Guidelines for Objective Print Quality Measurements using Flatbed Scanners

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Keywords: analysis, capture, flatbed, quality, scanner

Abstract

Scanner-based systems for automated print quality measurements have become important and widely used tools in digital printing. New algorithms are continuously added to the large library of more or less known image analysis routines for quantization of print quality parameters. However, the quality of these measurements will not only be determined by the performance of the algorithms. The properties of the printed substrate, the colorants and the printing procedure in different combinations together with the properties of the capturing device are all factors that will have a large influence on the final result of any objective print quality measurement. In this presentation, guidelines will be given for the use of flatbed scanners for image acquisition of the printed substrate. The presentation will also describe the problems associated with the influence of substrate properties on the image acquisition. The work presented in this paper is a part of an ongoing research project, developing a set of characterization procedures that can be applied to a variety of different print engines and substrates.

Introduction

The quality of digital prints has improved substantially over the recent years and presently; in general, the quality of prints produced by digital print engines is high. Improved and refined technology has contributed to more consistent printing processes in terms of runnability and printability. Higher resolutions and the possibility to use multi-level dots have contributed to the quality improvement. The latest xerographic print engines have reached a print quality level not far from offset printing. With the latest inkjet printers, it is possible to achieve a print quality in parity with traditional photographic technology. As a result, the demands on systems for objective print quality measurements will be higher as well.

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Scanner-based systems for automated print quality measurements have become important and widely used tools in digital printing. However, the quality of these measurements will not solely be determined by the performance of the image analysis routines for quantization of print quality parameters that these systems are built around. As the quality of digital prints continues to improve, the print defects are decreasing in both number and magnitude. Hereby, consistent image acquisition of the printed substrate is becoming even more important in order to obtain reliable measurements. It is quality variations in the printed substrates that are to be measured, not variations brought on by a poorly controlled image acquisition. Thus, to calculate print quality parameters from images obtained from an uncontrolled image acquisition situation is to take a risk of producing inferior measurements. In this paper, the importance of being aware of the limitations of the scanner, as well as having control over scanning parameters such as dynamic range, pixel depth and tone curve adjustments is described. Furthermore, properties of the printed substrate such as color gamut and gloss variations will also influence the image acquisition. For that reason, a study has been carried out to examine the effect gloss variations in the printed substrate will have on the final acquired image.

Scanner-based systems for print quality measurements

The workflow of a typical scanner-based system for objective print quality measurements is illustrated in figure 1.

1. A printed print quality test form is placed in the scanner.
2. One or more images of the printed sample are captured.
3. Print quality parameters, such as print mottle and edge sharpness are calculated from the acquired image and outputted by the system.

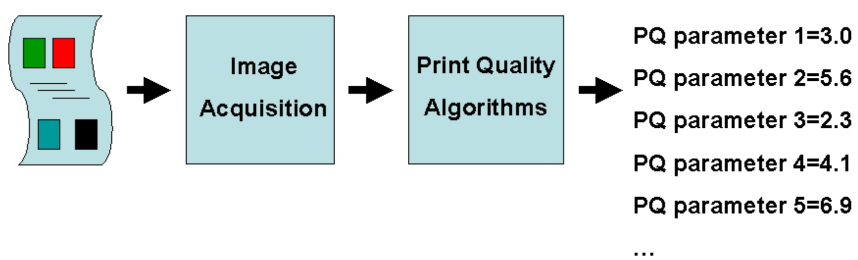

Figure 1. The workflow of a typical scanner-based system for measurement of print quality.

Image acquisition

A well-controlled image acquisition is fundamental for obtaining accurate and repetitive measurements from a print quality measurements system. There are however hazards related to the use of these systems. The systems will still deliver output values even if the scanning procedure is being carried out as an uncontrolled ‘black box’ operation. Therefore, it is important is to have full control over scanning parameters such as resolution and pixel depth to ensure that they are correctly set for the print quality algorithm that is to be applied to the scanned image. The scanning parameters are all possible to control and thus making it possible to minimize errors caused by incorrectly set parameters. Error sources that are more difficult to control are the effects of the substrate properties on the image acquisition. Therefore, knowledge of the capabilities of the scanner is important in order to have the scanner working within its range of capability for all types of printed substrates that are to be scanned. Properties of the printed substrate as color gamut and gloss variations in combination with the construction and properties of the scanner can introduce error sources in the image acquisition.

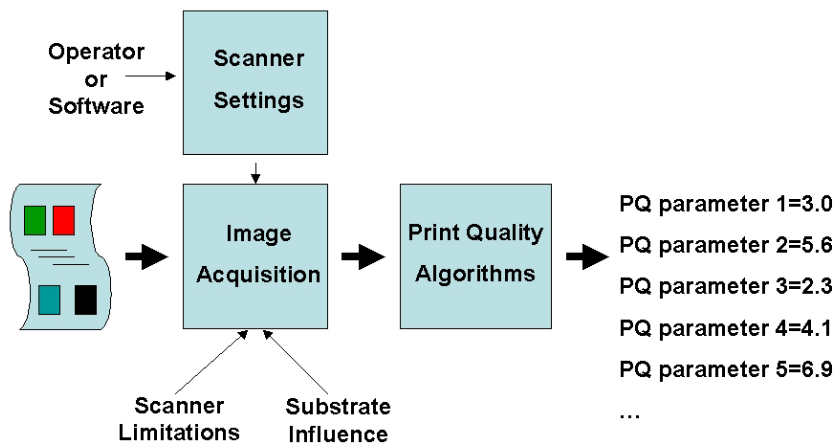

Figure 2. Error sources in the image acquisition step of a scanner-based system for print quality measurements.

The flatbed scanner

Over the last years, scanners have become popular devices for image acquisition. Decreasing prices and increasing image quality are two of the contributing factors for this development. This study is focusing on midrange flatbed scanners based on CCD (charged coupled device) technology. The CCD sensor is the core component of the scanner. It is an array consisting of thousands of photosensitive elements that measures light intensity and converts the intensity into electrical charge (Janesick, 2001). In a flatbed scanner, the CCD is located in a scanning unit consisting of a lamp, mirrors and a lens. The scanning process is illustrated in figure 3. With the printed substrate placed on a glass bed, the scanning unit moves underneath the glass. The printed substrate on the glass bed is illuminated and light is reflected from the printed substrate.

Subsequently, the light is reflected by a series of mirrors through the lens, which is focusing the image onto the CCD sensor. The CCD converts the incoming light into a proportional amount of electrical charge, which is finally digitized by an ADC (analog to digital converter). Every single element and stage in the scanning process is going to be critical for the quality of the acquired image.

