3) and (4) show the light source, the light collector lenses, sample (illuminated and measured with $0^\circ:45^\circ$ geometry) and the monochromator with integrated detector (5) for scanning the dispersed light, respectively. Furthermore a board computer for computing and displaying the diagrams or numerical results is also used, which is shown in Figure 2.12.

Figure 2.12: The simplified principle of a spectrophotometer.

The light source is mainly either a halogen lamp with a tungsten filament or a xenon lamp (Wyszecki & Stiles, 2000). The light from the light source focuses and illuminates the measuring object. Dependent on the surface color of the measuring object a part of the light spectrum from the surface will be reflected back. Depending on the viewing geometry the spectral quantity of the object surface changes. Hence the measuring geometry should be standardized. The two well known bidirectional standard geometries for the reflectance color measurement are the $0^\circ:45^\circ$ and the $45^\circ:0^\circ$. The $0^\circ:45^\circ$ means that the object is illuminated at 0° angle and the reflection is at 45° angle, see Figure 2.13.

Figure 2.13: The standard geometries of the spectrophotometer. Left shows the $0^\circ:45^\circ$ geometry and right $45^\circ:0^\circ$ (also well known as ring geometry).

The reflected light then remits into a monochromator (4 in Figure 2.12). The monochromator disperses the reflected light on a detector (5 in Figure 2.12). Different spectrophotometers could have different characteristics and hence have to be calibrated before usage. During the calibration a correction factor is

calculated. For the calibration an absolute white reference sample is needed. The absolute white reference is usually a piece of pressed powder of barium sulfate (DIN 5033-9, 2004). The device manufacturer saves the spectral reflectance of the reference white sample in the spectrophotometer permanently and delivers the device with the corresponding absolute white reference. The correcting factor of the calibration is the mathematical ratio shown in Equation 2.14 (Loos, 1989).

$$C(\lambda) = \frac{R_{abs}(\lambda)}{R_{meas}(\lambda)}, \quad (2.14)$$

where $C(\lambda)$, $R_{abs}(\lambda)$ and $R_{meas}(\lambda)$ are the calibration correcting factor, the saved original spectral reflectance of the absolute white reference and the measured spectral reflectance during the calibration phase. The correcting factor will thereafter be automatically multiplied with the spectral reflectance being measured.

The CIEXYZ tri-stimulus values are determined by using the spectral reflectance, the spectral power distribution (SPD) of the illumination and the CIE Color-matching functions according to Equations 2.2 to 2.5.

A spectrophotometer measures the spectral reflectance and thereby can compute the CIE tri-stimulus values CIEXYZ and CIE 1976 $L^*u^*v^*$, CIE 1976 $L^*a^*b^*$ (CIELAB) and the color difference value if two samples are to be compared with each other. Furthermore the values can be presented numerically or/and graphically (Schanda, 2007).

2.6 Optical Density

The optical density is a value for the light absorbance of a material. The quantitative measurement of the optical density is called densitometry. The densitometry is commonly used in the graphic industry. In this section the term optical density will be explained and it will be shown that the density value correlates to the thickness of the printed ink. Furthermore, the simplified principle of a densitometer will be explained.

The optical density is the logarithm to the base 10 of the reciprocal of the "general" reflectance factor (DIN 16536-2, 1995). Equation 2.15 shows the mathematical formula for the "general" optical density, where D and R are the "general" optical density and the "general" reflectance factor.

$$D = \log_{10} \frac{1}{R} = -\log_{10} R \quad (2.15)$$

Observe that the "general" density and "general" reflectance are two integrated values hence they are not a function of lambda (wavelength).

Since a printing substrate has its own surface color, the substrate color affects the measuring of the reflectance and thereby the measuring of the ink density. Therefore, for determining the ink density independent of the substrate surface color value a relative reflectance is necessary. The relative reflectance $R_{rel}(\lambda)$ is demonstrated in Equation 2.16 (Heidelberg, 2006).

$$R_{rel}(\lambda) = \frac{R_{sample}(\lambda)}{R_{pap}(\lambda)}, \quad (2.16)$$

where $R_{sample}(\lambda)$ denotes the reflectance of the printed substrate and $R_{pap}(\lambda)$ denotes the reflectance of the unprinted substrate.

Equation 2.17 demonstrates how the "general" relative reflectance factor can be determined.

$$R_{rel} = \frac{\int_{\lambda_1}^{\lambda_2} R_{sample}(\lambda) \cdot S(\lambda) \cdot \eta(\lambda) \cdot \tau(\lambda) \cdot d\lambda}{\int_{\lambda_1}^{\lambda_2} R_{pap}(\lambda) \cdot S(\lambda) \cdot \eta(\lambda) \cdot \tau(\lambda) \cdot d\lambda}, \quad (2.17)$$

where R_{rel} , $R_{sample}(\lambda)$, $R_{pap}(\lambda)$, $S(\lambda)$, $\eta(\lambda)$ and $\tau(\lambda)$ are the "general" relative reflectance factor, the reflectance of sample, the reflectance of unprinted paper, SPD of the illuminant, spectral efficiency of the light detector and the characteristic of spectral transmission of the complementary filter (Helbig, 1993). From now on in this thesis, the terms reflectance factor and density will be used instead of the "general" relative reflectance factor and "general" relative density. For measuring the optical density of the printing process inks, namely cyan, magenta and yellow, their complementary filters have to be used. The complementary filters are transparent subtractive filters red, green and blue color for filtering the reflectance of cyan, magenta and blue inks, respectively (Section 2.2.1). Figure 2.14 demonstrates that a filter only transmits the part of the light of its own color.

2.14: The white light and the transmittance of r, g and b filters.

The corresponding complementary filters have to be used for each process ink. In Section 2.7 the complementary filters are discussed in more detail.

2.6.1 Transmission

In optics there are mainly two phenomena occurring when an object is illuminated (Heidelberg, 2006). First, the light is either specularly or diffusely reflected, meaning that it doesn't pass through the medium/object. Such a medium is called opaque. A part of the light is absorbed depending on the color of the surface of the illuminated object and the rest will be reflected back diffusely. The thrown back part is the reflection (Lübbe, 2012). As mentioned before in the graphic industry, the relative value of reflectance is commonly used (Equation 2.15).

Another effect that might occur is when the light passes through the medium (like a glass or the ink layer). Such objects can be almost completely transparent (like glass) or partly transparent (like an ink layer). Therefore a part of the light is absorbed and the rest of the light is transmitted through the medium. The light crossing through a medium is called transmitted light. Equation 2.18 shows the transmission factor.

$$T(\lambda) = \frac{l_{out}(\lambda)}{l_{in}(\lambda)} \quad (2.18)$$

where $T(\lambda)$ is the transmission factor and $l_{in}(\lambda)$ and $l_{out}(\lambda)$ are the radiation energy of light from the source and the radiation energy of transmitted light through an illuminated object.

2.6.2 Ink Layer and Optical Density

A print machine operator always needs a specific value to control the thickness of the ink layer at a printing machine. Directly measuring or determining the thickness of the ink layer [μm] or the gravimetric ink value [g/cm^2] is difficult and not economically beneficial in practice. A more practical way is to use an indirect value to determine and control the ink amount in a print production. The optical density is such an indirect value, which depends on the pigment concentration and the thickness of an ink layer. The plots shown in Figure 2.15 are the result of an ink mileage test (see Section 6.4.3 for the detailed description of the ink mileage test). As demonstrated in Figure 2.15(a) the reflection factor is reciprocal logarithmic proportional to the gravimetric ink value of a magenta ink (Ink academy, 2013). Figure 2.15(b) demonstrates the optical density curve of the same magenta ink, which clearly shows its dependency on the amount of

the printed ink. The black dashed line shows the working range of the magenta ink whose density is in this example between 0.8 and 1.6.

Figure 2.15: The dependency of the reflection factor and the optical density on the gravimetric ink value.

The working range of an ink is a suitable density range for the print production that a print machine operator chooses to use. For example in the offset printing the working range of magenta is usually from 1.3 to 1.6. Usually the density level of magenta printed on a glossy coated paper is about 1.50 in the offset printing. The needed thickness of an ink in the printing process and thereby its density value mainly depend on the ink properties and the substrates. As seen in Figure 2.15(b), the optical density in the working range is almost linear. Hence the optical density is an easy and useful indirect value to control the ink layer thickness at the printing machines.

2.7 Densitometry Devices

Densitometers and spectrophotometers are commonly used in the graphic industry but for different purposes. While a spectrophotometer is used for measuring the color values of a printed ink (for example in order to compare these values with the CIELAB target), a densitometer is used for measuring the ink density (indirect value to control the ink layer thickness).

A densitometer is an instrument that measures the light absorption of an ink layer or a printing substrate in order to determine their densities. Furthermore different print quality criteria such as tone value, dot gain, trapping, gradual fading of the ink, ghosting, and the printing contrast, can be evaluated and controlled by using a densitometer (Brehm, 2001).

In the following the principle of a densitometer will briefly be explained. In principle, there are six components involved in a densitometer: the light source, the measuring spot and the collecting optic for focusing the light flux, the polarization filters, the complementary filters for printing process inks, a detector and a calculator combined with a display for the presentation of the measuring data (Kipphan, 2001). Although there are some similarities between a densitometer and a spectrophotometer, they are two different devices with two different principles. In Figure 2.16 (1), (2), (3), (4), (5) and (6) show the light source, the light collecting lenses, the polarization filters (crossed), the sample (illuminated and measured with $0^\circ:45^\circ$ geometry), the complementary filters and the detector of the light intensity. Furthermore there are a board computer for computing and a display for showing the numerical results.

2.16: The simplified principle of a densitometer.

Depending on the color of the sample a part of the incoming light spectrum will be reflected and reach the light collecting lenses. The light then passes through a complementary filter. In the following example the role of complementary filters in a densitometer is described and clarified. Assume that a thin cyan ink printed on a substrate is illuminated with a white light source (Figure 2.17). The cyan ink layer absorbs a part of the red component of the white light and the printing substrate reflects the rest. Please observe that a thin cyan ink layer appears as a bright cyan because a part of the red light will not be absorbed in the thin cyan ink layer. Therefore the cyan appears bright because in that case a part of the white light ($R+G+B \Rightarrow$ white light) is still reflected. The thicker the cyan ink layer is the more the red light is being absorbed. As shown in Figure 2.17, the blue and green part of the light will be reflected from the cyan ink layer, which are additively mixed to create cyan. As mentioned before, the complementary filter of cyan is red which absorbs the cyan (green + blue) part

of the reflected light. Then, the red part of the reflected light is passed through the red filter and can be detected. The detector is a light sensitive sensor.

2.17: The principle of additive color mixing of the incoming light and the subtractive color mixing of the cyan ink layer (4) and the subtractive color mixing through the red complementary filter.

Therefore, the thicker the cyan ink layer is the less the red light is included into the reflectance of the cyan ink layer. In other words, small red light means a small transmittance through the red filter on the detector (6 in Figure 2.17), which means that the detected signal will be smaller. The analog detected signal is then converted to a digital one (A/D in Figure 2.16). A calculator computes the density from the detected reflected light and displays it. According to Equation 2.15 the ink density is the negative logarithm to the base 10 of reflectance. Hence the thicker the printed cyan ink layer the smaller the detected signal of red light and the bigger the calculated density value of the cyan ink.

The density range of a reflectance densitometer is mostly between zero and 2 (with highly pigmented ink also possible between 1.7 and 2.6), where zero means the relative density of the unprinted substrate. Even different densitometers but identically constructed can measure differently. A slope calibration is therefore recommended to reduce the individual error of the densitometers. The slope calibration uses a calibration card which is measured by the manufacturer of the densitometry device.

It is worth mentioning that parallel to the "conventional densitometers with physical complementary filters" there also exist spectral densitometers. A spectral densitometer contains spectral complementary filters instead of physical material filters. Such a spectral densitometer has a spectrophotometer and measures the spectrum of the color reflectance (Weber, 2006). Figure 2.18(a) and 2.18(b) show the plot of the spectrum of a cyan printed ink and the spectrum of the standard CIE-A illuminant with respect to wavelength.

2.18: Spectral reflectance, SPD of illuminant A, spectral complementary filters and the spectral filtered reflectance.

Figure 2.18(c) demonstrates the spectral complementary filters for cyan, yellow and magenta. Zero means that the filter completely absorbs the light, so there is no transmission and 1 means a complete transmission. The characteristics of such filters are described in more detail in DIN 16536-2 (1995). Figure 2.18(d) shows the filtered spectrum of the cyan illuminated by CIE-A after going through the filters shown in Figure 2.18(c). As can be observed the level of the filtered cyan reflectance in the red region is the lowest. Hence the density value for cyan (called main density of cyan) is higher than the magenta and the yellow density (called side density of cyan).

2.8 Summary

The color vision is an outcome of an impression of interplay between a physical stimulus and the neural system and the brain. In order to give a psychophysical definition of colors the knowledge about how the human visual system works is necessary. At the end of the 1920s Wright and Guild investigated methods for specifying the colors. In 1931, the Commission Internationale d'Eclairage (CIE) conducted experiments to find the color matching functions representing the response from the cones and thereby being able to specify colors based on these functions.

A color space is a three-dimensional coordinate system in which the color of an object can be specified by its position in the space. CIELAB is a uniform color space, which has a lightness axis (L^*), which is scaled from zero (dark) to 100 (bright), a red-green axis (a^*) and a yellow-blue axis (b^*). In 1976, the CIE recommended an equation for computing the color difference (ΔE_{ab}^*) between two colors based on their CIELAB values. A spectrophotometer optically measures the quantity of the spectral radiation. In graphic industry it is used for the measurement of the tri-stimulus color values and the further computation of CIELAB.

The optical density, a value for the light absorbance of a material, is an indirect value, which depends on the thickness of the ink layer. A densitometer is an instrument that measures the light absorption of an ink layer or a printing substrate in order to determine their densities. Different print quality criteria such as density value, tone value, dot gain, trapping, gradual fading of the ink, ghosting, and the printing contrast, can also be evaluated and controlled by using a densitometer.

Densitometers and spectrophotometers are commonly used in the graphic industry but for different tasks. While a spectrophotometer is used for measuring the color values of a printed ink (for example in order to compare these values with the CIELAB target), a densitometer is used for measuring the ink density.

In the next chapter the fundamentals of reproduction techniques are briefly described. Furthermore, different printing technologies are introduced with the main focus on the offset printing process.

Chapter 3

REPRODUCTION TECHNIQUES AND PRINTING PROCESS

Halftoning

Color Reproduction Models

Printing Technologies

Offset Printing Process

Offset Printing Machine

Summary

"More than gold, it's lead that changed the world, and more than the lead in a gun, it was the lead in the typesetter's (printer's) case" (Georg Christoph Lichtenberg, 1742-1799). Johannes Gutenberg (birthname: Johannes Gensfleisch von Sorgenloch) invented the movable type (the principle of letterpress printing) in 1450. This principle was known in China long ago, but the global knowledge of print technique occurred after Gutenberg's invention in Europe. Since Gutenberg's invention different printing technologies have been developed which will briefly be introduced in Section 3.3.

Most printing productions pass through three technical departments, namely prepress, press and postpress. Figure 3.1 demonstrates these three typical departments of a classical printing company and their tasks.

Figure 3.1: Three technical departments of a classic printing company.

In the graphic industry, the applied techniques in the prepress are called reproduction techniques. In the prepress department, devices and software such as scanners or digital cameras (including software) for image capturing and color correction and raster graphic editor programs (e.g. Photoshop) are used (Kipphan, 2001). All the needed data for a print production (i.e. photos, scans, graphics and texts) have to be collected, prepared, produced and processed. The prepared and proceeded data are set in a layout and imposition program. The printing jobs must be rasterised (halftoned) before the printing plate is exposed. Finally a hard proof will be printed (usually by a calibrated digital printer for example Inkjet) and, if everything is alright, then the printing plates will be exposed. An alternative to the hard proof is the soft proof (Fejfar, and et al., 2001). Contrary to the hard proof the soft proof uses only a color calibrated screen. The used technique for rasterizing is called halftoning, which will be briefly described in Section 3.1.

The press department then prints the halftone data digitally or from a physical image carrier (printing plate) via ink on the printing substrate. If the halftone data is printed digitally, then there will be no need for a printing plate and proof.

After the printing, if necessary, the printed products are finished. Books and brochures are examples of products which have to be finished after printing. The finishing is done in the postpress department (Teschner, 2010).

3.1 Halftoning

As mentioned before an image has to be halftoned before being printed. In the past, the printing contents were mainly analogously halftoned until the beginning of the 1980s. Between the 1980s and 1990s the desktop publishing system was developed. This development had influence on the prepress techniques and gradually the classic analog prepress and of course the halftoning techniques changed into digital. The digital prepress and digital halftoning have great economical and technical benefits compared to the analog prepress. Therefore, the domination of the digital prepress was intensified from the beginning of the 1990s, and today the printing contents are mainly digitally halftoned.

The digital information, such as digital images, can be produced by scanning continuous tone images (or photos) or directly by a digital camera. Digital images have an image resolution which depends on the resolution of the image capturing devices. For example if a scanner scans an image with 300 pixel per inch (ppi), it means that for each direction (horizontal or vertical) the image includes 300 pixels within each inch. A scanner or a digital camera produces a color or monochrome (grayscale) image. A grayscale image is an image in which each pixel holds a value representing a discrete gray level (grayscale). The number of possible grayscales of a digital pixel (or an image) depends on the digital production and the digital storing of its data. Nowadays, the grayscale images are produced and stored mostly by a minimum of eight bits. That means, eight bits per pixel can include 256 gray levels, from white (0 or 255) to black (255 or 0). The digital color images, scanned by a scanner or captured by a camera, usually consists of three color channels, namely Red, Green and Blue. Every color channel with eight bits per pixel contains 256 levels. That means a three channel image can contain $(2^8)^3 \approx 16.8$ million different colors.

Obviously, it is not possible to print an image containing so many different colors directly in a printing device, because a printing device has a limited number of printing units and thus only a limited number of color inks can be printed. Normally a four color printing device is used for color productions. In a printing device like an offset printing machine or a digital printing device (with single-bit technique) each printing unit can only produce two levels, (0) for white or no print and (1) for the inked dot. Hence the printing data with 256 gray levels cannot be printed directly and have to be prepared before printing. Halftoning techniques transform the original image with a high number of gray levels into a binary (bi-level) image. Halftoning is also referred to as

rasterisation and even screening in the literature and graphic and printing industries.

The conventional halftoning techniques use a halftone cell which consists of micro dots. The number of micro dots within a cell decides the maximum number of the gray levels that can be represented by the halftone cell. In a conventionally halftoned image the fractional area covered by a dot in the halftone cell represents the gray level at the same position in the original image. Figure 3.2 shows an image being conventionally halftoned. If the halftone dots are small enough, the human eye will not perceive the dot patterns (Gooran and Yang, 2015).

Figure 3.2: (a) the enlargement of a part of the image, (b) shows a halftone image (print resolution: 600 dpi and screen frequency: 50 lpi).

3.1.1 Gray Level

As mentioned in the introduction of this section, conventional halftoning techniques use halftone cells to reproduce different gray levels. Each halftone cell includes a number of micro dots which can be either white (zero) or inked (one). The number of the possible representable gray tones (or levels) of the halftone cells and thereby the halftone image depend on the number of micro dots within each halftone cell. As mentioned before the fractional area in the halftone cells should correspond to the gray tone of the corresponding region of the original image. Figure 3.3 shows three 16 x 16 halftone cells, each including 256 one-bit micro dots. The halftone cells in Figure 3.3 (a), (b) and (c) represent the gray tones of $16/256=0.0625$, $176/256=0.6875$ and $240/256=0.9375$, respectively (Gooran and Yang, 2015).

Figure 3.3: Three halftone cells representing three different gray levels. (a) Light area (16/256). (b) 3/4-tone or shadow area (176/256). (c) Dark area (240/256).

3.1.2 Screen Frequency

Beside the possible representable numbers of gray levels of a halftone image the screen resolution or the screen frequency is also very important for the quality of the printed images. The screen frequency is the number of halftone cells within an inch in horizontal or vertical direction. The screen frequency is usually defined by the number of lines per inch (lpi) and sometimes by the number of lines per centimeter (Gooran and Yang, 2015). The higher the frequency of the screening is the better the details of an image are reproduced. Figure 3.4 demonstrates an image conventionally halftoned and printed using two different screen frequencies, namely 50 and 25 lpi.

The ISO 12647-2/13 is a standard for the printing quality of the offset printing and it is the most important ISO for the graphic industry. It recommends that the screen frequency for offset printing with AM screens (Section 3.1.4) on coated paper should be between 120 lpi and 200 lpi and for uncoated paper 120 lpi and 175 lpi (ISO 12647-2/13, 2013).

Figure 3.4: Two halftone images printed using two different screening frequencies, (a) 50 lpi and (b) 25 lpi (imaging resolution (a) 600 dpi and (b) 300 dpi).

3.1.3 Print and Imaging Resolution

The print, imaging or exposure resolution is the resolution of a digital printer or a Computer to Plate (CtP) device. It corresponds to the number of micro dots per inch in horizontal or vertical direction. Both the possible representable numbers of gray levels and the screen frequency have direct influence on the needed imaging (or print) resolution (Gooran and Yang, 2015). Equation 3.1 shows the relationship between the needed imaging resolution, the number of representable gray levels and the screen frequency.

$$IR = \sqrt{PRNOGL - 1} \cdot SF, \quad (3.1)$$

where IR, PRNOGL and SF are the needed print/imaging resolution for a digital printer (or the exposure resolution for a CtP) in dots per inch (dpi), the possible representable numbers of gray levels and the screen frequency in lpi.

Figure 3.5 shows the relationship between the needed resolution for the exposure of the printing plates, the possible representable numbers of gray levels and the screen frequency. The red dashed line embodies 256 possible gray levels which is standard in the graphic industry. The different colored curves demonstrate the different screen frequency from 86 to 305 lpi. The ISO 12647-2/13 recommends that the resolution of the plate setter (imaging resolution) should

be selected such that at least 150 gray levels are produced (ISO 12647-2/13, 2013).

Figure 3.5: An image setter needs higher exposure resolution if the chosen screen frequency or the number of gray levels increase.

3.1.4 AM and FM Halftoning

There are two main types of halftoning methods, namely Amplitude Modulated (AM) and Frequency Modulated (FM). It is worth mentioning that AM and FM halftoning are sometimes called conventional and stochastic halftoning, respectively. Although these terms are not the completely correct terms to call AM and FM, they are used in some literature and documents. AM halftoning is the method partly explained in the previous sections. The AM method uses a regular grid with constant spatial frequency while the size of dots (amplitude) within the halftone cells varies. The FM method, on the other hand, uses dots with the constant size and shape while the number of micro dots (frequency) in the halftone cells vary (Gooran, 2001). Figure 3.6 shows two different halftone cells for the FM and two different halftone cells for the AM halftoning technique; (a) and (c) demonstrate the gray level 4/64 and (b) and (d) 16/64 of an AM and FM halftone cell (Gooran and Yang, 2015). It is worth mentioning that FM halftoning techniques generally do not use a halftone cell. Hence the term lpi is not used for the modern and commonly used FM halftoning techniques. The only term used in this type of halftoning techniques is print (or exposure) resolution. Hence, the size of micro dot (e.g. 20 μm or 30 μm) plays an important role in print quality. The ISO 12647-2/13 recommendation for printing with FM screens is as follows: the dot size for coated paper should be between 20 μm (corresponding to 1270 dpi) and 30 μm (847 dpi) and for uncoated paper between 30 μm and 40 μm (635 dpi) (ISO 12647-2/13, 2013).

Figure 3.6: (a) and (b) are two AM cells and (c) and (d) are two FM cells.

The AM halftoning technique is much older than FM. Although, FM halftoning has a lot of advantages compared to AM, in offset printing AM halftoning still dominates. One important reason for FM halftoning not dominating in the offset printing process is the challenges such as FM's larger dot gain (Section 4.2.4) or more tone value variation (Section 4.2.3.1) compared to AM. Unlike offset, FM halftoning dominates in some types of digital printing (especially in Inkjet). The AM and FM halftoning techniques have their own advantages and disadvantages. The first advantage of FM versus AM is the fact that the commonly used FM has no regular grid. This avoids the moiré effect. The moiré effects are visually disturbing patterns that occur when viewing a set of dots that are superimposed on another set of lines or dots (Weber, 2006). Moiré is typical for AM halftoning. The second advantage of FM versus AM is the better reproduction of details, especially if the imaging resolution is low.

Figure 3.7 shows two images (a) and (b) halftoned with an AM on the right side and with a FM technique on the left side. Both image parts are halftoned with the same imaging resolution (a) 600 dpi and (b) 300 dpi. The screen frequency for the AM parts are for (a) 50 lpi and for (b) 25 lpi. The FM part reproduces the details better compared to AM, especially in the image printed at the lower resolution. For FM halftoning these images Photoshop's diffusion-dither has been used. The disadvantages of FM halftoning for the offset printing are that the dot gain is relatively high and the reproducibility for repeating jobs is difficult. In addition, an AM halftone leads to better reproduction for parts of an image where the tones vary smoothly, leading to more homogenous reproduction compared to a FM technique (Simon, 2007).

Figure 3.7: The left part of each image is FM and the right part is AM halftoned. The print resolution for (a) is 600 dpi and for (b) 300 dpi.

There is an alternative halftoning method to the pure AM or the pure FM halftoning technique, namely the Hybrid halftoning technique. The Hybrid AM-FM halftoning has the aim to combine the advantages of both halftoning techniques. That means using the advantages of the FM technique for the details of the original image and the AM in the homogenous parts (Gooran, 2005).

3.2 Color Reproduction Models

There are a large number of devices that can be used for color reproduction. Monitors, proof devices, digital printers and conventional offset printing machines are all reproduction devices. Each reproduction device can reproduce a specific amount of colors which is known as the color gamut of the reproduction device. Monitors usually have a bigger color gamut than an offset printing machine. This means that there might be colors that can be reproduced by a monitor but cannot be correctly printed using an offset machine. Therefore, these different color gamuts have to be matched. As mentioned in Chapter 2, there are two color mixing strategies, namely additive and subtractive. The additive color mixing uses the RGB color lights as primaries and the subtractive uses the CMY color inks as the primary colors (Section 2.2). For example, scanners, digital cameras, and monitors work in RGB color space and the print machines usually work in CMYK color space. Different color reproduction models are therefore developed to match and compensate these differences for a reproducible printing workflow (Gooran and Yang, 2015). Important tasks of

the color reproduction are predicting, separating, controlling and reproducing the colors from the beginning (scanning or digital photography) to the end of the printing process (printing). In this section two well known color reproduction models that are used in this thesis are discussed.

3.2.1 Murray-Davies Model

The Murray-Davies model is a monochrome reproduction model. In this model it is assumed that the reflectance of a printed halftone area (or patch) is equal to the sum of the reflectance of the inked and non-inked areas. Equation 3.2 demonstrates Murray-Davies model.

$$R_{\text{screen}} = a \cdot R_{\text{solid}} + (1 - a) \cdot R_{\text{pap}}, \quad (3.2)$$

where R_{screen} , R_{solid} , R_{pap} and a are the total reflectance of a printed halftone patch, the reflectance of the inked (printed) area, the reflectance of the non-inked (unprinted) area and the fractional area of the ink in the halftone patch.

Figure 3.8 shows an example for the Murray-Davies' model. The total light reflectance of a printed halftone patch with 25% coverage is equal to the sum of the reflectance of the printed fractional area ($0.5^2 \cdot 1 = 0.25$) and the reflectance of the unprinted fractional area ($(1 - 0.5^2) \cdot 1 = 0.75$) of the same patch.

Figure 3.8: An example; the printed fractional area is 0.25 and the reflectance of the unprinted fractional area is 0.75.

Equation 3.2 can be modified to determine the fractional area of a printed halftone patch, if the optical dot gain (Section 4.2.4) is neglected, see Equation 3.3.

$$a = \frac{R_{\text{pap}} - R_{\text{screen}}}{R_{\text{pap}} - R_{\text{solid}}} \quad (3.3)$$

Since the relative reflectance of the unprinted paper is equal to 1, Equation 2.14 can be rewritten as shown in Equation 3.4.

$$a = \frac{1-10^{-D_{screen}}}{1-10^{-D_{solid}}}, \quad (3.4)$$

where a , D_{screen} and D_{solid} are the fractional area of a printed halftone patch (or the printed tone value), the density of the printed halftone patch and the density of the printed solid patch. Equation 3.4 is very common in the graphic industry. As can be observed, a densitometer and three patches, namely solid, screen and unprinted patches, are needed for using this formula to calculate the fractional area of the printed patch (Kang, 1997).

3.2.2 Neugebauer Model

Hans E. J. Neugebauer-Charlottenburg expanded Murray-Davies' monochrome reproduction model into a multi-color one. In 1937, he published his work with the title: "Color reproduction model for the multi-color printing" in the Journal for the scientific photography (Neugebauer, 1937).

In his model, the total reflectance of a printed patch is approximated by the sum of reflectance of each involved Neugebauer primaries. For example, for three color printing (CMY) there are eight Neugebauer primaries: unprinted substrate, cyan, magenta, yellow, red (magenta and yellow), green (cyan and yellow), blue (cyan and magenta) and black (cyan, magenta and yellow). Equation 3.5 shows Neugebauer's equation.

$$R(\lambda) = \sum_i a_i \cdot R_i(\lambda), \quad \sum_i a_i = 1, \quad (3.5)$$

where $R(\lambda)$, i , a_i and $R_i(\lambda)$ denote the reflectance of the color patch or main reflectance, i -th printed ink, the fractional coverage and spectral reflectance of each ink.

3.3 Printing Technologies

The conventional printing process reproduces the information from a physical image carrier. Conventional printing is a process in which the ink is transferred from an image carrier or plate onto a printing substrate. This printing process is also known as impact printing. Parallel to the conventional printing process digital printing also exists. In digital printing the halftone information are directly transferred from the computer to the printing head. In other words, the inks are transferred without a physical image carrier (or plate) onto a printing substrate. Such a printing process is referred to as non-impact printing (NIP). The industrial ink jet printing machines have done great developing steps since

the end of the 1990s. The most important feature of NIPs is the flexibility of the printing information during a production. That means, if necessary the printed information can vary from page to page. This variability makes the NIP unique. The conventional impact printing can be divided into four printing processes which are classified according to their image carrier. There are letterpress, gravure printing, screen printing and lithography.

Typical for the letterpress is that the printing elements are raised on the image carrier. The image carrier is hard and the used inks are commonly highly viscous. The viscosity of a fluid is its internal resistance to flow. The more viscous a printing ink the slower and the less its penetration into the paper (6.4.1) and the less the dot gain in print (4.2.4). A too high ink viscosity has also disadvantages such as picking the paper fiber, streaking and ink build-up on the blanket and rollers. Figure 3.9 demonstrates the principle of a letterpress image carrier. After inking the image carrier, the ink will be transferred by high pressure onto the printing substrate. Flexography is the most important subgroup of the letterpress printing process. Contrary to the classic letterpress, flexography uses low viscosity ink and the printing plate is soft, which allows a low pressure for transporting the ink from carrier onto the printing substrate. This printing process is mostly used for the packaging and foil substrate (Böhringer et al, 2008).

Figure 3.9: Letterpress image carrier inked with cyan ink.

In the gravure printing press, the printing elements are recessed on the image carrier. Figure 3.10 demonstrates the principle of a recessed image carrier.

Figure 3.10: Gravure printing image carrier inked with cyan ink.

In an industrial gravure printing machine the image carrier cylinder is partly flooded into the low viscosity ink. The image carrier cylinder rotates and its surface passes through an ink pan and then a doctor blade removes all the excessive ink from the surface of the image carrier cylinder. Therefore the ink only remains in the recessed areas of the image carrier cylinder. The printing substrate is then pressed on the image carrier cylinder via a rubber coated impression cylinder. By a relatively high pressure, the ink is transported from the recesses on the printing substrate. Gravure web printing machines are the

largest and fastest web printing machines compared to all impact printing processes. Typical products for the gravure printing process are multi-color magazines with a circulation bigger than 500,000 runs (Böhringer et al, 2008).

In the screen printing process the image carrier is in form of a stencil on a fine woven mesh from nylon, polyester or steel. Figure 3.11 demonstrates the principle of a screen printing image carrier. The ink is high viscous and during the printing it covers the mesh. Only the open areas of the stencil allow the ink to pass through the mesh. A squeegee pushes the ink through the mesh onto the substrate. The thickness of the ink layer in screen printing is the highest compared to the other printing processes. Hence this printing process is used if a relative thick ink layer is demanded (Böhringer et al, 2008).

Figure 3.11: Screen printing image carrier inked with cyan ink.

In offset printing, which is the most important printing process within lithography, the printing and the non-printing elements are at the same planographic level on the image carrier. In the next sections the offset printing process and the sheet-fed offset printing machine will be explained in detail.

3.4 Offset Printing Process

The offset printing is the modern and industrial sub-printing-process of lithography (printing with stone image carrier). The word lithography is from the Greek words *lithos*, "stone" and *graphein*, "to write" (Brockhaus 1996). Alois Senefelder (1771-1834) is the inventor of the lithography. In 1797, he tried to develop an economical reproduction technique for printing expensive sheet music. He found out that Solnhofen limestones reacted differently to grease and water. That was the birthday of lithography. The physical and chemical principle of the offset printing is still similar to the lithography although the technical possibilities, especially in the industrial machine techniques, have completely changed.

In offset, a printing plate is used as the image carrier. The printing plate has two areas, one image free area uncovered aluminum oxide and one image area with a special coating layer. The image and image free areas are both at the same planographic level. The chemical and physical surface properties are completely different for the aluminum oxide and this coating layer. The printing plate is from an aluminum oxide sheet with a thickness between 0.1 mm to 0.4 mm dependent on the size of the printing machine (DIN 16620-1, 1994). A new and

unexposed printing plate is fully coated with a light sensitive layer. This layer is selectively exposed in the prepress according to the printing image. The exposing is done in a computer to plate machine. The plate imaging process will be finished after developing the exposed plate. After the plate imaging, the image free parts of the coating layer are deleted and the aluminum oxide is uncovered. The imaged plate can now be used as an image carrier in an offset printing machine. The printing plate has to be wetted in the dampening unit before it is inked in the inking unit. During the wetting phase the image free areas (with only aluminum oxide) takes the dampening solution while the image areas (the coated layer of plate) repel the dampening solution. Now the printing plate can pass the inking unit. The image free (wetted areas) are now ink-repellent and do not take ink. Hence only the image areas take ink. Figure 3.12 shows a microscopical photograph of an offset printing plate. The white-silver areas are hydrophilic, which means that this area can be wetted well in a dampening unit. The aluminum plate is eloxal that means it is electrolytic oxidated. The aluminum oxide is highly hydrophilic. The dark areas are image areas which do not take dampening solution (hydrophobic) and can be inked in the inking unit. After inking, the inked image is printed on a rubber blanket which then prints the image on the printing substrate. Hence the offset printing is an indirect printing process (Kipphan, 2001).

Figure 3.12: An enlargement of an offset printing plate.

The offset process is usually a very sensitive and instable printing process. This printing process works successfully, only if all important parameters are set correctly and precisely. Therefore, the offset printing process has to be continuously controlled and optimized if necessary.

3.5 Offset Printing Machine

There are two general types of offset printing machines, namely web and sheet-fed. A web offset printing machine prints substrates which are in form of paper web. Typical products for a web offset printing machine are newspapers, magazines and advertising supplements. A sheet-fed offset printing machine prints the substrates which are in form of sheets. This thesis only focuses on the sheet-fed offset printing, and hence in this section the most important parts of an offset sheet-fed machine will be systematically described. From now on in this thesis, the term printing machine is used instead of offset sheet-fed printing machine. Figure 3.13 shows a printing machine with its three technical main sections; (a), (b) and (c) show the feeder, printing units and the delivery system.

Figure 3.13: Simplified scheme of a four color offset printing machine.

3.5.1 Transport of Printing Substrates

The printing substrates are stacked on palettes and hence the substrates have to be separated (decollated) into sheets before they can be printed, shown in Figure 3.13(a). The separated sheets have to be transported through all the printing units, shown in Figure 3.13(b). The printed sheets have to be transported carefully from the last printing unit to the delivery system. The printed sheets will be collected again to build a stack on a palette in the delivery system, shown in Figure 3.13(c). The sheet transport occurs with a very fast speed. The modern printing machines print with a speed of up to 20,000 sheets per hour. In spite of the high production speed the whole process has to be done with an enormous accuracy and without damaging the fresh printed ink, e.g. by scratches or set-offs.

3.5.1.1 Feeder System

The modern printing machines use a stream feeder. The separation of sheets is made by a suction head. The lifting suckers take the top sheet on the stack and the warding suckers move the sheet to the feeding table, where a rotated band

takes the sheet with suction air and moves it to the lays. Before the sheets can go into the first printing unit they have to be horizontally and vertically aligned. This occurs by side and front lays. The sheet alignment influences the position of the printed image on the printing substrate (Kipphan, 2001).

The accuracy of sheet alignment in an offset machine has to be very high. The German Printing and Media Industries Federations (bvdM) defined the needed accuracy of sheet alignment in an offset machine for a printing acceptance test. The standard deviation of the feeder's register variation (i.e. the error of the sheet alignment's misplacement) has to be less than 15 μm . The acceptance test printing has to be run with 80% speed of the maximum possible speed of the machine (bvdM, 2002).

3.5.1.2 The Gripper System of the Impression Cylinder

As shown in Figure 3.13, after the printing substrates were separated into the sheets and aligned in the feeder they can be transported into the first printing unit for the printing. A pre-grripper takes the aligned sheet and moves it to the gripper of intermediate drum. The intermediate drum (Figure 3.13(d)) transfers the sheet to the first impression cylinder. The impression cylinder has grippers for taking and transferring the printing substrate. In the printing unit the substrate goes through the impression and blanket cylinders. The ink is transported from blanket on the printing substrate under pressure. After the printing in the first printing unit, the substrate has to go into the next one. From the second printing unit to the last one, each printing unit has its prior transfer cylinder (Figure 3.13(e)) and hence there is no need for further intermediate drums. The impression cylinder transports the substrate to the next transfer cylinder. This procedure is repeated until the printing substrate passes the last printing unit (Kipphan, 2001). The print quality of a printing machine highly depends on a good and accurate sheet placement in the printing units. The accuracy of the sheet placement in the printing units depends on both an accurate sheet transport from gripper to gripper and from printing unit to the next one and also on the driver technique (Section 3.5.3). This accuracy is directly related to the register variation (Section 4.2.3) of a printing machine. Therefore measuring and evaluating the register variation values are very important. The bvdM also defined the needed accuracy of the sheet transfer in a multi-color printing machine for a printing acceptance test. The standard deviation of the register variation (the sheet transfer's error) in a four color printing machine has to be less than 10 μm . The current industry standard method for measuring the register variation is based on image processing, which is a very expensive method. It was a great demand to determine the register variation by an alternative and affordable technique. Development of a densitometry and a spectrophotometry model to determine the register variation is an important part

of this thesis (Hauck and Gooran, 2011a and 2015). These models will be introduced and explained in detail in Chapter 5.

3.5.1.3 Delivery System

The sheets have to be transported to the delivery system after passing the last printing unit. The ink on a printed sheet is fresh and wet. These sheets are to be transferred and fed to the delivery pile. Since the printing speed is very high, the lightweight sheets tend to flutter, and the fresh ink may smear on contact with printing machine elements in the area of the delivery system during the fluttering of the sheets. A sheet guidance and a calm sheet transport in the delivery are fundamentally important for a completely smudge free sheet delivery. The space in a delivery system can be also used to install drying units. A drying unit can support the drying process with the radiation of different spectra of the light, e.g. ultra-violet or infra-red light, and hot air (Buschmann and Hauck, 1997). Furthermore the application of powder helps to keep a short distance between the fresh printed and the next sheet in the pile. This distance reduces the risk of smearing, offsetting and blocking in the pile (Kipphan, 2001).

3.5.2 Printing Unit

An offset printing unit consists of three subunits, namely dampening unit, inking unit, and the cylinder groups. Figure 3.14 shows an offset printing unit and its subunits.

Figure 3.14: Simplified scheme of a sheet-fed offset printing unit.

(a), (b), (c), (d), (e), and (f) are the dampening unit, inking unit, plate cylinder, blanket (or offset) cylinder, impression cylinder and transfer drum.

3.5.2.1 Dampening Unit

As mentioned in Section 3.4, the printing plate has to be wetted in the offset printing process. The aluminum oxide for the image free areas of the printing plate has to be wetted before the printing plate is inked. The dampening solution makes the aluminum oxide layer ink-repellent. The dampening units have to work precisely, which means the dampening solution has to be applied absolutely evenly and equally over the entire plate. The dampening solution has much lower viscosity than the ink. Hence for building a thin and equal dampening solution film it is much easier to distribute the dampening solution than it is for the ink film. Therefore, as it can be seen in Figure 3.14, the number of the needed rollers used in the dampening unit is less than that in the inking unit.

In the dampening unit, there exists a water pan roller that rotates and takes the dampening by the adhesion power. Adhesion is the tendency of two or more different materials to cling to each other. In some printing machines the pan roller's surface is coated with ceramic. A dose roller coated with rubber presses the water pen roller and doses the dampening film. More pressure means a thinner dampening film and vice versa. Finally, a dampening form roller transfers the dampening film on the printing plate (Kipphan, 2001).

3.5.2.2 Inking Unit

The high viscosity offset ink is filled in the ink fountain. The ink fountain roller rotates and the ink-adjusting-screw presses the ink fountain blade and doses the needed amount of ink on the ink fountain roller. Then an oscillated roller takes the ink stripe width with the corresponding ink profile and transfers it to the other rollers. The freshly dosed ink is then transferred and distributed to the ink form rollers. Finally, four ink form rollers transfer the ink to the image area of the printing plate.

The most important task for an inking unit is to provide a constant supply of fresh ink for the image area on the printing plate. The inking unit has to supply and replace the amount of the used-up ink and has to keep the amount of the ink in the printing process constant. The amount of the ink cannot be kept constant if there is no equal balance between the used and replaced ink. All color prediction models assume and will work only if the inking film on the image area of the printing plate is equally thick (Kipphan, 2001).

Furthermore, there are some printing quality criteria which are influenced not only by one part of the printing unit (e.g. dampening or inking unit), but by a combination of different parts and possibly also by the used consumables. An important example for such a print quality criterion is ink trapping (Section 4.2.5). The amount of trapping has a great impact on the gray balance and color reproduction of the print products. Hence it has to be measured, evaluated and observed to control the printing quality. There have therefore been conventional

print density based models to estimate the effect of trapping which only give a percentage value. Presenting a colorimetric model to determine the ink trapping is an important part of this thesis (Hauck and Gooran, 2011b). This model will be introduced and explained in detail in Chapter 6. Furthermore, the surface (gloss etc.) and ground (ink penetration etc.) effect also may have impact on the print result depending on the substrate and inks but these effects have mainly been ignored in all trapping models. Hence, in this thesis, the proposed model for determining trapping is extended to investigate the impact of both effects for high quality glossy coated paper and a set of sheet-fed offset inks (Hauck and Gooran, 2013).

3.5.2.3 Plate Cylinder and Blanket Cylinder

The printing plate is mounted on the plate cylinder. It is clamped in the plate cylinder gap via the plate clamp grippers. Hence the shape of a plate cylinder is not a 360° cylinder. Its shape is cylindrical but with a cylinder gap. Figure 3.15 shows the plate and blanket cylinders, where (a) and (b) are the lateral and plan view of the plate and blanket cylinders and (c), (d), (e), (f), (g), (h), (i), and (j) are the plate cylinder gap, plate cylinder clamp grippers, blanket cylinder gap, blanket cylinder clamp system, the bearer rings of plate and blanket cylinders, the plate cylinder packing, the blanket cylinder packing and gear-wheels of plate and blanket cylinders.

Figure 3.15: A simplified scheme of a plate and blanket cylinder of an offset machine.

The ink is first printed from the plate on the blanket and then from the blanket on the substrate. As mentioned before, a pressure is needed for the printing and ink transfer. The pressure between the plate and blanket cylinder is adjusted by

the plate and blanket under-packing which also affects the cylinder developing. The rule for the adjustment of the cylinder developing is that the level of the plate should be 0.10 to 0.14 mm over the bearer ring of the plate cylinder and the level of the blanket should be equal to zero (Kipphan, 2001).

3.5.2.4 Impression Cylinder

The impression cylinder presses the substrate to the blanket to print the image from the blanket on the substrate. The amount of the pressure should be in its range. The needed pressure depends on the evenness of the printing substrate. The distance between the blanket and the impression cylinder has to be between -0.1 to -0.15 mm plus the thickness of the printing substrate. If the pressure is too low, the ink will not be transferred completely and the image will look mottled. In contrast, a too high pressure causes large dot gain (Section 4.2.4). In the modern printing offset machines the impression cylinder's circumference is generally two times bigger than the blanket and plate cylinder. Using bigger impression cylinder has some advantages. The first important advantage is that the deformation of the printed details (such as dots, line and text) is less, hence the dot gain is smaller. The second advantage is that it is also possible to print on the flexural resisted substrates such as lenticular printing foil, thick cardboard or sheet metal plate. Figure 3.16 shows an offset printing unit, where (a), (b), (c) and (d) are the impression cylinder, its grippers, the transfer cylinder and its grippers.

Figure 3.16: A simplified scheme of a modern offset machine.

As seen in Figure 3.16, the transfer cylinder is not really cylindrical. Hence in some books it is called a transfer module or transferter module. It is worth

emphasizing that, as also seen in Figure 3.16, each impression and each transfer cylinder has two different grippers.

3.5.3 Driver Technique and Related Accuracy of Printed Detail

In an offset printing machine there are a number of cylinders. As also shown in Figure 3.15(j), each cylinder has a mounted gear-wheel on its left side. The teeth of the gear-wheels engage in each other accordingly. A main driver moves the printing machine. Figure 3.17 shows a part of a multi-color offset printing machine and its main driver (a) which is mounted in this case in the first printing unit.

Figure 3.17: A simplified scheme of an offset printing machine and its main driver.

The driving power moves a gear, e.g. the impression cylinder of the first unit, which moves the intermediate drum and the transfer cylinder of printing unit 2. The moving power from the first printing unit moves the feeder, the printing units 2 to 4 and the delivery system. In the contact zone of the gear teeth with the next one a play (distance) exists. This play also has a direct impact on the register variation hence during the to-put-in-operation of a printing machine it should be adjusted.

3.6 Summary

The printing data have to be prepared for printing. The preparation is called halftoning technique. There are two main types of halftoning techniques, namely AM and FM. While AM mainly dominates in the offset printing, FM dominates in inkjet.

There are different models for predicting the color in the printing process. Two of the most important prediction models are Murray-Davies and Neugebauer

models. While the Murray-Davies model is a monochrome prediction model, the Neugebauer model is multi-chromatic. In the graphic industry the modified Murray-Davies formula (Equation 3.4) is commonly used to determine the fractional area of a printed halftone patch.

The printing process can be separated into non-impact and impact printing groups. The digital printing belongs to the group of non-impact printing process which does not need a physical image carrier. The impact printing can be classified in four sub-groups, namely letterpress, gravure, screen and lithography. The most important sub-printing-process of lithography is offset printing. The image and image free areas are both at the same planographic level on the offset printing image carrier.

The printing quality of an offset printing machine is greatly dependent on the register variation. The register variation and its standard deviation depend on the accuracy of the sheet transfer between the printing units and an accurate adjustment of the plays (distance) between the teeth of the gear-wheels. The standard deviation of register variation has to be in the tolerance range and therefore has to be measured and evaluated. The current method for measuring and evaluating the register variation is based on image processing and is very expensive. In Chapter 5 two alternative models for measuring and evaluating the register variation will be proposed and explained in detail. These models are based on densitometry and spectrophotometry.

The amount of trapping (see Chapter 6 for more detail) has a great impact on the gray balance and color reproduction of the print products. Hence it has to be measured, evaluated and observed to control the printing quality. Presenting a colorimetric model to determine the ink trapping is an important part of this thesis. This model will be introduced and explained in detail in Chapter 6.

In Chapter 4 the most important print quality criteria will be briefly described. Furthermore, the essentials of ISO 12647-2/13 are also explained in Chapter 4.

Chapter 4

PRINT QUALITY IN PRODUCTION

Process Parameters in a Print Workflow

Print Quality Criteria

ISO 12647-2/13

Summary

Introduction to the Conducted Research

The quality of a print product depends on many factors. The duplication of information (books, magazines and newspapers) and other aspects such as design, colors, different glossy or matt effects, and packaging are all among the factors affecting the quality of printing products. Above all factors the color may be the most important characteristic of print products. Printing colors' predictability and equally reproducibility during the production is a daily challenge and one of the most important tasks for every printing company. This task can be managed successfully, only if the print quality is measured and controlled. The print quality can be detracted by different defects. There are a variety of print quality defects that occur if the production process is not controlled. This chapter starts with a brief discussion about the possible disturbance sources for print quality defects. Then different selected and very important print quality criteria will be explained. Furthermore the quintessence of ISO 12647-2/13 will be briefly illuminated.

4.1 Process Parameters in a Print Workflow

Finding the disturbance sources of print quality defects is not a simple task without a systematic analysis. Very often the printing machine operators wrongly compensate a disturbance by another misadjustment to force the printing result into a tolerance range. This kind of work is, however, not efficient and causes an instable printing process. For example, if the printing machine has a problem with doubling (Section 4.2.3.1), which causes a high dot gain, the compensation of the high dot gain by generating a new dot gain compensation curve (Section 7.2) is not constructive because the doubling causes not only a high dot gain, but also a permanent tone value variation. In such a case the amount of tone value variation is mostly higher than the allowed tolerance of the dot gain shift for a standardized printing process. Hence quality defects should be distinctly analyzed to locate its source in order to reduce or eliminate the cause of the disturbance. The print quality defects are either caused by consumables (such as wrong printing substrate, ink, dampening solution, plate or blanket) or by the prepress (such as incorrect halftoning, exposing and developing of printing plates) or by the printing machine (such as incorrect ink value, tone value variation, incorrect dot gain, dot gain variation, doubling, trapping, and slurring), just to name only the most important of them. Figure 4.1 shows these three important sources affecting the print quality. The disturbance of the prepress and printing machine can be separated in two important categories, namely the technical (like the mechanical condition, maintenance and service of a machine) and the operating condition of a machine (like its setting and adjustment). In the following section different important print quality criteria will be explained.

Print quality depends on:				
Consumables:	Prepress:		Printing machine:	
Printing substrate Ink Dampening solution Plate Blanket etc.	Technical	Operating	Technical	Operating
	Maintenance and service	Setting and adjustment	Maintenance and service	Setting and adjustment
	Layout Color reproduction Halftoning Dot gain compensation Plate exposure Plate development etc.		Ink value Dot gain Ink value and tone value varia- tion Doubling Trapping etc.	

Figure 4.1: A categorization of process parameters which impact the print quality.

4.2 Print Quality Criteria

The criteria characterizing the quality of a print product are called print quality criteria. There are various quality criteria for a printing product, such as ink value, dot gain, doubling, trapping etc. This chapter mainly focuses on those criteria that are important for a stable printing process and reproducible printing products. The stability and reproducibility are both absolutely necessary for the quality adjustment processes. All selected and explained print quality criteria in this thesis are important for generating the dot gain compensation curves (Chapter 7) and the CtP calibration. In Chapter 8 an Automated CtP Calibration System will be proposed. The stability and reproducibility of the print quality is an important requirement for this system.

4.2.1 Ink Value

The appearance of a printed color varies with the amount of the printed ink. The amount of an ink can be measured by its thickness [μm] or its weight per area [g/m^2]. Since the ink value affects the printed tone values, it is necessary to have a defined ink value to be able to predict correctly the printed color values.

As explained in Section 2.6.2, the amount of ink printed on the substrate is related to the ink density. However, it is worth emphasizing that the color cannot be defined (characterized) by the ink density. Therefore ISO 12647-2/13 (2013) recommends CIELAB values for colors known as color target values. Nevertheless, for a print machine operator it is easier to control the amount of ink by just one parameter such as ink density than the CIELAB values which

are three parameters. Hence the densitometry is an easy way for controlling the ink layer in the printing process (Brehm, 2001).

However, it is common to use both technologies (spectrophotometry and densitometry) in printing companies. In the first step the measurements of the colors and their comparison with ISO target values is done by a spectrophotometer in the make-ready phase. After the target values of colors are achieved and verified by a spectrophotometer, the ink densities of the ok-print can be measured by a densitometer. The make-ready phase is finished with the ok-print (ok-sheet). Thereafter, these density values are production densities and can be used in the production phase. The production density values are used in the production to control and keep the ink level constant during the printing process.

4.2.2 Slurring

In Section 3.5.2.3 the adjustments of cylinder developing (cylinder packing) for the plate and blanket cylinder were described. The cylinder packing affects the tangential speed of the plate and the blanket while they rotate. During the different packing of plate and blanket their tangential speeds are different. If the tangential speed variation of the plate and the blanket is too high, the printed detail will slur. The slurring affects the tone values and dot gain, hence the slurring should be avoided in printing.

4.2.3 Register and Mis-Registration

In color printing, registration is the method of correcting the superimpositions of colors in halftone print. Mis-registration occurs when one or more colors in a set are not aligned (Gooran, et al., 2011). The mis-registration should be minimized during the make-ready time, and if it is within an acceptable range, then the printing production can begin. Usually the mis-registration should be less than 100 μm between two or more process inks (ISO 12647-2/13 and ISO 12647-3/13, 2013). There are different forms of register marks designed to check the accuracy of the registration. Figure 4.2(I) shows the register marks during the make-ready phase (in this case sheets no 1 to 100), and (II) shows the register marks during the production phase (in this case sheets no 101 to end of production). Furthermore in Figure 4.2(IIa), (IIb) and (IIc) the register marks of a well registered printing job, mis-registration, and register variation are demonstrated. As illustrated in Figure 4.2(IIa) and (IIb), the registration quality, or in other words the accuracy of superimpositions of inks, is always statical because the position of registers do not change from sheet to sheet. The registration or mis-registration should not be confused with register variation which is always dynamic (Figure 4.2(IIc)), meaning the position of registers changes for the consecutive printed sheets.

Figure 4.2: Register marks during the make-ready (I) and the production (II) phase. (a) and (b) show two different registrations and (c) shows the register variation.

4.2.3.1 Register Variation and Doubling

As mentioned in Section 3.5.1.2, the print quality of a printing machine strongly depends on a good and accurate sheet placement in the printing units. A misplacement of printing sheet in the printing unit causes register variation, which can further lead to doubling, as will be explained. In an offset printing machine, the previous printed ink on the substrate is still wet when reaching the next printing unit. This leads to ink resplitting. In offset printing, ink resplitting occurs when the wet ink from the previous printing unit comes into contact with the blanket in the current printing unit and is printed reversely, i.e. from the substrate on the blanket of the current printing unit. This means that the ink is not printed only in the current printing unit, but also in the following printing units. Hence, in a four color printing machine the black ink, which is the first ink to be printed, is not printed only once but four times. Thus cyan is printed three times, magenta twice and yellow once. Due to wet-on-wet printing, if the register variation value is high, then the printed elements will not be printed sharply but partly or totally doubled which causes the printing error called doubling. Therefore, a register variation together with wet-on-wet printing causes doubling. Register variation also generates dot gain variation and accordingly tone value variation in a print production. A print production with tone value variation is useless and is mostly to be replaced. Hence a high register variation can be an economical loss for a printing company. Figure 4.3 demonstrates the visible color shift and gray balance variation in a number of consecutive printed sheets caused by register variation.

Figure 4.3: Register variation causes visible color shift and gray balance variation in consecutive printed sheets.

The following example aims at clarifying the relationship between the register variation and the variation of tone value. In this example it is assumed that the printing job is halftoned by a FM screen, square dot shape and a dot size of $30\text{ }\mu\text{m}$. Furthermore, for the sake of simplicity, it is assumed that the register variation occurs only in one direction and the density of double printed area is equal to the density of the printed halftone area. Figure 4.4(a), and (b) demonstrate the printed halftone dot in the current printing unit (no register variation and thereby no doubling yet) and the printed halftone dot including a $15\text{ }\mu\text{m}$ register variation. l is the side length of a printed square dot and r_1 is the printed doubling area. This register variation increases the tone value in this simplified example by 50%.

Figure 4.4: The higher the register variation the more the tone value increases.

The printed elements, like dots and lines, can only be printed sharply if the register variation value is low and within the tolerance range. Reducing and controlling the register variation is the most difficult task for all print machine manufacturers. For reducing and controlling the register variation its value has to be measured. The measuring of the register variation is also very important for putting a multi-color printing machine in operation and for its repair and service. Furthermore the manufacturers of printing machines also need the evaluation of register variation to develop new products. In Chapter 5 two novel

models, based on densitometric and spectral measurements, will be introduced for measuring and evaluation of register variation.

4.2.4 Dot Gain

Usually, the printed dots are increased in size compared to the dots on the printing plate. This phenomenon is the physical (mechanical) dot gain. The physical dot gain is partly because of the consumable, such as ink and printing substrate, and partly because of the setting and maintenance of a printing machine. The physical dot gain is for example high if the ink viscosity is too low or the paper fibers are openly porous. The physical dot gain is also affected by the pressure of the impression cylinder (Kipphan, 2001). As mentioned before, the physical dot gain can also increase if the printing machine has a problem with slurring or/and doubling.

Beside the physical dot gain, an optical phenomenon called optical dot gain occurs which causes the printed dots to appear bigger than their physical size. The optical dot gain occurs due to light scattering in the printing substrate. If a partly printed substrate is illuminated, the light photons can travel in different paths. Figure 4.5 shows a simplified demonstration of such effects.

Figure 4.5: The dashed line demonstrates the effect of optical dot gain. The photon that enters in the unprinted area scatters inside the paper and goes through the ink.

The mechanical and optical dot gain effect together are what is generally called dot gain. All the recommended dot gain values in the ISO 12647-2/13 are for the total dot gain including both physical and optical dot gain (ISO 12647-2/13, 2013). Like ISO recommendation the printing companies also consider the total dot gain and do not separate their effects. Furthermore, ISO uses the term Tone Value Increase (TVI) for the recommended target dot gain level in offset printing. Hence in this thesis from now on, the term dot gain is used instead of

total dot gain and the term TVI is used instead of ISO recommended target dot gain level in offset printing.

For measuring and evaluating the dot gain, a densitometer or spectrophotometer is needed. Dot gain is defined by Equation 4.1.

$$TV^{DG} = TV^{Print} - TV^{data} , \tag{4.1}$$

where TV^{DG} , TV^{Print} and TV^{data} denote the dot gain value, printed or effective tone value (calculated by Equation 3.4) and the nominal or reference tone value in data.

4.2.5 Trapping

In a multi-color offset printing machine, the process inks (KCMY) are printed consecutively on the substrate in one printing unit after the other. The dots in different ink units are printed, either isolated, partly or completely overprinted, and the overprinted inks are printed wet-on-wet. The thickness, or the amount, of the second printed ink on the first ink is not the same as when the second ink is printed on the paper. This phenomenon is called trapping and shown in Figure 4.6.

Figure 4.6: The amount of the overprinted ink on the previously printed ink is not the same as when the overprinted ink is printed on the bare paper.

For example, assume that the cyan and yellow are both printed with an ink film thickness of 1 μm . In the overprinting, which results in green, the cyan ink film thickness is still almost 1 μm (or 100%), but the wet yellow cannot be printed with 1 μm on the wet cyan and in this example the thickness of yellow ink film

is just 0.5 μm when printed on cyan. This results in a total overprinting ink thickness of 1.5 μm or 150% for green instead of 2 μm (or 200%).

There are different factors, such as ink temperature, dampening, printing speed, etc. that affect the trapping value. As mentioned in Section 3.5.2.2, the trapping affects the color appearance (secondary and tertiary colors) and the gray balance of the printed products. Dependent on the amount of the trapping value, the gray balance and the color appearance of the multi-color printed product can be very different, even if the printed single solid ink values are identical. Figure 4.7 demonstrates the trapping effect. Although the ink values of the single printed inks for all prints have the same value in all samples, the results of overprinting due to different trapping are not equal. In this example the trapping effect increases from left to right in the overprinted area, which means that the quality of the ink transfer of the overprinted ink decreases and therewith the contrast is lost on the right side.

Figure 4.7: The trapping effect on the overprinted color and the trapping effect on the gray balance on a multi-color image printed with different trapping values.

Therefore, it is very important to have an explicit value for measuring trapping. There are different conventional trapping models, such as Preucil (1952), Brunner (Du Pont, 1979) and Ritz (1995), which are all named after their inventors. All the conventional trapping formulas work with densitometry input values and give a trapping value based on the amount of the second printed ink on the top of the first one just in percent. The Preucil and Ritz models are the most well known trapping models, and they will briefly be discussed in the following subsections. As previously mentioned, a novel spectral trapping model will be introduced in Chapter 6.

4.2.5.1 The Preucil Trapping Formula

A simple method for measuring and evaluating the trapping value is the Preucil method which is based on the relation between the density of the real and the density of the ideal overlapping. The overprinting of cyan and magenta inks is illustrated in Figure 4.8.

Figure 4.8: A scheme of a solid value print involving paper, cyan, magenta and ideal ink overlapping.

Where $S(\lambda)$, $R_p(\lambda)$, $R_c(\lambda)$, $R_m(\lambda)$, $R_b(\lambda)$ denote the incoming light intensity, the reflectance of the paper, the reflectance of solid cyan, the reflectance of solid magenta and the reflectance of the overlapped inks, in this case magenta printed on cyan (blue). The Preucil formula is given in Equation 4.2.

$$D_{12} = D_1 + D_2 \cdot Tr, \quad (4.2)$$

where D_1 , D_2 and D_{12} denote the density of the first printed ink, the density of the second printed ink and the density of the overprinted inks. Tr is the amount of trapping which is always less than 1. Factoring out Tr gives Equation 4.3, which is the Preucil trapping formula, multiplied with 100 to achieve a percentage value (Preucil, 1952).

$$Tr = \frac{D_{12} - D_1}{D_2} \cdot 100 \quad (4.3)$$

4.2.5.2 The Ritz Trapping Formula

Ritz used the Murray Davies model (Equation 3.2) and modified it as shown in Equation 4.4.

$$R_{12} = R_1 + R_2 \cdot Tr + (1 - Tr) \cdot R_p, \quad (4.4)$$

where R_1 , R_2 , R_{12} , R_p , Tr denote the reflectance of the first printed ink, the reflectance of the second printed ink, the reflectance of the overlapped printed

inks, the reflectance of unprinted paper and the amount of trapping, which is always less than 1.

By factoring out Tr and replacing the reflectance with density, Equation 4.5 is obtained, which is the Ritz trapping formula, multiplied with 100 to achieve a percentage value (Ritz, 1996).

$$Tr = \frac{1-10^{-(D_{12}-D_1)}}{1-10^{-D_2}} \cdot 100, \quad (4.5)$$

where D_1 , D_2 , D_{12} and Tr denote the density of the first printed ink, the density of the second printed ink, the density of the overlapped printed inks, and the amount of trapping (a percentage value).

4.3 ISO 12647-2/13

ISO 12647-2/13 with the title "Graphic technology -Process control for the production of halftone color separations, proof and production prints- Part 2: Offset lithographic processes" is the most important and popular standard in the graphic industries for offset printing. The first version was published in 1996, which meant a big milestone for the standardization of offset multi-color printing. For the first time there was a worldwide agreement for the uniformity recommendation for the ink target values and dot gains dependent on substrates.

Simplified and shortly it can be said that the target of ISO 12647-2 is the predictable and accurate color communication between halftoning and offset printing. The revision of this ISO started in 2004 and continued until the end of 2013. The reason for the long revision time was to find compromises between the huge number of national and international working groups and interests. The revised version of ISO 12647-2 from 2013 contains definitions for the printing substrates, CIELAB target values, recommendation for dot gain levels and their tolerances for the print production and recommendation for the used measurement instrument (Kraushaar, 2013).

4.3.1 Eight Printing Conditions

ISO categorizes all different offset printing workflows into eight printing conditions (PC). These eight conditions mainly depend on eight different printing substrates (PS). Each PC has its own colorant description (CD) as ink target values. Five different screening descriptions and their corresponding dot gain curves (tone value increase, TVI) are referred to the eight PCs. The screening descriptions are separated into periodic (AM halftoning technique) and non-periodic screens (FM halftoning technique). Table 4.1 demonstrates the

eight standard printing conditions for typical printing substrates (ISO 12647-2/13, 2013).

Table 4.1: Eight printing conditions by ISO 12647-2/13.

PC	PS	CD	Screening description			
			Periodic screen		Non Periodic screen	
			TVI curve	Frequency [cm ⁻¹]	TVI curve	Dot size [μm]
PC1	PS1	CD1	A	60 to 80	E	20
PC2	PS2	CD2	B	48 to 70	E	25
PC3	PS3	CD3	B	48 to 60	E	30
PC4	PS4	CD4	B	48 to 60	E	30
PC5	PS5	CD5	C	52 to 70	E	30
PC6	PS6	CD6	B	48 to 60	E	35
PC7	PS7	CD7	C	48 to 60	E	35
PC8	PS8	CD8	C	48 to 60	E	35

It is worth mentioning that in practice the number of printing conditions are much higher than only eight PCs because of different consumables and their possible combinations, see Section 4.3.5.

4.3.2 Eight Printing Substrates

The printing substrates (PS) are categorized dependent on their surface color, fluorescence, gloss, CIE whiteness and the mass-per-area [g/m²].

Table 4.2: Four of eight printing substrates by ISO 12647-2/13.

Characteristic	Paper type and surface											
	PS1			PS2			PS3			PS4		
	Type of surface			Mass-per-area [g/m ²]			CIE Whiteness			Gloss		
	Premium coated			Improved coated			Standard glossy coated			Standard matte coated		
	80 to 250			51 to 80			48 to 70			51 to 65		
	105 to 135			90 to 105			60 to 90			75 to 90		
	10 to 80			25 to 65			60 to 80			7 to 35		
	Color			coordinates			coordinates			coordinates		
	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
White backing	95	1	-4	93	0	-1	90	0	1	91	0	1
Black backing	93	1	-5	90	0	-2	87	0	0	88	0	-1
Tolerance [+ or -]	3	2	4	3	2	2	3	2	2	3	2	2
Fluorescence	moderate			low			low			low		

The surface color is to be measured with a spectrophotometer in accordance with ISO 13655-D50 (M1 illuminant, 2° observer, 0:45 or 45:0 geometry) (ISO 13655, 1996). Table 4.2 shows only four of the eight printing substrates (ISO 12647-2/13, 2013). The white backing in Table 4.2 means that during the measurement there are a number of unprinted sheets (the same kind as the test substrate) under the test substrate. This number depends on the opacity of the test sample. The black backing means that there is a black cardboard under the test substrate.

The measuring of florescence recommendation is mainly possible for the paper manufacturer companies. Although the concentration of florescent whitening agents is important for the colorimetry, the measuring of florescence is not possible for most printing companies because they do not have suitable instruments.

4.3.3 Demanded Ink Value

The target ink value is defined as the colorant description (CD) in the new ISO 12647-2/13. For each print condition there is one colorant description recommended. There is a recommendation for the white and a recommendation for the black backing measurement. The color values are measured with a spectrophotometer in accordance with ISO 13655-D50 (M1 illuminant, 2° observer, 0:45 or 45:0 geometry) (ISO 13655, 1996). Table 4.3 shows only four of the eight colorant descriptions and for the white backing (ISO 12647-2/13, 2013).

Table 4.3: Four of eight colorant descriptions by ISO 12647-2/13.

Characteristic	Colorant description											
	CD1 Premium coated			CD2 Improved coated			CD3 Standard glossy coated			CD4 Standard matte coated		
	Coordinates			Coordinates			Coordinates			Coordinates		
Color	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
Black	16	0	0	20	1	2	20	1	2	24	1	2
Cyan	56	-36	-51	58	-37	-46	55	-36	-43	56	-33	-42
Magenta	48	75	-4	48	73	-6	46	70	-3	48	68	-1
Yellow	89	-4	93	87	-3	90	84	-2	89	85	-2	83
Red	48	68	47	48	66	45	47	64	45	47	63	41
Green	50	-65	26	51	-59	27	49	-56	28	50	-53	26
Blue	25	20	-46	28	16	-46	27	15	-42	28	16	-38
Overprint CMY	23	0	-1	28	-4	-1	27	-3	0	27	0	-2

Table 4.4 shows the CIELAB ΔE_{ab}^* tolerances of the colorant description as deviation tolerance for the ok-print and as variation tolerance for the production print. In the make-ready phase the print has to achieve the closest tolerance (deviation tolerance of ok-print) to the proof print. The ok-print separates the

make-ready and production phase. The ok-print is the printed sheet, which is the closest to the proof printing and normally approved and signed by the quality controller. The ink value of the ok-print is now the new target value for the production. From now on, the print machine operator has to produce the printing-job with the closest tolerance (variation tolerance of production print) compared to the ok-print. The hue difference (Equation 2.13) between the ok-print and the production sheets has to be in tolerance as well.

Table 4.4: CIELAB ΔE_{ab}^* tolerances for the solids of the process inks by ISO 12647-2/13.

Process color	Deviation tolerance	Variation tolerance	
	Ok-print	Production print	
	ΔE_{ab}^*	ΔE_{ab}^*	ΔH
Black	5	4	-
Cyan	5	4	3
Magenta	5	4	3
Yellow	5	5	3

It is worth mentioning that ISO also introduces the tolerances in Table 4.4 using ΔE_{00} just for information purpose and not as a necessary recommendation. Hence there is no description of ΔE_{00} in this thesis.

4.3.4 Demanded Dot Gain Level

ISO recommends five different TVI curves which are numerically described and used depending on the print conditions (Table 4.1). Table 4.5 shows TVI for five different printing conditions (ISO 12647-2/13, 2013).

Table 4.5: A, B, C, D and E are five groups of numerical TVI by ISO 12647-2/13.

Reference tone values in data [%]	TVI values [%]				
	A	B	C	D	E
0	0.0	0.0	0.0	0.0	0.0
5	3.3	4.6	5.8	6.4	6.8
10	6.1	8.3	10.6	11.6	12.6
20	10.5	13.9	17.2	19.3	21.2
30	13.5	17.2	20.9	23.7	26.4
40	15.3	18.8	22.3	25.4	28.5
50	16.0	19.0	22.0	25.0	28.0
60	15.6	17.9	20.3	22.8	25.3
70	14.0	15.7	17.4	19.1	20.7
80	11.0	12.1	13.2	14.0	14.7
90	6.5	7.0	7.5	7.7	7.7
95	3.5	3.8	4.0	4.0	3.9
100	0.0	0.0	0.0	0.0	0.0

On the paper the halftoned dots should certainly be transferred during the printing process from 2% to 98% fractional area for coated paper (150 to 200 lpi for AM and 20 μm dot size for FM halftoning technique) and 4% to 96%

fractional area for uncoated paper (150 lpi for AM and 30 μm dot size for FM halftoning technique).

The dot gain values of the ok sheet should be in the tolerance range (deviation tolerance as called in the ISO). Furthermore the deviation of printed tone value at mid-tone (50% tone value) between cyan, magenta and yellow has to be less than 5% for the ok sheet definition. If these conditions are fulfilled, the tone value of the ok sheet will be the new target value for the dot gain in the print production. The tolerance of the dot gain or TVI values are described in Table 4.6.

Table 4.6: Tolerance of TVI by ISO 12647-2/13.

Tone level [%]	Deviation tolerance	Variation tolerance
	ok-sheet	production
< 30	3	3
30 to 60	4	4
>60	3	3
Maximum mid-tone spread	5	5

In the production at least 68% of the printed sheets have to be within the tolerance range of the dot gain values. The deviation of dot gain for the mid-tone of the ok-sheet has to be less than 5% in the production.

4.3.5 Practical Problems with ISO 12647-2

The first task of an ISO-standard is to recommend target values and tolerances. Hence a big part of the aim of standardized offset printing is achieved by the ISO 12647-2. If the recommended target values in the print process are achieved and the tolerances are within the recommended range, the predictability and the color communication between halftoning and offset printing will be satisfactory. However, ISO 12647-2 only describes a part of the most important parameters, i.e. printing substrate and screening description, for the printing conditions. The number of parameters, that affect dot gain, is much higher than just these two. For example, blanket, ink, dampening solution, printing process (UV or conventional drying ink), are also important factors affecting dot gain in an offset printing process. Even inside a printing substrate group (for example PS1) there are a lot of different substrates with different coatings and different ink penetration behaviors which have a big impact on dot gain. Hence, theoretically as many dot gain compensation curves as the possible number of consumables are needed. Otherwise the dot gain will most certainly end up out of the allowed tolerance range.

In order to print according to the right dot gain curve different possible combinations of consumables have to be taken into account. The next example clarifies this point. This is a real example for the combination of consumables

and screening resulting in different printing conditions in a printing company: Three different printing substrates (PS), two different printing processes (conventional and UV printing), and four different process inks. For each printing process two different ink sorts (for example one sort for straight/one-side printing and one sort for both-side printing), two different dampening solutions (with alcohol for UV printing and alcohol free for conventional printing) are considered. Four different screening types (Am 150 lpi, 180 lpi, 200 lpi and FM 20 μm) are also used. The result in this case will be 48 possible combinations of printing conditions. A DGCC-set includes for each ink (kcmY) its own DGCC, 48 DGCC-sets result in 192 DGCCs. Achieving the ISO recommended TVI demands generating many dot gain compensation curves which is very time demanding and costly. Actually, this is one of the biggest challenges for the printing companies if they have to print according to ISO standard.

The next difficult task is the fact that usually the dot gain compensation curves have to be renewed after 3 to 6 months. The reason is that the quality of the consumables slightly changes with time and the climate condition of different seasons is also an important variable. All these influence the dot gain level and finally the print result, which means that the existing dot gain curves have to be renewed after a short time. Worldwide there is no company which can afford generating, administrating and renewing the high number (for example 192 DGCCs or more) of dot gain compensation curves for economic reasons.

Therefore in Chapter 8 a networked workflow is introduced for a fully automated CtP calibration system (Hauck and Gooran, 2011c).

4.4 Summary

The predictability and reproducibility of the printing colors during the production is the daily challenge for printing companies. There are different criteria describing the print quality. Different methods are necessary to describe and measure the values of these criteria. The ink value affects the printed tone values, therefore it is necessary to have a defined ink value for an accurate color prediction. The slurring affects the tone values and dot gains, hence the slurring should be avoided in printing. A misplacement of printing sheet in the offset printing unit causes register variation and thereby doubling. The measurement of the register variation is therefore very important for putting a multi-color printing machine in operation or for its repair or service.

4.5 Introduction to the Conducted Research

Until now the basic concepts, models and definitions to understand the research conducted in this thesis have been described. From Chapter 5 to the end of this

thesis, the novel research carried out in the PhD study and the developed models are described.

In Chapter 5 two novel models, a densitometry and a spectral one, are introduced for measuring and evaluating register variation.

The thickness or the amount of the second printed ink on the first one is not the same as when the second ink is printed on the paper. This phenomenon is called trapping. In Chapter 6 a novel spectral trapping model is introduced.

Usually, the printed dots increase in size compared to their correspondence on the printing plate. This phenomenon is called dot gain and should be within the recommended range of ISO 12647-2, 13. This is the most important and popular ISO used in the graphic industries and offset printing. ISO 12647-2, 13 recommends target values and tolerances for different print quality criteria. Furthermore this ISO categorizes all the different offset printing workflows into eight printing conditions. Five different screening descriptions and their corresponding dot gain curves are referred to as the eight PCs. The number of the involved parameters affecting dot gain in an offset printing process is high, e.g. blanket, types of ink, dampening solution, printing process (UV or conventional drying ink). Even inside a printing substrate group (for example PS1) there are a lot of different substrates with different coating and ink penetration characteristics which have a big impact on dot gain. Achieving the ISO recommended TVI demands generating many dot gain compensation curves which are very time and cost intensive. In Chapter 7 a non-iterative method is proposed for generating dot gain compensation curves for the offset printing.

In Chapter 8 a networked workflow is introduced for a fully automated CtP calibration system. This workflow allows the automated generation, storing, administration and renewal of dot gain compensation curves.

Chapter 5

NOVEL DENSITOMETRY AND SPECTRO- PHOTOMETRY METHODS TO DETERMINE REGISTER VARIATION

Introduction

Image Processing Method

Design, Assumptions and Restrictions

Densitometry Method

Spectrophotometry Method

Statistical Evaluation of the Register Variation

Experimental Results, Comparisons and Discussions

Summary

5.1 Introduction

As mentioned before, there are a number of factors that affect the print quality. The register variation during the printing production is one of the most important factors influencing the print quality. It is important not to confuse the terms register variation with registration and mis-registration. In color printing, registration is the method of correcting the superimpositions of colors in halftone print. Mis-registration occurs when one or more colors in a set are not aligned. There are different forms of register marks designed in order to check the accuracy of the registration.

Register variation occurs when the transportation of a printing substrate from one printing unit (PU) to the next one is not accurate. In a wet-on-wet printing (multi-color offset printing machine) register variation leads to doubling which causes visual color variation from one sheet to the other one, shown in Figure 4.3. Register variation occurs because of a number of technical factors such as high printing speed, the quality of the printing substrate, misadjustment or damage in the printing machine, for example grippers, gear-wheels and driver system. Although attempts have been made to reduce the register variation, in practice it is impossible to completely eliminate the register variation in offset printing.

Obtaining an acceptable register variation is the biggest challenge for all printing machine manufacturers. Therefore it is very important to attain an acceptable tolerance for register variation in multi-color printing (bvdm, 2002; FOGRA, 2005). The tolerance and parameters of the register variation are given in (bvdm, 2002). For example, the standard deviation of register variation in the circumferential direction (press direction) from the first printing unit (PU1) to the last one has to be less than 19 μm for a 10-color offset printing machine. The commonly used method for measuring the register variation is based on image processing, which is a very expensive method. For example, the basic version of the register measuring system LUCHS (Luchs, 2014; Loh, 1998 and 2006) costs around 35,000 €. Therefore, there is a great demand to evaluate the register variation by an alternative inexpensive and affordable technique.

In Chapter 8, an automated CtP calibration system will be introduced. For this system one important requirement is the print quality control, for which the register variation value is among the most important tasks. The measuring element of the proposed register variation method, introduced in Section 5.3, can simply be integrated in the needed measure bar (Section 8.2.2.1) of the dot gain compensation curve. The measurements needed to determine the register variation can be carried out using the densitometer or spectrophotometer of the printing machine.

The remainder of this chapter is organized as follows. In Section 5.2 the image processing method is briefly described. In Section 5.3 the design of needed

measuring elements and the basic calculation is introduced. In Section 5.4 and 5.5 the densitometry (Hauck und Gooran, 2015) and the spectrophotometry method (Hauck und Gooran, 2011a) for determining register variation are introduced and explained. In Section 5.6 the statistical evaluation of a set of printed sheets are described and explained. Section 5.7 demonstrates the experimental results of the proposed methods and compares them with the image processing method. Section 5.8 gives a short summary of the whole chapter.

5.2 Image Processing Method

The image processing method is the industry standard to semi-automatically determine register variation. LUCHS is the most known image analysis based device. Unfortunately, PIDSID-Institution (the manufacturer of LUCHS) has not released any detailed description on how the LUCHS method works. However, it is known that the device produces a high-resolution image of the measuring element as shown in Figure 5.1 (Luchs, 2014). In the following this method is briefly explained.

Figure 5.1: LUCHS measuring element and an enlargement of a part of it.

The frame, (F) in Figure 5.1, is printed in the first PU (in this example black) and the horizontal and vertical lines (b) are printed in the following PUs (in this example cyan PU2, magenta PU3 and so on). The pixel positions of the horizontal and vertical lines are determined and compared to those of the black frame in order to give a measure for the register value.

Figure 5.2 illustrates the simplified work principle. The black frame (F) is for example about 1x1 mm. Line (a), a part of the frame F, is a horizontal base line printed in PU1 and (b) is a reference line printed in PU2. A high-resolution

camera system takes an image of the frame and the reference line using for example 1,000 x 1,000 pixels. That means in this case it automatically gives a metric unit, i.e. 1 pixel/ μm . The register value in the circumferential direction is defined as the distance between these two lines ((a) and (b) in Figure 5.2). Now by calculating this distance in two consecutive printed sheets the register variation can be determined by the difference between the two distances.

Figure 5.2: Simplified work principle of the image processing tool for evaluating the register variation.

The register variation in the lateral (sidewise) direction based on the vertical lines is determined correspondingly. For more detail please see (Luchs, 2014) and (Loh, 2006 and 1998). The result of evaluating the register variation is illustrated by a graph and the standard deviation. Notice that the absolute register value in each sheet is not so important for putting the printing machine in operation or repair. The graph of the register variations for a set of evaluated sheets is more important, but the most important factor is their standard deviation (bvdm, 2002).

5.3 Design, Assumptions and Restrictions

Before introducing the two novel methods based on densitometry and spectrophotometry to determine the register variation, a short introduction is given in the following.

In this section the necessary concepts and elements needed to understand these two methods are described. As mentioned the goal of the proposed methods is to determine the register variation by only using a densitometry or a spectrophotometry tool. In order to do that a special color stripe (or bar) is proposed here. Figure 5.3 shows a sample for such a stripe for determining the register variation between the second and the third PU. This figure illustrates an enlargement of the necessary color stripe, which consists of solid patches (C_{solid} , M_{solid} , B_{solid}), and patches including single printed (Base line Cyan - C_{BaseL} and

reference line magenta (M_{RefL}) and partly overlapped lines and gaps (B_{olapL}). C, M and B stand for cyan, magenta and blue (magenta on cyan), respectively.

Figure 5.3: The enlargement of the measuring color stripe for the proposed methods.

How the width of these lines is chosen will be discussed later in this section. These patches are printed in two different printing units; in this example cyan is printed in PU2 and magenta in PU3. Generally the register variation is determined between two consecutive PUs (e.g. PU2 and PU3) or between the first and the last PU (e.g. PU1 and PU4 for 4-color printing).

The register deviations occur because of the inaccurate transportation of the printing substrate from PU2 to PU3. When the consecutive printed sheets are compared to each other, a variation of the position of the base lines to the reference lines can be visually observed (by using for example a 50x magnifying glass).

Figure 5.4: (a) the overlapped lines in the prepress file and after make-ready in the print. (b) and (c) the overlapped lines if the register variation occurs in two different directions.

Figure 5.4(a) illustrates an enlargement of a part of the partly overlapped lines (B_{olapL}) in Figure 5.3, it shows the overlapped lines as they are designed in the prepress file. Figure 5.4(b) and (c) illustrate how they would look like if register variation occurred in two different directions. Therefore the width of cyan lines, blue lines (overprinted area), magenta lines and unprinted white gaps for different sheets is a variable of the amount of the register variation. Of course the width of these lines also corresponds to their coverage. In the proposed methods the coverage of the lines (cyan, blue, magenta and the white gap) is determined for each printed sheet. The focus in this section is on the vertical lines for the lateral register variation but a similar color stripe is designed using horizontal lines for the register variation in the circumferential direction.

Figure 5.5 shows an enlargement of a part of the single printed and the partly overlapped lines in the designed color stripe in the prepress file. As seen in Figure 5.5(a) the width of the basis line (cyan) and unprinted gap (white) are equal and correspond to the area coverage 0.5 or 50%. The width of the reference line (magenta) and the unprinted gap correspond to 0.25 and 0.75, respectively, see Figure 5.5(b). In Figure 5.5(c), the width of the overlapped area (blue) corresponds to 0.125. Therefore, in B_{olapL} the width of pure cyan, pure magenta and the unprinted gap correspond to $(0.5-0.125=0.375)$, $(0.25-0.125=0.125)$, and $(0.5-0.125=0.375)$, respectively.

Figure 5.5: Enlargement of (a) base line (C_{BaseL}), (b) reference line (M_{RefL}) and (c) partly overlapped lines (B_{olapL}).

The variation in the width of cyan (corresponding to a_c), blue (corresponding to a_b), magenta (corresponding to a_m) and paper (corresponding to a_w) lines in Figure 5.5(c) can be used to determine the amount of the register variation.

However, in this study the variation of the width of blue line is used to determine the register variation. Notice that a_c , a_b , a_m and a_w denote the coverage of the corresponding color, which are proportionally related to their width. According to Figure 5.5(c), the working range of this system to detect the register variation corresponds to 12.5% in each direction (left or right). The reason is that the width of the reference line (magenta) is chosen by an area coverage of 0.25 or 25%, hence during a register shift the reference line can move $\frac{25\%}{2} = 12.5\%$ in each direction (left or right). In this design the width of the cyan lines and magenta lines in Figure 5.5(a) and (b) are 128 and 64 μm , respectively. This means that this design is able to detect the register variation up to $0.125 \cdot 256 \mu\text{m} = 32 \mu\text{m}$ in each direction, which means a total register variation of 64 μm . Usually, this working range is enough to put the printing machine in operation (bvdm, 2002; FOGRA, 2005). It is possible to expand the width of the lines and the unprinted gaps in the design to increase the working range if demanded. In this experiment a densitometry tool with a measuring spot of 3 mm in diameter was used. If there is a need to increase the width of the lines then using a measuring spot bigger than 3 mm in diameter is recommended.

It is worth emphasizing that the width of magenta lines is chosen to be less than (in this case half) that of the cyan lines to avoid total coverage of the patch B_{olapL} in Figure 5.3 due to dot gain, which could decrease the dynamic range of the measurement data.

5.3.1 Basic Calculation

In Figure 5.5(c), it is assumed that a_c is the coverage of cyan (base line), a_b is the coverage of blue (overprinting area of cyan and magenta), a_m is the coverage of magenta (reference line), and a_w is the coverage of white (unprinted area) after print. A_c is the coverage of the single printed base line, which is determined by measuring C_{BaseL} region in the color stripe, see Figure 5.3. A_m is the coverage of the printed reference line, which is determined by measuring M_{refL} region in the color stripe, see Figure 5.3.

Notice that the effect of dot gain is included in the determined values of A_c and A_m because the calculations are based on the measured density or spectral reflectance after print which also include the effect of dot gain (Namedanian and Gooran, 2011). It has to be mentioned that the effect of dot gain is taken into account for each printed sheet separately.

As mentioned earlier, the register variation from sheet to sheet corresponds to the variation of the width/coverage of the blue lines (a_b). Now Equation 5.1 to 5.3 can be derived using Figure 5.5(c).

$$a_c = A_c - a_b \quad (5.1)$$

$$a_m = A_m - a_b \quad (5.2)$$

$$a_w = 1 - A_c - A_m + a_b \quad (5.3)$$

In Section 5.4 and 5.5 it will be shown how to calculate a_b by using a densitometric tool and a spectrophotometry tool, respectively.

5.4 Densitometry Method

Some printing machines and ink inline control system manufacturers such as manroland, KBA and QuadTech, use a densitometry tool to control the press. Therefore the densitometry method to determine register variation has been developed for such printing machines. Equation 5.4 is the inverse function of Equation 2.15.

$$R = 10^{-D}, \quad (5.4)$$

where D is the density measured with the complementary filter of the overprinted ink (magenta in this experiment). Recall that in this experiment cyan is printed in PU2 and magenta in PU3. In order to minimize the additional noise that might occur because of the optical quality variation of the paper surface, it is recommended to use the densitometer in the absolute density mode and to measure its own paper's density value for each sheet.

As discussed earlier in the proposed methods the color stripe in Figure 5.3 is used. Since it is easier to write the equations using R (reflectance) than D (density) all equations are written using R which is converted to D at the end.

For B_{olapL} region in Figure 5.3, Equation 3.5 (Neugebauer, 1937) can be modified to Equation 5.5.

$$R_t = [(A_c - a_b) \cdot R_c] + [(A_m - a_b) \cdot R_m] + (a_b \cdot R_b) + [(1 - A_c - A_m + a_b) \cdot R_w], \quad (5.5)$$

where R_t denotes the total reflectance of the halftone print (B_{olapL}) and R_c , R_m , R_b and R_w denote the reflectance value of cyan, magenta, blue and bare paper. Equation 3.3 (Murray, 1936) is modified to Equation 5.6 to calculate A_c and A_m .

$$A_i = \frac{R_w - R_i^{Line}}{R_w - R_i^{Solid}}, \quad (5.6)$$

where the index i is c for cyan and m for magenta and w denotes the unprinted gap (paper). The superscript Solid and Line denote the solid and line screened patches for the corresponding color, see Figure 5.3. For example, R_c^{Solid} and R_c^{Line} are the measured reflectance of C_{solid} and C_{BaseL} in Figure 5.3, respectively. Equation 5.6 is set in 5.5 resulting in Equation 5.7.

$$R_t = \left[\left(\frac{R_w - R_c^{Line}}{R_w - R_c^{Solid}} - a_b \right) \cdot R_c^{Solid} \right] + \left[\left(\frac{R_w - R_m^{Line}}{R_w - R_m^{Solid}} - a_b \right) \cdot R_m^{Solid} \right] + (a_b \cdot R_b^{Solid}) + R_w - \left(\frac{R_w - R_c^{Line}}{R_w - R_c^{Solid}} \cdot R_w \right) - \left(\frac{R_w - R_m^{Line}}{R_w - R_m^{Solid}} \cdot R_w \right) + (a_b \cdot R_w), \quad (5.7)$$

where R_t is the measured reflectance value of the patch B_{olapL} in Figure 5.3 and R_c^{Solid} , R_m^{Solid} , R_b^{Solid} and R_w denote the measured reflectance value of the solid cyan, magenta, blue and bare paper. Now a_b is determined by Equation 5.7, as shown in Equation 5.8.

$$a_b = \frac{R_t + R_w - R_c^{Line} - R_m^{Line}}{R_b^{Solid} + R_w - R_c^{Solid} - R_m^{Solid}} \quad (5.8)$$

The reflectance values in Equation 5.8 are now replaced by their corresponding density values resulting in Equation 5.9.

$$a_b = \frac{10^{-D_t} + 10^{-D_w} - 10^{-D_c^{Line}} - 10^{-D_m^{Line}}}{10^{-D_b^{Solid}} + 10^{-D_w} - 10^{-D_c^{Solid}} - 10^{-D_m^{Solid}}} \quad (5.9)$$

5.5 Spectrophotometry Method

The secondly proposed novel method to determine register variation uses the spectrophotometry application. CIEXYZ values measured by a spectrophotometry tool are used to determine the register variation.

Neugebauer's equation (Equation 3.5), written for spectral reflectance, can be modified for CIEXYZ values since there is a linear relationship between the spectral reflectance and the tri-stimulus CIEXYZ values (Gooran, 2001). The modification results in Equation 5.10.

$$\begin{bmatrix} X_{ave} \\ Y_{ave} \\ Z_{ave} \end{bmatrix} = \sum_i a_i \cdot \begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix}, \sum_i a_i = 1, \quad (5.10)$$

where $(X_{ave}, Y_{ave}, Z_{ave})$ denote the average CIEXYZ values of the halftone print and (X_i, Y_i, Z_i) denote the CIEXYZ values of the solid ink (Cyan, Magenta or Blue) and (X_w, Y_w, Z_w) are the CIEXYZ values for the printing substrate. Furthermore, a_i is the fractional area covered by each Neugebauer primary.

For B_{olapL} region (Figure 5.3) Equation 5.10 can be written as Equation 5.11.

$$\begin{cases} X_{ave} = (A_c - a_b) \cdot X_c + (A_m - a_b) \cdot X_m + a_b \cdot X_b + (1 - A_c - A_m + a_b) \cdot X_w \\ Y_{ave} = (A_c - a_b) \cdot Y_c + (A_m - a_b) \cdot Y_m + a_b \cdot Y_b + (1 - A_c - A_m + a_b) \cdot Y_w \\ Z_{ave} = (A_c - a_b) \cdot Z_c + (A_m - a_b) \cdot Z_m + a_b \cdot Z_b + (1 - A_c - A_m + a_b) \cdot Z_w \end{cases} \quad (5.11)$$

where A_c , A_m and a_b have the same meaning introduced for Equations 5.1 to 5.3.

Notice that Equation 5.11 is an equation system in which there are more equations than unknowns. This type of equation systems is called overdetermined in mathematics. An overdetermined equation system does not necessarily have solutions, but they have solutions in some cases, for example if some equations are linear combinations of others. In Equation 5.11, there are three equations and one unknown, i.e. a_b , which is to be calculated. Since the equations actually are driven from spectral reflectance then the equations are not independent and the equation system might have solutions. One way of solving this equation is to solve a_b using one of the three equations and then check whether or not this a_b satisfies the other two equations. If it does, then this is the solution and otherwise the equation system has no solution. Another way of calculating a_b is to rewrite Equation 5.11 as Equation 5.12. a_b is then calculated by multiplying the first row in the inverse matrix with the column vector. This solution is accepted if the other two rows in the inverse matrix multiplied by the column vector result in 1. This has been checked in all of the calculations carried out in this thesis and they always resulted in a number between 0.95 and 1.05.

$$\begin{bmatrix} a_b \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} (X_b + X_w - X_c - X_m) & A_c \cdot (X_c - X_w) & A_m \cdot (X_m - X_w) \\ (Y_b + Y_w - Y_c - Y_m) & A_c \cdot (Y_c - Y_w) & A_m \cdot (Y_m - Y_w) \\ (Z_b + Z_w - Z_c - Z_m) & A_c \cdot (Z_c - Z_w) & A_m \cdot (Z_m - Z_w) \end{bmatrix}^{-1} \cdot \begin{bmatrix} (X_{ave} - X_w) \\ (Y_{ave} - Y_w) \\ (Z_{ave} - Z_w) \end{bmatrix} \quad (5.12)$$

A possible solution to an overdetermined equation system, especially those with linearly independent equations, is to find an approximation to the solution by using linear optimization, which is out of the scope of this thesis.

5.6 Statistical Evaluation of the Register Variation

For the evaluation of the register variation a number of consecutive printed sheets are needed. Normally the print machine manufacturers evaluate a series of about 30 to 50 consecutive printed sheets. This number of sheets allows a meaningful evaluation and statistics. Assume that there is a series of measured data of a_b for n printed and measured sheets. The arithmetic average of a_b is determined by Equation 5.13.

$$\overline{a_b} = \frac{1}{n} \sum_{i=1}^n a_b^i, \quad (5.13)$$

where a_b^i is the coverage of blue (a_b) for printed sheet no. i .

Now the centered and metric transformed value (r_i) of a_b is calculated by Equation 5.14.

$$r_i = (a_b^i - \overline{a_b}) \cdot \delta, \quad (5.14)$$

where δ denotes the metric conversion factor for the register variation values. The factor δ is used to transform the centered coverage to a metric amount [μm]. As discussed in Section 5.3, in this experiment the width of a cyan line is 128 μm , which corresponds to the coverage of 0.5. Therefore, a coverage of unity means 128 $\mu\text{m} \cdot 2 = 256 \mu\text{m}$ and thereby $\delta = 256 \mu\text{m}$. For example, if a_b is equal to 0.35 for sheet no. 1 and equal to 0.5 for the consecutive printed sheet (i.e. no. 2) then there will be a shift of 0.15 which corresponds to $0.15 \cdot 256 \mu\text{m} = 38.4 \mu\text{m}$.

5.7 Experimental Results, Comparisons and Discussions

The graph of the register variation and the standard deviations are the most important data for evaluating and interpreting the register variation of a printing machine. Figure 5.6 shows the test form, including six LUCHS elements and the designed color stripe, used to compare the results of the proposed method with those of the LUCHS method.

Figure 5.6: (a) The six LUCHS elements are placed around the designed color stripe. The elliptical marked areas show the needed elements. (b) The enlargement of the needed elements. These elements correspond to the three demonstrated patches in Figure 5.3.

Figure 5.7 and Table 5.1 illustrate the graphs and the statistical results of the LUCHS device, the densitometry and spectrophotometry methods.

For testing and comparing these methods it was necessary to have samples with register variations. Hence the samples were produced under following printing conditions: The test was carried out using a Roland 700, a printing machine, installed at manroland Print Technology Center in Offenbach, Germany. The printing machine was accelerated from 8,000 to 13,000 sheets/hour with an opened driver shaft. The used paper substrate was a relative stable and both side glossy coated 150 g/m². For the densitometric and spectrophotometry measurements a Color Pilot from Grapho Metronic (manroland) was used. This experiment was done by experts of a printing machine manufacturer. A set of consecutive printed sheets (48 sheets) from this run has been evaluated. Most of the modern sheet fed offset printing machines have double impression cylinders (Section 3.5.2.4). Therefore every impression cylinder and every transfer cylinder has two different gripper systems. The register variation value of the consecutive printed sheets are therefore evaluated separately for the first gripper system using odd and for the second gripper system using even printed sheets. That is necessary for analyzing the register variations of a modern printing machine. In Figure 5.7, the red and blue graphs show the odd and even printed sheets, respectively. Figure 5.7 shows the graph of the centered registered value in [μm] for LUCHS (s_i) and the proposed methods (r_i in Equation 5.14).

Figure 5.7: The comparison of the register variation between the LUCHS (s_i) and the proposed methods (r_i). The red and blue curves show the register variation for the odd and even printed sheets, respectively.

For determining the register variation using the LUCHS method the middle LUCHS element in the upper row was used. As seen in Figure 5.7 the shape and the characteristic of the curves of all three methods are similar. As discussed in Section 5.2 the absolute register value of each sheet is not so important. The shape of the register variation for a set of evaluated sheets is more important and the most important factor is their standard deviation (bvdn, 2002; FOGRA, 2005). In Table 5.1 the standard deviation and the linear correlation of all three methods are shown.

Table 5.1: Up-The comparison of the standard deviation between the LUCHS and the introduced methods. Down: correlation coefficients between LUCHS and the proposed methods.

Standard deviation	Measuring method			
	LUCHS	Densitometry	Spectrophotometry	Paper instability (LUCHS)
	8.5 μm	8.8 μm	7.6 μm	abs [9.2 - 8.5] = 0.7 μm
<p>The linear correlation between different measuring methods for evaluating register variation</p> <p>LUCHS register values and Densitometry register values: 0.87</p> <p>LUCHS register values and Spectrophotometry register values: 0.85</p> <p>Densitometry register values and Spectrophotometry register values: 0.91</p>				

The difference of the standard deviation between all three methods is less than 1 μm , which is very good in comparison to the range of the register variation (bydm, 2002; FOGRA, 2005). The correlation coefficient value between LUCHS and the proposed methods is also shown in Table 5.1. The achieved correlation coefficient values are more than 0.85, which shows a good correlation between the methods. In order to figure out the instability of the paper surface the results of the LUCHS method were even compared using the six LUCHS elements. The arithmetic average value of the LUCHS elements were taken and compared to the results of the middle LUCHS element in the upper row. As seen in Table 5.1, this difference is about 0.7 μm .

5.8 Summary

As demonstrated in this chapter the achieved results are good and comparable with the LUCHS method. The register variation value can be determined in any printing company dependent on their measuring equipment, either by the densitometry or the spectrophotometry method. The needed measuring tools are available in almost all printing companies. The biggest advantage of the proposed methods is that they are not expensive compared to the image processing method and the needed measuring elements can be integrated in a color and tone value measuring bar for generating a dot gain compensation curve (Section 8.2.2.1). The simultaneous evaluation of register variation and generation of a dot gain compensation curve is important for the print quality control which is an important requirement for an automated CtP calibration system introduced in Chapter 8. Furthermore, dependent on the paper size and the number of LUCHS elements and evaluated sheets the image processing method can be time consuming and not ergonomically satisfactory for the operator. In a printing machine with ink inline control system using a

densitometry or a spectrophotometry system, the evaluation of register variation can be done automatically by using the proposed methods, which saves time, human resources and costs.

Chapter 6

A NOVEL SPECTRAL METHOD TO DETERMINE INK TRAPPING

Introduction

Proposed Spectral Trapping Model

Experimental Results of the Proposed Trapping Model

Spectral Trapping Model including Ink Penetration and Gloss
Effect

Experimental Results of the Modified Spectral Trapping
Model

Summary

6.1 Introduction

In a multi-color offset printing machine, the process inks (KCMY) are printed consecutively on the substrate in one printing unit after the other. The dots in different ink units are printed either isolated or partly or completely overprinted. The overprinted inks are printed wet-on-wet. The thickness or the amount of the second printed ink on the first one is not the same as when the second ink is printed on the paper. This phenomenon is called trapping, which was briefly introduced in Chapter 4. Trapping varies due to different parameters such as ink temperature, dampening, printing speed, etc. Trapping affects the gray balance and the color appearance (secondary and tertiary colors) of the printed products. Therefore it is very important to have an explicit value for measuring trapping.

In order to determine the trapping value, it is necessary to make a comparison between the ideal (calculated) and the real (printed and measured) overlapping. The real overlapping means the measured overlapped reflectance value of two different overprinted inks at full coverage (for example magenta on cyan resulting in blue). The ideal overlapping is calculated using the reflectance of both single printed inks on paper resulting in an “absolute value” or a “best value”, shown in Figure 4.8.

There have been many conventional trapping models proposed in literature: Preucil (1952), Brunner (Du Pont, 1979) and Ritz (1996).

All conventional trapping models are based on density (Kipphan, 2008). In Chapter 4 the two most well known conventional models designed by Preucil and Ritz were introduced. These conventional formulas for trapping only provide the amount of the second printed ink on the top of the first one in percent. This value on its own (e.g., 63%) is not very useful and meaningful for printing machine operators. The results obtained by these formulas also differ from each other.

In Section 6.2 a novel spectral trapping model is proposed (Hauck and Gooran, 2011b). In Section 6.3 the result of the experimental tests using this model is described and a comparison between two conventional models and the proposed model is made. One of the advantages of the proposed model is that the trapping is presented by a color difference value, ΔE^*_{ab} .

In all proposed trapping models the effect of ink penetration (ground effect) and gloss (surface effect) were ignored. Although both the first and the second single printed inks change the incoming light due to the surface effects (such as gloss, etc.), the surface effects only play a role for the second (over-)printed ink in the real overlapping. On the other hand, the ink penetration plays a role mainly for the first (under-)printed ink in the real overlapping. In Section 6.4, the spectral trapping model is modified to take into account the ink penetration and the gloss effect (Hauck and Gooran, 2013). In Section 6.5 the experimental results of this

modification are illustrated and compared with the results of the non-modified spectral trapping model. In Section 6.6 a summary of this chapter is given.

6.2 Proposed Spectral Trapping Model

The main difference between the proposed model and the conventional models is that it is based on the reflectance spectra, and the resulting trapping value is not “only” a percentage value. The effect of trapping in this model is presented as the color difference, which is much more understandable and useful for the printing machine operators. The color difference is computed between the calculated overlapped and the measured overlapped spectra. For a single printed ink, for example cyan or magenta in Figure 4.8, the reflectance $R_c(\lambda)$ or $R_m(\lambda)$ can be calculated by Equation 6.1 and 6.2, respectively.

$$R_c(\lambda) = T_c^2(\lambda) \cdot R_p(\lambda) \quad (6.1)$$

$$R_m(\lambda) = T_m^2(\lambda) \cdot R_p(\lambda), \quad (6.2)$$

where $R_p(\lambda)$, $T_c(\lambda)$ and $T_m(\lambda)$ denote the reflectance of the paper, the transmittance of solid cyan and solid magenta, respectively. The transmittances are squared because the incoming light passes through the ink layer twice before it is reflected back. The reflectance of the overlapped inks, in this case magenta printed on cyan (blue), is calculated by Equation 6.3.

$$R_b^{\text{calculated}}(\lambda) = T_c^2(\lambda) \cdot T_m^2(\lambda) \cdot R_p(\lambda), \quad (6.3)$$

where $R_b^{\text{calculated}}(\lambda)$ denotes the calculated reflectance of blue. Inserting Equations 6.1 and 6.2 in Equation 6.3 gives Equation 6.4, which is the calculated overlapped spectral reflectance based on the reflectance of the single inks printed on paper and the reflectance of the paper.

$$R_b^{\text{calculated}}(\lambda) = \frac{R_c(\lambda) \cdot R_m(\lambda)}{R_p(\lambda)} \quad (6.4)$$

Figure 6.1 shows the measured spectral reflectance of the single inks, overlapped inks and the theoretically calculated overlapped inks, where c denotes cyan, m magenta, y yellow, c+m the measured overlapping of magenta on cyan, c+y the measured overlapping of yellow on cyan (green), m+y the measured overlapping of yellow on magenta (red), (c+m)+y the measured overlapping of yellow on blue. The dashed lines show the corresponding

spectral curves of the calculated overlapping and p shows the spectral reflectance of the paper.

Figure 6.1: The measured and calculated spectral reflectance of single and overlapped inks.

For the calculation of trapping, both the measured and the calculated overlapped spectral reflectance of blue are needed. As seen in Figure 6.1, the calculated and measured spectral reflectance of the overlapped inks is not identical. The main reason for this difference is trapping and therefore we propose to measure the trapping value based on this difference. In order to represent the trapping value by ΔE_{ab}^* , the CIELAB values are calculated using the spectral reflectance of the measured and calculated overlapped spectra.

Therefore the spectral trapping value for blue (magenta printed on cyan) is defined as the color difference between the measured and calculated CIELAB values of blue, shown in Equation 6.5.

$$\Delta E_{ab_b}^* = \sqrt[3]{[(\Delta L_b^*)^2 + (\Delta a_b^*)^2 + (\Delta b_b^*)^2]}, \quad (6.5)$$

where $\Delta E_{ab_b}^*$ and ΔL_b^* denote the spectral determined trapping value for blue and the difference of lightness between the measured blue ($L_b^{*\text{measured}}$) and the calculated blue ($L_b^{*\text{calculated}}$). Δa_b^* and Δb_b^* denote the difference of red-green values and the difference of the yellow-blue values between the measured

and calculated blue, respectively. The spectral trapping values of other ink combinations (for example green or red) are calculated correspondingly.

6.3 Experimental Results of the Proposed Trapping Model

Table 6.1 shows the measured overlapped *CIELAB* values and the measured and calculated *CIELAB* values for overlapped inks. Furthermore, the trapping values are calculated by the proposed model (represented with ΔE_{ab}^*), the Preucil and Ritz models and demonstrated for four sample sheets (m+y, c+y, c+m and blue+y). blue+y denotes the trapping value between the secondary color blue and the primary color yellow.

Table 6.1: Trapping values according to ΔE_{ab}^* , Preucil and Ritz and correlation values between the proposed method and the conventional methods.

Sheet no.	Combination	measured			calculated			Trapping values according to:		
		overlapping data			overlapping data			ΔE_{ab}^*	Preucil	Ritz
		L^*	a^*	b^*	L^*	a^*	b^*			
1	m+y	46.2	63.8	40.0	44.2	64.6	53.3	14	63	90
	c+y	49.7	-63.2	23.2	47.6	-64.5	28.6	6	75	95
	c+m	24.8	19.8	-45.8	16.3	24.9	-45.2	10	65	93
	blue+y	23.5	-1.4	-4.2	12.1	6.9	3.8	16	53	85
2	m+y	46.2	64.1	40.5	44.0	65.1	53.6	13	65	91
	c+y	49.6	-63.8	23.5	47.3	-65.1	28.9	6	75	95
	c+m	25.2	19.1	-45.6	16.0	25.4	-45.8	11	64	93
	blue+y	23.7	-1.2	-4.6	11.6	6.8	3.6	17	52	84
3	m+y	46.5	63.4	41.1	44.0	65.0	54.3	14	63	90
	c+y	49.3	-63.1	21.9	46.9	-64.5	30.0	9	69	93
	c+m	25.7	17.7	-45.9	15.8	25.2	-45.2	12	60	92
	blue+y	24.9	-4.3	-4.1	11.5	7.1	4.5	20	50	83
4	m+y	46.5	63.5	40.9	43.9	65.6	54.1	14	63	90
	c+y	49.3	-63.1	21.1	46.8	-65.2	29.4	9	70	93
	c+m	25.9	16.8	-46.1	15.4	25.6	-45.8	14	58	91
	blue+y	24.8	-3.8	-4.5	11.1	7.0	3.7	19	51	84
Correlation coefficient between the spectral and the corresponding conventional trapping method:									-0.96	-0.93

In Table 6.1 the correlations (linear correlation coefficient values) between the ΔE_{ab}^* and the results by the conventional methods are displayed, which indicates for high correlations between the methods. The reason for the negative correlation (negative sign) is that if the trapping effect decreases, the ΔE_{ab}^*

trapping value also decreases (which means less trapping) while the percentual trapping value increases (which also means less trapping).

In Table 6.2 the trapping values for blue+y in sheet 2 and 3 are compared. The comparison shows an increase of the trapping effect on the third sample sheet. Furthermore, Table 6.2 demonstrates the relative differences of trapping values between sheet 2 and 3 being the ratio of the trapping difference to the trapping value. For example the relative difference value for the proposed method is: $\frac{|2.9| \cdot 100}{16.6} = 17.5\%$, and for Preucil is: $\frac{|-2.7| \cdot 100}{52.5} = 5.1\%$. The relative difference describes how sensitive a model is to the trapping effect between two samples (dynamic range). As can be seen the dynamic range of the recommended trapping model is the largest. In this example the dynamic range of the proposed method is almost 3.5 times higher than the dynamic range of the Preucil method and 13.5 times higher than the one of the Ritz method. The advantage of a high dynamic range is that the printing machine operators can better differentiate the trapping values.

Table 6.2: Trapping values for blue+y for two different sheets and their differences.

blue+y	Sample no	ΔE^*_{ab}	Preucil	Ritz
	2	16.6	52.5	84.3
	3	19.5	49.8	83.2
Difference		2.9	-2.7	-1.1
Rel. Difference [%]		17.5	5.1	1.3

Figure 6.2 shows the correlation between the trapping values (from Table 6.1) obtained by the proposed, the Preucil (1952) and Ritz (1996) conventional trapping models, which exhibits a linear trend.

Figure 6.2: The linear regression lines between the trapping values obtained by the proposed and the conventional models from Table 6.1.

It can also be observed that the dynamic range of the Preucil model is larger than that of the Ritz model. However, the dynamic range of the proposed model is the largest as demonstrated in Figure 6.2. In conclusion, it could be said that one of the main improvements of the proposed trapping model is the extension of the very low dynamic range of the conventional models into a more sensitive and understandable trapping value $[\Delta E_{ab}^*]$, which helps the printing machine operators to differentiate the trapping values better and thereby reacting faster to control the printing process. Another advantage of this model is that, unlike the conventional density models that can only determine the trapping value for process inks, this spectral model can determine the trapping value both for process and special inks. The reason is that, as described in Chapter 2, the complementary filters used in densitometers are only optimized for process inks.

6.4 Spectral Trapping Model including Ink Penetration and Gloss Effect

As mentioned before, all trapping models neglect the effect of gloss and ink penetration in the calculation of the ideal overlapping. In this section it is explained how the proposed trapping model is extended to take into account the ink penetration and gloss effect. Later in Section 6.5, the proposed trapping model and its extended model are compared by experiments carried out on a high quality glossy paper. For simplicity, from now on the proposed model in Section 6.3 is called the simple model and the model described in this section the modified model.

6.4.1 Ink Penetration

Ink penetration has a great impact on the print result (Rousu et al., 2000; Yang, Lenz and Kruse, 2001). Ink penetration is explained by explaining the following terms: ink components, separation effect, penetrability of different substrates, and ink drying and absorption.

6.4.1.1 Ink Components

Conventional offset inks may contain the following elements: colorant agents (pigments, organic as well as certain inorganic pigments), vehicles (hard resins, alkyd resins, vegetable and mineral oils), auxiliaries (waxes, drying agents (siccative), fillers and inhibitors) and thinners (mineral and/or vegetable oils) (Ink academy, 2013).

6.4.1.2 Separation Effect

The paper coating is a barrier for the ink, which resists the penetration (Ozaki, Bousfield and Shaler, 2008). The preparation of the paper fibers and the calendering process in the paper manufacturing process can also be important for the behavior of the penetration of ink components (Schoelkopf et al., 2003a and 2003b). The fresh printed ink penetrates (with all of its components, i.e., pigments, vehicles, auxiliaries and thinners) into the layer of the paper coating and the paper fiber dependent on the separation effect of the paper. The separation effect is a result of the capillary characteristics of paper fibers and the structure of the coating layer on the paper. Like a sieve filled with a mixture of particles, the surface characteristics of the paper separates some components of the ink (mostly colorant pigments) from the other components of the ink (such as the ink vehicle). The amount of penetration depends on the average diameter of pores and the capillarity of the sieve mesh. If the pore diameter of paper is small mainly the oil penetrates into the paper while the colorant pigments remains on the surface. If the pore diameter is large (or there is no coating layer as in newspaper substrate), both oil and colorant pigments can penetrate (ink penetration) into the paper, leading to an increase in reflectance and a reduced density and color saturation of the printed ink (Ink academy, 2013). It is important to mention that because of the separation effect the different ink components do not penetrate equally into the paper. Usually, for a high quality glossy paper (the paper investigated in the present research), most of the colorant pigments remain on the coating surface. However, the pore and capillary diameter of the tested paper (and its coating) is not an absolute (100%) barrier.

6.4.1.3 Penetrability of Different Substrates

According to penetration and separation effect, printing substrates can be categorized into three groups: non-penetrative (metal sheet, plastic and foil), partly penetrative (e.g., glossy coated paper, which is investigated in this study), and totally penetrative (uncoated and newsprint paper). For non-penetrative substrates the ink cannot penetrate into the substrate. For a penetrative substrate, mainly the ink oil and partly the auxiliaries, thinners and ink vehicle can penetrate into the substrate (this is a time dependent process). Depending on the paper fibers, the coating mixture and the calendering process of substrate, the number of penetrated pigments into the coating varies, but most of the pigments remain on the surface while only a small portion of the pigments penetrate into the substrate. For a totally penetrative substrate, all ink components penetrate into the paper. Hence, in order to achieve the target ink density using a penetrative substrate, the thickness of the printed ink has to be more than that in the other two types of substrate in order to compensate the high rate of ink penetration.

6.4.1.4 Ink Drying and Absorption

Conventional offset inks dry chemically, physically or, mostly, as a combination of both (as the ink investigated in the study for this modified model). Chemical drying means that when the ink vehicles (vegetable oils and alkyds) are exposed to atmospheric oxygen, they polymerize to form a tough, elastic film which fixes the ink on the substrate. This process is generally referred to as “oxidative drying”, which represents the most common form of chemical drying. Chemical drying of inks can be described as cross-linking of components and can take many hours. Physical drying means that mineral oils and many esters of vegetable oils do not polymerize when exposed to air, as drying oils do, but they penetrate into absorbent substrates and separate from the other ink components. This specific form of physical drying is called “setting”. The absorption process is thus an interaction between ink and printing substrate (Rousu et al., 2000). The absorption rate is dependent on the diameter and the number of the pores and the viscosity of the ink vehicle. Larger pore diameters result in a higher absorption rate. The higher the viscosity of the ink vehicle is, the lower the absorption rate. As discussed above, the coating layer of a high glossy paper sieves most of the ink pigments on the surface. However, depending on the coating quality of a high glossy paper, the diameter and form of the paper fibers, and the colorant pigment size, some pigments can also penetrate into the paper. It has already been shown that, due to the ink penetration, the reflectance of the printed ink increases and its density decreases (Yang, Lenz and Kruse, 2001).

From now on in this thesis the term ink penetration is used to refer to ink vehicle penetration and only a minor pigment penetration of ink into the coating layer of the paper (Ink academy, 2013).

6.4.2 Gloss

In addition to ink penetration, gloss has also an impact on the reflectance (density) of the print. The fresh printed ink is at first uneven (wavy) and hence not glossy. Very rapidly it acquires a relatively even and glossy surface. Hence, part of the incoming light will be specularly reflected at the surface of the printed ink and will therefore not pass through the ink layer. The gloss therefore has an effect on the measured results depending on the physical and optical principles of the measuring device. The gloss value of the fresh printed ink changes with time after the printing. The drying process starts after the printing and continues until the ink is completely dry. Because of the fast drying of the upper layer of the ink surface compared to the lower layers, the ink builds a rough skin and crust, which reduces the gloss effect. Because of this rough skin more incoming light will be absorbed in the same measuring area (2D- to 3D-effect). This effect causes a decrease of the reflectance and consequently an increase of the density, assuming that no ink penetration occurs. This explains why sometimes the gloss

value and also the reflectance decrease after printing (on plastic or foil which have no ink penetration). This paradoxical behavior of gloss is also illustrated and demonstrated later in Section 6.4.3.

Figure 6.3 demonstrates the reflectance levels of the first and second single printed inks and the real (printed and measured) overlapping, all printed on a partly penetrative substrate (glossy coated paper). As illustrated, in reality the effective thickness of magenta is smaller if magenta is printed on cyan than on the paper (because of trapping). As mentioned before, the reason for trapping is wet-on-wet printing. Therefore the reflectance level of the real overlapping is higher than the calculated overlapping in the simple model. The difference between real and calculated overlapping in *CIELAB* was approximated as the effect of trapping in the simple model.

Figure 6.3: A schematic of a solid value print involving paper, cyan including gloss and ink penetration, magenta including gloss and ink penetration, real ink overlapping and the calculated overlapping of the simple and the proposed modified model.

Furthermore, Figure 6.3 also illustrates the relationship between the reflectance levels of the real, the calculated overlapping of the simple and the calculated overlapping of the modified models. In the proposed model the gloss and ink penetration effect on high quality glossy coated papers are taken into account. The ink penetration of single printed magenta leads to a higher reflectance (lower density). If now the ink penetration effect of magenta is excluded in the modified model, it will mean that the effective thickness of magenta is larger than that in the simple model. As the surface effect is generally smaller than the ink penetration effect, especially for cyan and yellow (on the materials used in the experiments), the effective thickness of cyan is almost the same in both models.

In the modified model, the intention is to approximate the trapping effect when the measurements are done at 30 seconds (wet) after printing. This is the average time that the print machine operator needs to measure the fresh printed sheets. For simplicity, the case for blue (magenta on cyan) is described. Thirty seconds are taken as the reference point and the study is done between 30 seconds and 48 hours. All that has happened before 30 seconds is of no interest in this study.

It is also very difficult for the operator of a printing machine to carry out the measurements of the fresh printed sheet before 30 seconds.

In order to have a realistic model for trapping the ink penetration for cyan and the surface effect (gloss effect) for magenta should be taken into account. The modified model will then be as in Equations 6.6.

$$R_{b,model}^{calculated}(\lambda) = [T_c^{meas,wet}(\lambda) \cdot T_c^{ip}(\lambda) \cdot T_m^{meas,wet}(\lambda) \cdot T_m^{gl}(\lambda)]^2 \cdot R_p(\lambda), \quad (6.6)$$

where $R_{b,model}^{calculated}(\lambda)$ denotes the reflectance of calculated blue according to the modified model when the measurements are done at 30 seconds (wet). $T_m^{meas,wet}(\lambda)$ and $T_c^{meas,wet}(\lambda)$ denote the measured transmittance for single magenta and single cyan at 30 seconds, respectively. $T_m^{gl}(\lambda)$ and $T_c^{ip}(\lambda)$, denote the transmittance of the gloss effect for magenta and the ink penetration for cyan, respectively. It can be argued that the effects of gloss (which is dependent on the shrinking and roughness of the ink surface) and ink penetration are normally not mutually independent. This will be discussed in detail in Section 6.4.3.

As shown earlier, the relationship between the transmittance and reflectance is described by Equation 6.7.

$$[T(\lambda)]^2 = \frac{R(\lambda)}{R_p(\lambda)}, \quad (6.7)$$

where $T(\lambda)$ and $R(\lambda)$ denote the measured transmittance and reflectance.

6.4.3 Approximating Gloss and Ink Penetration

In order to approximate the gloss and ink penetration effect an ink mileage test has been done. Figure 6.4 shows how the ink mileage test is performed. The ink mileage is not a measure of ink penetration but a complex combination of transfer dynamic, ink solids content, rheology of the ink, surface energy relationships, roughness of surface and blanket, etc. In this study, the goal is to use the ink mileage test to determine the interaction between paper and ink. A typical use for the ink mileage test is to determine the relationship between the density or reflectance of an ink and the printed ink volume. The procedure is as follows: A definite ink volume (a few grams) is poured into an inking unit. During the rotation and oscillation of the rollers the ink is distributed in the inking unit, shown in Figure 6.4(a). At the inking unit, a printing form (a small cylinder with an offset printing blanket) is inked up for a limited time (in our tests for 1 minute). The printing form is removed from the inking unit and

weighted on a precision balance (Figure 6.4(b)) prior to the printing procedure. During printing, part of the ink is transferred onto the printing substrate, shown in Figure 6.4(c). After the printing procedure, the printing form is removed from the inking unit and weighted again on the precision balance. The weight difference of the printing form before and after the printing is the weight of the printed ink.

Figure 6.4: Ink mileage test and the needed equipment. (a) inking unit and the printing form. (b) the precision balance and the printing form. (c) the printing unit with mounted printing form and the printing substrate. (d) the produced sample with different density and reflectance dependent on the used ink weights per unit area [g/m^2].

The exact amount of ink weight per unit area [g/m^2] can be determined by the ratio of the weight of the printed ink and the size of the printed area (in this case 102.5 cm^2). It is important to perform the sampling of ink mileage with the highest possible accuracy. The accuracy of the ink mileage test has a great impact on the accuracy of the results of the trapping model. All the experiments were carried out at 22°C at a relative humidity of 55%. The printing pressure and printing speed were constant during the test.

A coated paper includes both gloss and ink penetration, but a foil only includes gloss and no ink penetration, which is important for the separation and

determination of both the gloss and the ink penetration effect. A white foil with similar surface roughness as the coated glossy paper was used in order to have similar printing conditions, shown in Figure 6.5. During the ink mileage test ten different ink weights per unit area [g/m^2] for paper and foil were printed and the same cyan, magenta and yellow inks as in the test offset printing machine were used. For each of the ink weights per unit area [g/m^2] and substrate (paper and foil) the density and the reflectance spectra as well as the gloss value between 30 seconds and 48 hours were measured.

Figure 6.5: The roughness of the surface of sample paper and of two different foils (measured optically with high resolution, ordered by manroland S&D department).

The roughness is visualized using different colors. (a) the roughness of the used paper, (b) the roughness of a foil with a similar roughness as the used paper, (c) a foil with a very even and smooth surface compared to the used paper. At the bottom, a colored scale shows the level of roughness [μm].

Figure 6.6 shows the result of the ink mileage tests which demonstrates the relationship between the ink value as weights per unit area [g/m^2] and the relative density for magenta ink printed on paper (a) and foil (b). For each single printed ink on both substrates (paper and foil) the density at 30 seconds and 48 hours were measured. The curves show the cubic spline interpolation for the ten data points. Since the same paper is used in offset printing and in the ink mileage test, the total effect (gloss and ink penetration) is the same in both cases.

Let us describe the approach by an example: Assume that a paper sheet printed in offset is being evaluated for trapping and is measured about 30 seconds after being printed. Assume also that the measured density value is 1.48. According to Figure 6.6(a), the red curve, this density corresponds to the ink value (weight per area) of $1 \text{ g}/\text{m}^2$. The ink value $1 \text{ g}/\text{m}^2$ corresponds to density value 1.46 in the blue curve (after 48h), meaning that the difference $1.46 - 1.48 = -0.02$ density is the effect of both ink penetration and gloss. The difference between the density at 30sec and 48h of ink mileage test on the foil at the same ink value

gives the gloss effect. Therefore, at 1 g/m² the density is 1.41 and 1.47 at 30sec and 48 hours, respectively, meaning that the gloss effect is at 1.47 – 1.41 = 0.06 density.

Figure 6.6: Graphs of the results of the ink mileage test for magenta. It demonstrates the relationship between density and ink weight per unit area [g/m²] for magenta. Each graph shows the wet (red curve) and dry density (blue curve). (a) magenta ink printed on the sample paper (including the surface effect and ink penetration). (b) magenta ink printed on foil (including only the surface effect). For both substrates, the gloss values (dashed line) are measured at different times.

The curves shown in Figure 6.6 are for magenta. Cyan and yellow have their own corresponding curves. It is worth emphasizing that the used cyan and yellow inks dried out more slowly than the magenta. It was also observed that an ink that dries fast has a stronger gloss effect. As discussed in Section 6.4.2, the reason is that during this fast drying process the ink surface builds a rough skin and crust. The building of this rough skin is dependent on the drying speed which depends on the type of the ink, the ink volume and the drying room temperature. Because of this rough skin, more incoming light is absorbed (2D to 3D-effect) which can lead to an increased density (reduced reflectance level). Hence, the gloss effect for the magenta ink used in this experiment is more evident than that for the other two inks. In order to find the ink penetration for magenta to be used in the modified model the spectrum for magenta on paper and foil were used, once after 30 seconds and once again after 48 hours. As discussed above, when printing on foil there is no ink penetration involved in the measurements. Therefore, the difference between the density at 30 seconds (wet) and 48 hours (dry) on the foil is approximated to be only the gloss effect,

see Equation 6.8 which is positive for magenta and almost zero for cyan and yellow in this experiment.

$$D^{gl} = D_{dry}^{foil} - D_{wet}^{foil}, \quad (6.8)$$

where D^{gl} , D_{dry}^{foil} and D_{wet}^{foil} denote the density of the gloss effect and the density of the dried and wet ink on foil, respectively. Equation 6.8 can be expressed for transmittance spectra by Equation 6.9.

$$T^{gl}(\lambda) = \frac{T_{dry}^{foil}(\lambda)}{T_{wet}^{foil}(\lambda)}, \quad (6.9)$$

where $T^{gl}(\lambda)$, $T_{dry}^{foil}(\lambda)$ and $T_{wet}^{foil}(\lambda)$ denote the transmittance of the gloss effect and the transmittance of the dried and wet ink on foil, respectively. Furthermore, the density difference of the inks on the paper at 30 seconds and 48 hours depends on both ink penetration and the gloss effect, see Equation 6.10.

$$D^{total} = D_{dry}^p - D_{wet}^p, \quad (6.10)$$

where D^{total} , D_{dry}^p and D_{wet}^p denote the density of the total effect (gloss and ink penetration) and the density of the dried and wet ink on paper, respectively. Excluding the gloss effect (Equation 6.8) from the total effect (Equation 6.10) then the ink penetration effect (D^{ip}) can be found by Equation 6.11.

$$D^{ip} = D^{total} - D^{gl} = (D_{dry}^p - D_{wet}^p) - (D_{dry}^{foil} - D_{wet}^{foil}) \quad (6.11)$$

As discussed in Section 6.4.2, the effects of gloss and ink penetration are normally not mutually independent. The reason is that the gloss is a function of roughness associated with the substrate, the amount of ink applied and ink penetration. The reason why, in the proposed model, these two effects are assumed to be independent is to make the model feasible and simple. The investigated paper and foil (Figure 6.5(a) and (b)) were also chosen in a way to support this assumption. One of the reasons supporting this assumption is that a foil with similar surface structure as the paper was chosen. Another reason is that the measured gloss value of the completely dried ink on paper is close to

that printed on the foil, shown in Figure 6.6(b). Notice that the measured gloss values of paper and foil before print ($t=0$, Figure 6.6(a) and (b)) are far from each other, although they have similar surface structure. The reason is that the surface materials are different and hence have different refractive indices. When both surfaces are covered by the same kind of ink and the same ink value in this experiment, they have the same gloss value when dried.

Equation 6.11 can be expressed for the transmittance spectra as shown in Equation 6.12.

$$T^{ip}(\lambda) = \frac{T^{total}(\lambda)}{T^{gl}(\lambda)} = \frac{T_{dry}^p(\lambda)}{T_{wet}^p(\lambda)} \cdot \frac{T_{wet}^{foil}(\lambda)}{T_{dry}^{foil}(\lambda)}, \quad (6.12)$$

where $T^{ip}(\lambda)$, $T^{total}(\lambda)$, $T_{dry}^p(\lambda)$ and $T_{wet}^p(\lambda)$ denote the transmittance of the ink penetration effect, transmittance of the total effect, and the transmittance of the dried and wet ink on paper, respectively. Inserting Equations 6.9 and 6.12 into Equation 6.6 results in Equation 6.13.

$$R_{b,model}^{calculated}(\lambda) = \left[\frac{T_c^{meas,wet}(\lambda) \cdot T_{c,dry}^p(\lambda) \cdot T_{c,wet}^{foil}(\lambda) \cdot T_m^{meas,wet}(\lambda) \cdot T_{m,dry}^{foil}(\lambda)}{T_{c,wet}^p(\lambda) \cdot T_{c,dry}^{foil}(\lambda) \cdot T_{m,wet}^{foil}(\lambda)} \right]^2 \cdot R_p(\lambda), \quad (6.13)$$

$T_c^{meas,wet}(\lambda)$ and $T_m^{meas,wet}(\lambda)$ are the measurement results of the transmittance of cyan and magenta printed on an offset machine at 30 seconds. The measured reflectance can be transformed to transmittance by Equation 6.7. $R_p(\lambda)$ is the reflectance of the paper which has to be of the same quality for print and ink mileage. The remaining variables in Equation 6.13 are known from the ink mileage experiment data and the necessary interpolation. The indices c and m in Equation 6.13 stand for cyan and magenta. Equation 6.13 gives an approximation of the reflectance of the calculated blue taking into account the ink penetration effect for printed cyan and the gloss effect for printed magenta. In order to find the trapping value, this reflectance has to be compared with the measured reflectance of the real blue printed at the offset printing machine at 30 seconds. The ΔE_{ab}^* difference between these two reflectance gives the trapping value.

For red (yellow on magenta), and green (yellow on cyan) Equation 6.13 can be modified correspondingly. For black (yellow on magenta on cyan) similar equation can be driven assuming that cyan only has ink penetration, magenta has neither ink penetration nor gloss effect, and yellow only has gloss effect.

6.5 Experimental Results of the Modified Spectral Trapping Model

In order to compare the results of the spectrophotometry model introduced in Section 6.3 with the modified model, an experiment has been carried out. In the experiment a high quality glossy paper and an offset printing machine are used. Table 6.3 and Table 6.4 illustrate the trapping values for red (m+y), green (c+y), blue (c+m) and black (blue+y) using the simple model and the modified model, respectively.

Table 6.3: The result of the simple spectrophotometry based trapping model.

spectrophotometry model	combination	measured overlapping data			calculated overlapping data			ΔE_{ab}^* Trapping value
		L*	a*	b*	L*	a*	b*	
	m+y	46.7	68.7	46.3	46.6	67.0	59.7	13.5
	c+y	52.3	-67.1	38.5	52.6	-63.1	43.6	6.5
	c+m	24.5	23.8	-47.5	20.6	26.7	-48.1	4.9
	blue+y	22.9	0.5	0.5	16.3	9.0	10.7	14.8

Table 6.4: The result of the modified spectrophotometry based trapping model which takes into account the ink penetration and gloss effect.

modified spectrophotometry model	combination	measured overlapping data			calculated overlapping data			ΔE_{ab}^* Trapping value
		L*	a*	b*	L*	a*	b*	
	m+y	46.7	68.7	46.3	46.7	67.5	61.0	14.7
	c+y	52.3	-67.1	38.5	52.9	-64.5	44.4	6.4
	c+m	24.5	23.8	-47.5	20.7	28.2	-49.2	6.0
	blue+y	22.9	0.5	0.5	15.9	9.7	12.5	16.6

Therefore in the results in Table 6.3, the gloss and ink penetration effect are included. A comparison between Tables 6.3 and 6.4 shows that the effect of trapping was somewhat underestimated in the simple model. It is worth emphasizing that all conventional trapping models also underestimate the effect of trapping. As seen in Table 6.3 and Table 6.4, the maximum difference between the trapping values of these two models is almost 1 ΔE_{ab}^* for the

primary color and less than $2 \Delta E_{ab}^*$ for the tertiary color. Therefore, for the paper substrate used, a high quality glossy coated paper, it can be concluded that the simple spectral trapping model works very well.

It is worth emphasizing that since the modified model has been applied to a high quality glossy paper and the ink mileage test was done using a foil with a similar surface structure as the paper, for a totally penetrative paper the proposed model may need modifications.

6.5.1 Used Material and Equipment

The used inks for the investigation in this chapter dried mainly conventionally (oxidative, not UV-ink system). The modified model works especially well with oxidation inks or alternatively also with combination inks (oxidation and penetration). In this chapter the focus of the investigation was on high quality glossy coated papers (in this investigation with 150 g/m^2). The following materials and equipment were used:

Paper for the ink mileage test and the offset printing: Sappi, Mega Gloss, 150 g/m^2 .

Blanket for the ink mileage test and the offset printing: Vulcan Folio.

Inks for the ink mileage test and for the offset printing: printcom, S118V.

Spectrophotometer: Gretag Spectroeye. Setting: no polarization filter, absolute, D50, DIN-NB (for density).

The ink mileage equipment of Thwing-Albert EUROPE and a precision balance with the ability to measure 0.0001 grams were used. The test was done by the Print Technology Center of the manroland Company in Germany on a manroland R710 DirectDrive printing machine.

6.6 Summary

The amount of trapping has a great impact on the gray balance and color reproduction of printed products. The conventional print density based models to estimate the effect of trapping only give percentage values. In the first part of this chapter a trapping model based on reflectance spectra was introduced and proposed defining the trapping effect as the ΔE_{ab}^* colorimetric differences between the measurements and the calculated values. The introduced trapping model has a higher dynamic range compared to the conventional trapping models, meaning that the effect of trapping can be better differentiated by the proposed trapping value. This helps the printing machine operators to react faster and earlier.

Although the surface (gloss) and ground (ink penetration) effects have an impact on the print results depending on the substrate and inks, these effects have

mainly been neglected in all previous trapping models. In this chapter the proposed trapping model was extended to investigate the impact of both effects for high quality glossy coated paper and a set of sheet-fed offset inks. An ink mileage test was carried out to find the gloss and ink penetration effects. The results of the investigation demonstrate that these two effects compensate each other and their total impact is almost negligible for the tested materials.

Chapter 7

GENERATING A DOT GAIN COMPENSATION CURVE

Introduction

Dot Gain Compensation

Iterative Dot Gain Compensation Methods

Non-Iterative Dot Gain Compensation Methods

Experimental Results of Non-Iterative Method

Selection of Correction Points for the RIP

Experimental Results of Selected Correction Points

Summary

7.1 Introduction

One of the most important conditions for printing color predictability is to have a dot gain within a correct range. As mentioned in Section 4.3.5, there are a large number of parameters, such as blanket, ink, dampening solution, printing process (UV or conventional drying ink), that affect dot gain in offset printing. Achieving the ISO-12647-2/13 recommended dot gain in print demands generating many dot gain compensation curves (DGCCs), which are very time demanding and costly. Otherwise dot gain will most probably end up out of the allowed tolerance range (Section 4.3.4). For compensating an incorrect dot gain, a DGCC has to be generated and used in the Raster Image Processor (RIP). Dot gain compensation means that the incorrect part of a dot gain (dot gain shift) but not the whole dot gain has to be compensated. Therefore, the terms dot gain correction curve or dot gain shift compensation curve would be more suitable than the term dot gain compensation curve. However, the term dot gain compensation curve is commonly used in the graphic industry and therefore it is also used in this thesis. The commonly used methods to generate a DGCC in offset printing are iterative which are time, material and cost intensive. In this chapter, two iterative as well as one non-iterative dot gain compensation methods are introduced. An efficient approach to select correction points in a RIP with limited number of correction points is also proposed and evaluated in this chapter. The non-iterative method is an important requirement for the automated CtP calibration system (Hauck and Gooran, 2011c), which will be introduced in Chapter 8.

In Section 7.2 the terms RIP, dot gain compensation, dot gain compensation curve and dot gain shift are described. In Section 7.3 two iterative methods for generating a DGCC are explained. In Section 7.4 a non-iterative method for generating a DGCC is explained and its results are demonstrated in Section 7.5. Section 7.6 provides a description of an approach to efficiently select the correction points in a RIP. The experimental results are summarized and discussed in Section 7.7. Section 7.8 summarizes the whole chapter.

7.2 Dot Gain Compensation

An incorrect dot gain in print must be corrected by generating a DGCC. After a DGCC is generated it has to be loaded in the RIP. A RIP (postscript-RIP) has normally three main components, namely the interpreter, the renderer and the rasterizer. The RIP rasterizer is the unit transforming the continuous-tone images into the halftoned images (bitmaps) (Kipphan, 2001). Furthermore, the rasterizer of a professional RIP offers the possibility to adjust the tone values in terms of a tone value correction. In order to be able to do the tone value correction there is a need for DGCCs in the corresponding part (look-up table)

of the RIP (and thereby the correction or compensation of tone values in print). Table 7.1 demonstrates such a table for tone value corrections in a RIP. TV^{Data} denotes the reference tone value in data and TV^{DGCC} the dot gain compensation for the corresponding tone value. $TV^{Data} = TV^{DGCC}$, $TV^{Data} > TV^{DGCC}$ and $TV^{Data} < TV^{DGCC}$ mean none, a negative or a positive correction of a reference tone value. For example, the third column in Table 7.1 shows that $TV^{Data} = 5\%$ and $TV^{DGCC} = 7\%$ which means that the 5% reference tone value in data has to increase 2%, while the fifth column indicates that the tone value at 15% level has to decrease with 3%.

Table 7.1: The tone value correction in a RIP.

TV^{Data}	0	5	10	15			90	95	100
TV^{DGCC}	0	7	10	12			80	83	100

Generating a DGCC usually requires three steps. The first step is the evaluation of uncompensated printed tone values. This can be done by calculating the tone values of a printed halftoned wedge by using a densitometer (or a spectrophotometer) and Equation 3.4. Equation 3.4 is expanded with index i and illustrated in Equation 7.1.

$$TV_i^{Uncomp.Print} = \frac{1 - 10^{-D_i^{screen}}}{1 - 10^{-D^{solid}}}, \quad (7.1)$$

where $TV_i^{Uncomp.Print}$ denotes uncompensated printed tone values and index i represents the i -th position in the halftoned tone value wedge. D^{solid} denotes the density of the ink at fulltone and D_i^{screen} denotes the density of the printed halftone patch at the i -th position in the wedge.

The second step is the determination of the dot gain shift shown in Equation 7.2.

$$TV_i^{DG\ shift} = TV_i^{Uncomp.Print} - TV_i^{ISO\ TV\ Print}, \quad 0 \leq i \leq 100, \quad (7.2)$$

where $TV_i^{DG\ shift}$ and $TV_i^{ISO\ TV\ Print}$ denote the value of dot gain shift and the ISO 12647-2/13 recommendation for tone value in print.

Figure 7.1 shows a graphic of an ISO recommended tone value curve (green curve) and the uncompensated printed tone value curve (red curve) and the linear line (black line), which is the theoretical line for print without dot gain (a $\hat{}$). (a), (b), (c), (d), (e), and (f) are reference tone value in data (TV_i^{data}), uncompensated dot gain in print, ISO recommended tone value increase

($TV_i^{ISO\ TVI}$), dot gain shift ($TV_i^{DG\ shift}$), ISO recommended tone value for print ($TV_i^{ISO\ TV\ Print}$) and uncompensated printed tone value ($TV_i^{Uncomp.Print}$), respectively.

Figure 7.1: ISO recommended tone value curve (green), the uncompensated printed tone value curve (red) and the linear line (black).

The third step for generating a DGCC is to calculate the amount of the dot gain correction. This is not a trivial task because on the one hand the characteristic of dot gain is non-linear as shown in Figure 7.1, and on the other hand a mathematical characterization of an offset dot gain curve depends on a large number of parameters. The most important parameters affecting dot gain are inks, substrate, plate, the halftoning method (FM or AM screening), the pressure of the impression cylinder, dampening, the printing machine, the setting and maintenance of the printing machine, temperature (in dampening unit, ink unit and on the printing cylinder) and printing speed. Hence, there is no known mathematical model to predict a needed DGCC without a test print.

7.3 Iterative Dot Gain Compensation Methods

There are iterative and non-iterative methods for generating DGCCs. The conventional methods for generating DGCCs for offset printing are usually iterative, meaning that a number of test prints (two to five) are used for

generating the curves. Two iterative dot gain compensation methods are described in this section.

7.3.1 Linear Difference Method

The method for the calculation of DGCC by using a linear subtraction is demonstrated in Equation 7.3.

$$TV_i^{DGCC} = TV_i^{data} - TV_i^{DG\ shift}, \quad 0 \leq i \leq 100, \quad (7.3)$$

where TV_i^{DGCC} , TV_i^{data} and $TV_i^{DG\ shift}$ denote the DGCC (set into row 2 in Table 7.1), reference tone value in data and dot gain shift (Equation 7.2). i represents the i -th position in the halftone wedge.

Figure 7.2 demonstrates the necessary iterations for generating a DGCC (in this example for magenta) for a real test using this method. The final DGCC was achieved after four iterations, using more than 18,000 test sheets and more than 20 hours of work. The screening type was FM. The result after the first iteration (b) is not much different from the fourth iteration (e), when the compensation procedure was terminated. Iterations 2 to 4 were performed as an attempt to further reduce the dot gain shift, which was not successful, as illustrated in Figure 7.2. The reason is that the dot gain compensation was overdriven due to a number of factors. First of all, the characteristic of printed tone value increase is not linear, meaning that the dot gain in highlights and shadows are less than the mid-tone, which is completely ignored in this method. Hence the linear difference method tends to overdrive during dot gain compensation. The second reason is the fact that the offset printing process is not fully stable and tends to vary in reproducing tone values; especially for FM and high screen frequency AM halftones. The third reason is that since the test prints for dot gain compensation were done within 3 days, the compensation process is less accurate. A tone value variation in print by ± 1 to 2 % is commonly occurring in offset printing, which additionally complicates the compensation process. For example, the tone value variation is higher using a cold printing machine (in the morning) than a warm printing machine (in the afternoon).

Figure 7.2: Uncompensated print and four iterations for generating a dot gain compensation curve.

7.3.2 Proportional Method

This dot gain compensation method considers the non-linearity of a dot gain curve which was neglected in the linear difference method. This method

patented by manroland Print Machine Manufacturing (Hauck, 2013) is based on simple proportional computations. The method has been successfully tested by manroland many times under various situations. Equation 7.4 demonstrates the calculation of dot gain compensation values.

$$TV_i^{DGCC} = \frac{TV_i^{ISO\ TV\ Print}}{TV_i^{Uncomp.Print}} \cdot TV_i^{data}, \quad 0 \leq i \leq 100, \quad (7.4)$$

where all involved variables are defined as in previous equations. As demonstrated in Equation 7.4, this method considers the non-linearity characteristic of a dot gain curve. Hence this method is more accurate and efficient than the linear difference method and usually needs one or two iterations for achieving the ISO recommended tone values for print. Nevertheless, this method calculates and estimates the dot gain compensation and is still an iterative method.

7.4 Non-Iterative Dot Gain Compensation Method

Since the characteristic of dot gain is non-linear, the calculation of correction values is not trivial. As shown before, the iterative methods for generating a DGCC are not very accurate and basically an estimation. Unlike the iterative methods, for a non-iterative method the dot gain compensation is accurately calculated and not estimated. A similar technique was used long time ago in the gravure printing to convert the tone values in gravure to the tone values in offset printing and vice versa (Ollech, 1993). The introduced method in this section is optimized and has been successfully applied many times under various test situations and was patented by manroland Print Machine Manufacturing (Hauck, 2012).

This method will be explained by using an example. Figure 7.3 shows uncompensated and ISO recommended tone values for a test print. As shown in Figure 7.3, the ISO recommended tone value in print for 50% reference tone value is 63%. Now the reference tone value corresponding to the uncompensated printed tone value of 63% is the dot gain compensation value, which in this example is around 43% (follow the green and magenta arrows). This means that in Table 7.1 the second row corresponding to 50% reference tone value is set to 43% according to this method.

Let $f(TV^{data})$, $g(TV^{data})$ and $k(TV^{data})$ denote the uncompensated printed tone value curve (function), the ISO recommended tone value curve for print and the DGCC with respect to the reference tone value in data (TV^{data}). According to the explanation above, Equation 7.5 is derived.

$$k(TV^{data}) = f^{-1}(g(TV^{data})) \quad (7.5)$$

Notice that Equation 7.5 is defined if function f has an inverse which is always valid as the uncompensated printed tone value curve is a strictly increasing function.

Figure 7.3: Simplified principle of non-iterative dot gain compensation method.

7.5 Experimental Results of Non-Iterative Method

To evaluate the dot gain compensation method introduced in Section 7.4, a high number of test prints were done at the Print Technology Centre of manroland Company between 2008 and 2012. All of the functional tests (performance tests) were successful from the very beginning. In the following the results of one of the test prints for dot gain compensation are demonstrated. Figure 7.4 shows the results of the uncompensated printed tone values for black, cyan, magenta and yellow as well as the ISO recommended tone values for print (green curve). As can be seen there is a big tone value difference between the green curve and the black, cyan, magenta and yellow curves for some tone values. The black linear line shows the theoretical tone value line for print without dot gain and the blue curves show the obtained non-iterative DGCCs.

Figure 7.4: Uncompensated printed tone value curve, ISO recommended tone value curve for print and non-iterative dot gain compensation curves for: (a) black, (b) cyan, (c) magenta and (d) yellow. The linear line (in black) is the theoretical line for print without dot gain.

The dot gain shift of the uncompensated print for black, cyan, magenta and yellow are shown in Figure 7.5. For example the dot gain shift for magenta is between -3% and 5%, meaning an absolute dot gain shift of 8%.

Figure 7.5: Dot gain shift of uncompensated print.

Table 7.2 shows the measured uncompensated printed tone values, the ISO recommended tone values for print and obtained DGCC of black, cyan, magenta and yellow for the results shown in Figure 7.4.

Table 7.2: Uncompensated printed tone values, ISO recommended tone value for print and obtained DGCC.

$TV_i^{Uncomp.Print}$; Uncompensated printed tone values [%]											
TV_i^{data}	0	10	20	30	40	50	60	70	80	90	100
K	0	18.9	31.5	43.7	55.2	67.0	75.5	82.4	88.9	95.5	100
C	0	19.7	32.3	45.3	57.6	68.3	76.4	83.2	89.5	96.3	100
M	0	17.8	31.4	46.0	56.2	67.0	74.8	82.0	88.3	95.8	100
Y	0	19.5	33.4	45.8	57.7	71.0	79.0	84.5	91.0	97.0	100
$TV_i^{ISO TVI}$; ISO 12647-2/04 recommended tone values for print [%]											
K	0	15.6	30.2	43.7	56.0	67.0	76.6	84.9	91.5	96.6	100
C	0	14.0	27.6	40.7	53.0	64.3	74.5	83.4	90.7	96.3	100
M	0	14.0	27.6	40.7	53.0	64.3	74.5	83.4	90.7	96.3	100
Y	0	14.0	27.6	40.7	53.0	64.3	74.5	83.4	90.7	96.3	100
$k(TV_i^{data})$; Dot gain compensation curves [%]											
K	0	8.0	20.0	30.0	40.0	50.0	62.0	74.0	84.0	92.0	100
C	0	6.0	16.0	26.0	36.0	44.0	58.0	70.0	82.0	90.0	100
M	0	8.0	18.0	26.0	38.0	46.0	60.0	72.0	84.0	90.0	100
Y	0	8.0	16.0	26.0	38.0	44.0	54.0	68.0	80.0	88.0	100

Figure 7.6 shows the printed tone values after the compensation. These printed tone values were achieved immediately after the first compensation.

Figure 7.7 demonstrates the dot gain shift after the dot gain compensation. Achieving a zero dot gain shift for all tone values is not possible in offset printing. All achieved values are in the tolerance range of ISO-12647-2 (compare with the uncompensated print in Figure 7.5). As seen in Figure 7.7, the dot gain shift for magenta is between -2% and 2%, meaning an absolute dot gain shift of 4%.

Figure 7.6: Compensated printed tone value curve, ISO recommended tone value curve for print and non-iterative dot gain compensation curves for: (a) black, (b) cyan, (c) magenta and (d) yellow.

Figure 7.7: Dot gain shift after compensation.

Figure 7.8 shows the results of this non-iterative compensation method for three different halftone screens, namely AM halftoning at 150, 175 and 200 lpi.

Figure 7.8: Left) (a), (b) and (c) show the tone value curves for uncompensated prints (magenta) for 150, 175 and 200 lpi screens. Right) The corresponding compensated tone value curves by using the non-iterative method.

All different screens were printed in the same run. To simplify the graphics only the results for magenta are shown in Figure 7.8. The dot gain shifts of all inks after compensation were within the ISO range. The compensation results for all

three screens were achieved without any iteration, using 4,000 printing sheets and four hours of work. This method was tested for a long time (more than 100 times) and under various conditions using different qualities of printing substrates and different inks and similar results as those shown in Figure 7.8 were always achieved. This method was tested for sheet-fed offset printing but there is no reason why this method should not work for web-offset as well.

7.6 Selection of Correction Points for the RIP

As shown in the previous section the results of the dot gain compensation using the non-iterative method were good. In the experiments, the tone value wedge used has 51 tone steps, which means two percent coverage steps from 0 to 100%. The obtained DGCC therefore include 51 tone values (or correction points). However, not all RIPs support such a high number of correction points. For example, the applied RIP at manroland PTC used in the experiments (Table 7.2) has only a capacity of 11 correction points, of which two correction points are reserved for 0% and 100% tone values. This means that only 9 correction points can be selected and all tone values between two correction points are automatically interpolated by the RIP. In the test results demonstrated in Section 7.5 and Figure 7.7, the correction points were uniformly distributed, meaning 0%, 10%, 20%, ..., 90% and 100% were set.

However, it was observed that using the same DGCC but selecting different correction points (for example 8%, 20%, 29% etc.) in the RIP, results in different dot gain compensation accuracy. Hence, a careful selection of correction points could improve the result of the dot gain compensation. After a number of test prints the following three statements can be concluded:

- 1- The position of the inflection points of DGCC was important for the selection of correction points for a RIP. An inflection point is a point on a curve at which the curve changes from being downward to upward, or vice versa.
- 2- The inflection points with a bigger absolute difference value (the absolute difference value between two consecutive values) of the first derivative of the DGCC are more important than the inflection points with a smaller absolute difference value of the first derivative.
- 3- The chosen correction points should neither have a too small nor too big gap in reference tone value. The used criterion here is that the distance between two chosen correction points should be as minimum 5% and as maximum 15% reference tone value in data (TV_i^{data}).

These three statements will be referred to as first, second and third statement in this chapter. In the next section, an approach is introduced to carefully select correction points of DGCC for a RIP with a limited number of correction points.

7.6.1 Selection of Correction Points based on Inflection Points

In the previous tests for compensating dot gain it was observed that there is a relation between the inflection points of a DGCC and the accuracy of the dot gain compensation. In order to select a set of correction points for a RIP with limited capacity, the inflection points of the DGCC have to be found. The mathematical definition of an inflection point of a function at the i -th position is that the second derivative of the function at this position is zero and its third derivative at the same position is non-zero. Therefore, the first, second and third derivatives of DGCC are calculated. Because of the relatively high number of measured tone values (51 steps) it is possible to find the derivatives numerically. Equation 7.6 demonstrates the numerical differentiation of DGCC.

$$k'(TV_i^{data}) = \frac{k(TV_{i+1}^{data}) - k(TV_i^{data})}{TV_{i+1}^{data} - TV_i^{data}}, \quad (7.6)$$

where $k'(TV_i^{data})$, $k(TV_i^{data})$, $k(TV_{i+1}^{data})$, TV_i^{data} and TV_{i+1}^{data} denote the first numerical derivative of DGCC, the dot gain compensation value at i -th position, the dot gain compensation value at the $i + 1$ -th position, the reference tone values at i -th position and reference tone values at $i + 1$ -th position. The second and third derivatives of DGCC are calculated accordingly.

Figure 7.9 shows the uncompensated dot gain shift of cyan (black curve) and its relative DGCC (cyan curve). For both curves the primary y-axis is shown on the left side. Relative DGCC means that the reference tone value is subtracted from DGCC.

Figure 7.9: Uncompensated dot gain shift and the derivatives of DGCC for cyan ink.

Figure 7.9 also shows the first, second and third derivatives of DGCC (in red, green and blue respectively), for which the secondary y-axis is shown on the right side. The secondary y-axis is used to be able to show the first, second and third derivatives of DGCC in the same graph as the uncompensated dot gain

shift and the relative DGCC. As seen in Figure 7.9, the second and third derivatives of DGCC intersect with the x-axis in a number of points. Figure 7.10 shows the relative DGCC (cyan curve) and its inflection points (black dots) for cyan.

Figure 7.10: The relative dot gain compensation curve and the inflection points for cyan ink.

There are 34 inflection points which exceed the number of allowed correction points for the used RIP. The second statement in Section 7.6 was that the inflection points with a bigger absolute difference value of the first derivative are more important than the inflection points with a smaller absolute difference value of the first derivative. Hence the inflection points are selected according to the absolute difference value of the first derivative. Now according to the third statement, the correction points in the RIP are chosen with gaps bigger than 5% and smaller than 15% in reference tone value. The inflection points with larger absolute difference value of the first derivative are picked first and as long as the third statement is valid.

Figure 7.11: Selected correction points using the proposed approach (black dots) and two manually selected correction points (blue arrows) for cyan.

Figure 7.11 shows the selected correction points for the dot gain compensation of cyan ink. The cyan curve is the relative DGCC, the black dots show the

selected inflection points according to the three statements. The remaining two correction points are chosen manually, being at position 60% and 70% (shown with blue arrows). Correction points at 0% and 100% are always set (green arrows).

7.7 Experimental Results of Selected Correction Points

After the dot gain compensation using the selected correction points a test print was carried out. Figure 7.12 demonstrates the result of the dot gain compensation for cyan. The cyan line shows the dot gain shift after the dot gain compensation by the non-iterative method using the proposed correction points.

Figure 7.12: Dot gain shift after compensation by the selected correction points according to the proposed approach for cyan.

Observe that for the 11 correction points, the dot gain shift is reduced to less than 0.5 percent. The dot gain shift after compensation is always less than 1.4 percent, which is a very good result. Recall that when the correction points were uniformly distributed (Figure 7.7, cyan curve), the dot gain shift after compensation was between around -2% and 2%. With the proposed selected correction points the dot gain shift is between -0.5% and 1.4%, which shows a clear improvement.

To further evaluate the dot gain compensation accuracy, the proposed approach to select the correction points was applied to magenta. The magenta curve in Figure 7.13 shows the relative DGCC of uncompensated print and the black dots show the found correction points according to the proposed approach. All selected points followed the rules in the three statements and there was no need to manually select any correction point for magenta.

Figure 7.13: Selected correction points using the proposed approach for magenta.

Figure 7.14 shows the magenta dot gain shift after compensation using the proposed approach to select the correction points. It can be noticed that for the 11 correction points the dot gain shift is reduced to less than 0.5% and the dot gain shift after compensation is always less than 1.5%, which is a very good result. Recall that when the correction points were uniformly distributed (Figure 7.7, magenta curve), the dot gain shift after compensation was between around -2% and 2%. With the proposed selected correction points the dot gain shift is between -0.3% and 1.5%, which shows a clear improvement.

Figure 7.14: Dot gain shift after compensation by selected correction points according to the proposed approach for magenta.

Comparing the results in Figures 7.12 and 7.14 with corresponding results shown in Figure 7.7 verifies that in a printing workflow with a RIP, which has a limited capacity of correction points, it is useful to carefully select the correction points. This method was tested for sheet-fed offset printing and high glossy coated paper with conventional ink (no UV-ink) five to ten times achieving similar as the ones illustrated in this section.

7.8 Summary

Printing within the ISO recommended tone value range is one of the most important requirements for color print predictability and reproducibility. Dot

gain out of the tolerance has to be corrected with a DGCC, which is loaded in the Raster Image Processor. Generating DGCCs with an iterative method is time and cost intensive and economically not efficient. An iteration for generating a DGCC normally needs three to five hours of work and 3,000 to 5,000 printing sheets. In this chapter a non-iterative method for generating a DGCC was introduced. The aim of this method was to find the DGCCs for the RIP in order to print according to the ISO recommended tone values. There has also been a method proposed to carefully select the correction points, which is especially useful for the RIPs with a limited number of correction points. The achieved results using the proposed approach to select the correction points show an absolute dot gain shift less than 2 percent for cyan and magenta, which is a very good result. This also shows a clear improvement compared to the case where the correction points were manually selected and uniformly distributed. The non-iterative method is an important requirement for realizing an automated CtP calibration system which is introduced in Chapter 8.

Chapter 8

A NETWORKED WORKFLOW FOR AN AUTOMATED CTP CALIBRATION SYSTEM

Introduction

Necessary Requirements for Automated CtP Calibration

Workflow Control System

Generating, Using or Renewing a DGCC

Summary

8.1 Introduction

As discussed in the previous chapter, dot gain shift is defined as the difference between the printed tone value and the ISO recommended tone value for print. The ISO recommended tone values for print and their tolerance for an offset printing process are described in ISO 12642-2/13. The calibration of computer to plate (CtP calibration) means correcting dot gain shift by generating a compensation curve. The CtP calibration is not to be misunderstood with linearization of a CtP. The linearization of a CtP is the adjustment of laser beams (focus, intensity etc.) and the setting and adjusting of the plate developing machine. The CtP linearization has to be checked regularly (e.g. weekly) and is done independently of CtP calibration (Kipphan, 2001). The dot gain compensation curves (DGCCs) are used in the Raster Image Processor (RIP) of a CtP. The CtP calibration is necessary for a precise color prediction in the printing process (Mittelhaus, 2000) and a basic condition for a successful Color Management (CM) process (Homann, 2007). Since CM is not a part but a process based on CtP calibration, it is out of the scope of this thesis.

As described in Section 4.3, ISO 12647-2/13 describes eight different print conditions (PC). For each print condition eight printing substrates (PS1 to PS8) are defined. Five different TVI (A to E) are also assigned, dependent on the printing substrate and the halftoning method (FM or AM screening) (ISO 12647-2/13, 2013). The description in ISO 12647-2/13 is very clear, easy and understandable, but keeping the dot gain within the demanded range for all the productions is very difficult in practice. There are two main reasons for that. Firstly, the needed test prints for generating a DGCC are very time demanding and expensive. Secondly, the offset printing process is not stable and the generated DGCC should be controlled and, if necessary, renewed and replaced regularly. Hence printing companies work only with a few DGCCs, but the combination of consumables and printing processes results in a high number of different printing workflows requiring a higher number of DGCCs. Any printing workflow is more or less different to the other one and demands its specific DGCC in order to be in the tone value range of the ISO recommendation.

This chapter describes a novel automated CtP calibration system for a modern and economical offset printing process (Hauck and Gooran, 2011c). The proposed system is a concept which either produces new, or renews the existing or uses the existing DGCCs taking into account all consumables and all offset printing processes. All the DGCCs for the different consumables and offset printing processes are saved in a database. A control unit (Workflow Control System) controls the workflow. The concept is based on three requirements which are necessary for this automated CtP calibration system. In the following section these three requirements are explained. In Section 8.3 the principle of the workflow control system (WCS) is described. For defining a print job

according to the ISO definition for the printed tone values, the WCS has to make a choice between generating a new DGCC, using an existing DGCC or renewing an existing DGCC. These three choices are explained in Section 8.3.1. From now on in this thesis, these three choices will be referred to as DGCC-Generation (Section 8.4.1), DGCC-Usage (Section 8.4.2) and DGCC-Renewal (Section 8.4.3). Finally, in Section 8.5 a summary of this chapter is given.

8.2 Necessary Requirements for Automated CtP Calibration

The requirements for realizing an automated CtP calibration system can be divided into three groups. The first requirement is the print quality control in order to avoid variation in the printing process. The automated CtP calibration system is designed to use and renew DGCCs parallel to the printing production and without a separate print test. Since the iterative methods for generating the DGCCs require a number of iterations they are inappropriate to be used in the automated CtP calibration system. Hence the second requirement is a non-iterative method to generate DGCCs. The third requirement is the workflow networking, controlling and managing. Figure 8.1 demonstrates these three necessary requirements for an automated CtP calibration system.

Figure 8.1. Three necessary requirements for automated CtP calibration.

8.2.1 Print Quality Control

A high number of parameters, such as consumable, the mechanical condition, maintenance and service of a print machine, its setting and its adjustment by the operators, temperature and humidity in the print room, influence the printing process and thereby the printed tone values. Offset printing is surely one of the most sensitive printing processes. Because of this fact the printing process should be controlled very often and carefully. An uncontrolled printing process

is subject to relatively high variations. Hence, the first and very important requirement for the automated CtP calibration workflow is the print quality control (PQC). PQC includes the check of different target values in the printing process and the check of different print quality criteria regarding the stability and reproducibility.

Generating a DGCC and thereby a CtP calibration only makes sense in a stable and reproducible printing process. Therefore, for an automated CtP calibration system, a print quality control program is needed to check different printing quality criteria before starting the calibration. Target ink value, tone values, maximum mid-tone spread, slurring, register variation and doubling and ink trapping are the most important criteria that should be stable and within the acceptable range, before and during a CtP calibration (Hauck and Gooran, 2011a, 2011b, 2013, 2015). These criteria and how to measure them were introduced and discussed in detail in Chapters 4, 5 and 6.

8.2.1.1 Print Quality Control Program

The print quality control program (PQC-program) contains two separated modules. The first module of the PQC-program checks the print quality criteria (see Chapter 4, 5 and 6) and compares their values with a table containing the allowed tolerances for each print quality criterion. If during the production phase all values of the print quality criteria are within their acceptable range, the program will send a message to the WCS. The WCS then sends a permission to generate a DGCC. If the print quality values are outside their acceptable range, the calibration procedure will be interrupted, see Section 8.4 for more details. The second module of the PQC-program generates a DGCC using a non-iterative method.

8.2.2 Non-Iterative Dot Gain Compensation Method

As mentioned in Chapter 7, the mathematical function characterizing dot gain is not linear. It has also been discussed that almost all existing methods for generating a DGCC for offset printing process are iterative (Hauck, 2013). This means that the generation of DGCC is in action in a loop until the printed tone values are within the ISO tolerance range. As mentioned earlier in this section, an iterative method for generating a DGCC cannot be used in this system. The second requirement for an automated CtP calibration workflow is therefore a non-iterative method for generating a DGCC (Hauck, 2012).

8.2.2.1 Measuring Devices

Printing companies employ densitometer/s and/or spectrophotometer/s to control the printing process. For both densitometry and spectrophotometry there are two types of instruments. The first type only measures a spot. The other type,

called scan-densitometer or scan-spectrophotometer, measures a number of spots which together build a bar like a print control bar, shown in Figure 8.2(c).

Figure 8.2: (a) shows a standard layout with the print control bar (c), (b) the same layout with the print control bar (c) and a second bar (d) for measuring the printed tone values.

Scan-densitometers or scan-spectrophotometers are just the notation of the instruments that are able to measure color bars but they are not the same as scanners used in image capturing. Online and inline measuring devices are commonly used in the graphic industry for industrial and economical printing processes.

Figure 8.2(d) shows a bar for measuring the printed tone values. This bar is needed for generating a DGCC in the proposed automated CtP calibration system. Hence the workflow with an automated CtP calibration system also needs a scan-spectrophotometer (online or inline). While for an online scan-

spectrophotometer the operator has to take the sheets from the machine to the measuring device to be measured, with an inline scan-spectrophotometer the printed sheets are measured automatically in the machine during the printing production. However, an automated CtP calibration system can employ both types (online or inline) of scan-spectrophotometers.

It is however important that the measuring instrument can automatically scan both color bars. The online scan-spectrophotometer ColorPilot (manroland) is able to scan two stacked color bars, shown in Figure 8.2(c) and (d). This scan-spectrophotometer was successfully tested for this purpose. Another advanced print quality measuring device is proposed in (Gugler and Hauck, 2008).

8.2.2.2 Imposition Program and Templates

Imposition programs, for example Heidelberg Prinect Signa Station (Heidelberg, 2015) or Kodak Preps (Kodak, 2015) are important programs for prepress, press, and post press. Normally an imposition defines the position of the pages after folding a printed sheet for producing books. An imposition program might even be used in case there is no folding sheet, e.g. for packaging or labeling sheets. An imposition program can employ different types of templates. A template contains a predefinition of the position of a printing control bar, the register marks, and of course the reserved area for printing the layout of a job (Kipphan, 2001). In an imposition program it is possible to define the position of a printing control bar and all needed marks. Then all needed marks and the print control bar are set automatically by the imposition program. Hence for a standard print job without the generation of a DGCC the template-I is chosen as usual, shown in Figure 8.3. For an automated CtP calibration at least two different templates are necessary for plate imaging. Figure 8.3 shows these two needed templates, where (a), (b), (c), and (d) show the printing control bar, the tone value wedge (DGCC-bar), the reserved area for print layout and the register marks.

Template-II is needed if a DGCC has to be generated, more details in Section 8.4. Observe that template-II contains all elements of template-I plus a DGCC-bar, shown in Figure 8.3(b). Hence in template-II the size of the reserved area for print layout is 3 to 5 mm shorter in the print direction than in template-I. However, this is no problem because the paper companies sell papers in standard sizes which mostly are 5 to 50 mm larger than the size of the print layouts. Exceptions are some packaging-printing, label-printing and book-printing companies which use the entire area of the paper.

Figure 8.3: Template-I is the standard print template, template-II has two bars (a) and (b), the stacked bar (b) is the tone value wedge for generating a DGCC.

8.2.2.3 DGCC Database

Most printing companies only use a small number of DGCCs (only one to five DGCCs). This is because of the complexity and the high cost of manually generating a DGCC and the fact that handling and managing more than five DGCCs without a WCS is practically impossible. Consequently a big part of the print products cannot be printed with the completely correct dot gain. As mentioned in Section 4.3.5, a huge number of DGCCs can be necessary in a printing workflow dependent on the number of combinations of consumables and printing workflows in a printing company. As will be demonstrated later in Figure 8.6(2), the DGCC database (DGCC-DB) is a component of this automated CtP calibration system. DGCCs are saved and then loaded to be used dependent on the combination of consumables and printing workflows. The

advantage of using DGCC-DB is that it is possible to save a large number of DGCCs. The managing (saving, overwriting, and calling) of the DGCCs in DGCC-DB has to be done via the WCS.

8.2.2.4 Renewal Date for a DGCC

A generated DGCC should be renewed after three to six months. The reason is that the quality of consumables and the print machine settings slightly change over the time and the climate in the printing room also changes in different seasons. These factors might cause a dot gain shift after a few months since the involved parameters were adjusted. Therefore it is necessary to save the date of generating a DGCC and specify a date for the earliest (e.g. three months after the generation of the DGCC) and the latest (e.g. six months after generating the DGCC) renewal of DGCC. An already existing DGCC should be renewed between the earliest and the latest date. These points in time are set in WCS as setting parameters. Figure 8.4 demonstrates the time bar of DGCC with three different points in time, namely the generation of a DGCC, the earliest date for renewing and the latest date for renewing a DGCC.

Figure 8.4: The time bar for the demonstration of generating, using, and renewing a DGCC.

These three points in time result in three different time corridors (time-level-I to time-level-III). A time-level is the time corridor (limit) between two points of time. For example, time-level-I is the time corridor from generating a DGCC to its earliest time for renewal. The other time-levels have their own time corridor as shown in Figure 8.4.

8.2.2.5 Nomenclature of DGCCs

As mentioned before, in a printing company the number of necessary DGCCs depends on the number of combinations of consumables and print workflows. This parameter can result in a high number of combinations. Hence for managing the DGCCs in the workflow it is necessary to have a distinct nomenclature for a generated DGCC. A useful DGCC-denotation should

contain the information about the consumable, printing workflow and renewal date of a DGCC. Figure 8.5 demonstrates the coding of a DGCC nomenclature as an example. Part (a), the first number, demonstrates the used printing substrate group from the eight PS according to ISO 12647-2/13 description. The five digits of part (b) demonstrate the nomenclature of the used ink dependent on its color, fabrication and type. The next number in part (c) demonstrates the used printing plates dependent on its fabrication and types. Part (d) demonstrates the used blanket dependent on its fabrication and type. Part (e) demonstrates the dampening concentrates dependent on its fabrication and type. Part (f) demonstrates the printing machines (for example 03 in Figure 8.5(f) means the third R700 printing machine in the print department). Part (g) demonstrates the print workflows (for example 1 for conventional printing, 2 for UV printing, 3 for alcohol reduced printing and so on). The dates in part (h) to (j) demonstrate the date of generating the DGCC, the earliest date for renewing the DGCC and the latest date for renewing the DGCC.

01.	10002.	3.	1.	4.	03.	1.	2014/11/28	2015/2/28	2015/5/28
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)

Figure 8.5: The nomenclature of a DGCC.

The demonstrated nomenclature can vary and be expanded dependent on the workflows in different printing companies. The nomenclature of DGCC is saved together with the corresponding DGCC in a DGCC-DB. If a specific DGCC is needed, the WCS will search for it in the DGCC-DB using its nomenclature.

8.2.3 Networked Workflow

The third requirement for an automated CtP calibration system is a networked workflow. Figure 8.6 shows a scheme of the needed networked workflow for an automated CtP calibration system. The demonstrated networked workflow contains the following components: (1) Management Information System (MIS) or alternatively a workflow control system (WCS) of a print machine manufacturer can also be used. In this thesis the term WCS is used for this module. (2) DGCC database (DGCC-DB). (3) Raster Image Processor (RIP). (4) Layout and Print data. (5) Imposition program with at least two different templates. (6) CtP (Computer to Plate). (7) Printing plates. (8) Printing machine. (9) Press control desk with an integrated scan-online-spectrophotometer (Section 8.2.2.1). The press control desk is the central part for controlling and commanding a printing machine. (10) Printed sheet to be measured. (11) Print quality control program (PQC) including the non-iterative method for generating a DGCC. In such a networked workflow the WCS firstly checks if the needed DGCC already exists (Section 8.3.1) in the DGCC-DB. To realize

system of print machine manufacturers are PrintNet system (manroland, 2014) developed by manroland, and Prinect system (Heidelberg, 2014) developed by Heidelberg.

8.3.1 Choices of WCS for Defining a Print Job

In this printing workflow, if a job has to be printed with a suitable DGCC, WCS first builds a list of demanded consumables and printing workflow and denote this list according to the nomenclature of DGCCs and searches for a DGCC or a similar DGCC in the DGCC-DB.

There are therefore three possible scenarios:

- 1- DGCC-Generation: If in the DGCC-DB neither the DGCC nor a similar DGCC exists, a new DGCC will be generated and saved in the DGCC-DB. This is explained in Section 8.4.1.
- 2- DGCC-Usage: If in the DGCC-DB the needed DGCC exists, then it can be used for the print production. This is explained in Section 8.4.2.
- 3- DGCC-Renewal: If in the DGCC-DB a DGCC (a time-level-III DGCC or a similar DGCC) exists, then it can be used for the print production but it has to be renewed during the print production. This is explained in Section 8.4.3.

The working principle of the WCS is demonstrated in Figure 8.7. After generating a job the WCS makes a list of all needed consumables. Then the information of this list is compared with the existing nomenclatures in DGCC-DB and then the decision (a) is made (Figure 8.7). If there is no suitable DGCC, then a similar DGCC (Section 8.4.3.1) is searched in (b). Depending on the result of decision (b) either the DGCC-Renewal or the DGCC-Generation related to the job is carried out. In the decision (a), if a suitable DGCC is available, then (c) will be executed. If the decision in (c) is no, then the DGCC-Renewal related to the job generation of WCS and needed DGCC has to be activated. If the decision (c) results positively, then the decision (d) has to be started. Now in order to generate a DGCC template-II has to be used. Hence the WCS checks if the reserved area is suitable for setting the print layout in template-II. If yes, then the DGCC-Renewal will start. Otherwise the decision (e) is made to check whether the already found DGCC can still be used (Figure 8.4, time-level-II). This results to the DGCC-Usage. Otherwise, if the DGCC is old and cannot be used (Figure 8.4, time-level-III), the decision (f) has to be executed. For this decision the WCS has to check if a similar DGCC is available or not. If a similar DGCC is available, then the DGCC-Usage, otherwise the DGCC-Generation will be performed.

Figure 8.7: Job generation in the WCS and choosing one of three possible choices (DGCC-Generation, DGCC-Usage and DGCC-Renewal).

8.4 Generating, Using or Renewing a DGCC

8.4.1 DGCC-Generation

Figure 8.8: DGCC-Generation, generating and saving a new DGCC.

As discussed in Section 8.3.1, at the beginning of managing a printing job the WCS searches for an existing or similar DGCC in DGC-DB dependent on consumable and workflow list. If there is no existing or similar DGCC or the existing or similar DGCC is in time-level-III, the WCS will order the DGCC-Generation. This generating procedure occurs less frequently compared to the DGCC-Usage or DGCC-Renewal.

Figure 8.8 demonstrates the flowchart for the DGCC-Generation, i.e. the generation of a new DGCC and its saving in the DGCC-DB. If the WCS decides the DGCC-Generation, then the imposition program will receive an order to use template-II (Figure 8.3). After the halftoning and plate making through CtP, the printing can start. When the make-ready is finished, the production phase (in the DGCC-Generation just a printing test) can start. For an exact generation of the DGCCs the printing process should be reproducible and the process variation (like target value variation, tone value variation or register variation) should be within the tolerance ranges (Figure 8.1, requirement 1). Hence, before the DGCC can be calculated, the stability of the printing process has to be checked. The DGCC-Bar has to contain the elements allowing to check the stability of the printing process (see Chapter 4, 5 and 6). In case of variation the calibration process is to be interrupted and optimized. After the make-ready and stabilization of the printing process the DGCC-bar is measured for the evaluation and calculation of the DGCC. This workflow works economically, if the printing process is controlled and stable. During the production the operator of the printing machine has to take several printing sheets and measure them for controlling the printing machine and the inks. An inline spectrophotometer does this procedure automatically. If the variation in the printing process is within the tolerance range, then the measuring system will get permission to measure the DGCC-Bar. It is also possible to measure several printed sheets (commonly 5 to 10) to build an average value. For the calculation of DGCC in this automated workflow a non-iterative DGCC generating method is absolutely necessary (Figure 8.1, requirement 2). The generated DGCC is saved in the DGCC-DB after generating a meaningful nomenclature. After having saved the new DGCC the WCS gets a feedback that the DGCC is saved, and the process will then successfully terminate.

8.4.2 DGCC-Usage

As discussed in Section 8.3.1, in the DGCC-Usage a DGCC can be used without the need to be renewed (Figure 8.4, time-level-I). The WCS decides to use an existing DGCC and does not generate a new one.

Figure 8.9 demonstrates the flowchart for the DGCC-Usage. For the DGCC-Usage, the imposition program receives an order from the WCS to use template-I, (Figure 8.3(a)). The WCS gives an order for the export of DGCC-Data from the DGCC-DB to the RIP. After the halftoning and plate making the make-ready

at the printing machine can start. After the make-ready phase is finished, the printing production phase can start.

Figure 8.9: DGCC-Usage, using a suitable DGCC.

8.4.3 DGCC-Renewal

As explained in Section 8.3.1, the WCS chooses the DGCC-Renewal if an existing DGCC is to be used for generating a new DGCC according to the used consumable and workflow in the printing production. According to the consumable and workflow list of WCS, the chosen DGCC can be an exactly identical DGCC which is to be renewed (Figure 8.4, time-level-II) or is chosen because it is a similar DGCC. Hence in the latter case for the future need of an exact DGCC a new one has to be generated during the printing production.

Figure 8.10 demonstrates the flowchart for the DGCC-Renewal. The imposition program receives an order for using template-II, (Figure 8.3). The chosen DGCC is exported from DGCC-DB to the RIP. After the halftoning and plate making through the CtP the make-ready at the printing machine can start. When the make-ready is finished, the printing production phase starts. As mentioned before, for an exact generation of the DGCC, the printing process has to be checked to make sure that the printing process variation is within the tolerance range. If this requirement is fulfilled, then the measuring system can measure the DGCC-bar. Similar to the DGCC-Generation the non-iterative method calculates a new DGCC.

Figure 8.10: DGCC-Renewal, the renewal of an existing DGCC or the generation of an exact DGCC by using a similar DGCC.

After generating the new DGCC it is saved in DGCC-DB. For the time-level-II (as demonstrated in Figure 8.4) the new DGCC replaces the old one in DGCC-DB. The WCS then gets a feedback that the process was successfully terminated.

8.4.3.1 Using Similar DGCC

There are different priorities for the list of the used consumables and processes. For example the most important priority for a DGCC is the group of printing substrates (PS) and the fabrication of the inks. Surely the type of the blanket or plate is also important, but not as important as the paper class and the fabrication of the ink. Dependent on the workflow and production, some consumables in the workflow can play a more or a less important role in the printed tone values. This is important for searching for a similar DGCC in DGCC-DB if an available DGCC does not exist.

To clarify how to find a similar DGCC in the DGCC-DB, an example is given. Assume that for a workflow manager the type of the substrate and the ink properties are the most important parameters. When searching for a DGCC in the DGCC-DB, the WCS checks if there is a DGCC generated using the same type of paper and ink. If so, then it checks other parameters (such as plate or blanket). If for example the plate is not the same for this existing DGCC, it can still be considered to be a similar DGCC because the plate is not of the higher priority.

8.5 Summary

To realize an automated CtP calibration workflow three requirements have to be fulfilled. The requirements are the controlling of print quality in order to avoid variation in the printing process, which were introduced in Chapters 4 to 6, the non-iterative generation of DGCCs, which was introduced in Chapter 7, and the networked workflow, which was introduced in this chapter.

This chapter described the needed control and the necessary logical communication between the workflow of the prepress and press. There are three possible choices for a WCS in order to use a DGCC at the beginning of job definitions. These three choices are generating a new DGCC, using an available DGCC, and the combination of using and generating a DGCC (for example the renewal of a DGCC).

The suggested workflow allows to considerably reduce the costs and the time needed for generating or renewing the DGCCs. An automated CtP calibration workflow facilitates a printing workflow with most productions following ISO standards. Furthermore an automated CtP calibration workflow enormously reduces the work of the staff at the prepress, press, and quality management. It saves time and costs and increases the print quality.

Chapter 9

SUMMARY AND FUTURE WORK

Summary

Future Work

9.1 Summary

An automated CtP calibration system for offset printing workflow has been introduced and described in this dissertation. The important requirements for print quality control, which is an essential part of the workflow, have been discussed and necessary quality control models to complete the existing methods have been developed and described.

Novel spectral and densitometric methods to determine the register variation, as an important part of the quality control module, have been proposed and successfully tested. Existing and standard methods to determine register variation are based on image processing, which are very expensive and not available in most printing companies. The proposed register variation models in this dissertation only require a spectrophotometer or/and a densitometer, which are available in the vast majority of printing companies. This makes the proposed models economically beneficial. The results of these models are comparable with the results of the image processing based models, which has been verified by the experiments illustrated in this dissertation.

A novel method to determine the trapping value has also been developed and introduced in this dissertation. Unlike the existing trapping models, which only provide a percentage value, the proposed model describes the trapping effect by a color difference metric, which is more useful and understandable for print machine operators. This also helps them to react faster and earlier if the trapping value is out of range. The comparison between the proposed trapping model and the existing models has shown very good correlations and it has also been verified that the proposed model has a bigger dynamic range. Some important quality aspects, such as gloss and ink penetration, have been neglected in the existing trapping models. The proposed trapping model has therefore been extended to take into account these effects. The extended model has been tested using a high glossy coated paper and the results have shown that the gloss and ink penetration can be neglected for this type of paper.

In offset printing, for a predictable and reproducible color production it is necessary to have the printed tone value within an acceptable range, which is defined by ISO 12647-2. To achieve this, dot gain has to be compensated in the Raster Image Processor (RIP). Two iterative and one non-iterative dot gain compensation methods have been introduced in this dissertation. One important requirement for an automated CtP calibration is to have a non-iterative dot gain compensation method. It has been shown in this dissertation that besides saving time and material compared to iterative methods, the introduced non-iterative method resulted in printed tone values within the ISO recommended tone value range.

9.2 Future Work

In the proposed trapping models the ink mileage test, like most ink mileage tests, was done without dampening (dry). Since the dampening reduces the ink viscosity, it increases the ink penetration and extends the drying time. Therefore, it is recommended, in case an ink mileage equipment including dampening is available, to carry out the ink mileage test including dampening. This would make the proposed extended trapping models, which include gloss and ink penetration effects, more realistic.

As demonstrated in this dissertation, the effect of gloss and ink penetration could be neglected for high glossy coated papers. It is also of interest to test the proposed extended trapping model on other types of paper.

The proposed extended trapping model requires measuring the printing sheets at 30 seconds after print. The reason is that the ink mileage test prints were measured at 30 seconds (wet) and 48 hours (dry). If the ink mileage test prints could be measured at a number of points of time, it would be possible to interpolate the measured values, which would make it possible to measure the offset prints at any time between 30 seconds and 48 hours.

Another important future work is to test the proposed automatic CtP calibration workflow in a practical offset printing workflow. This automatic system can best be realized by print machine manufacturers.

Because of the offset printing companies' economic situations, they merge together to make larger companies. The production process in larger companies has to be optimized and follow standards. The proposed automatic CtP calibration system increases the quality of the production, reduces print product rejections and waste, and saves time and production costs. Therefore, the proposed automatic system has the capacity to be a solution for future offset printing workflow.

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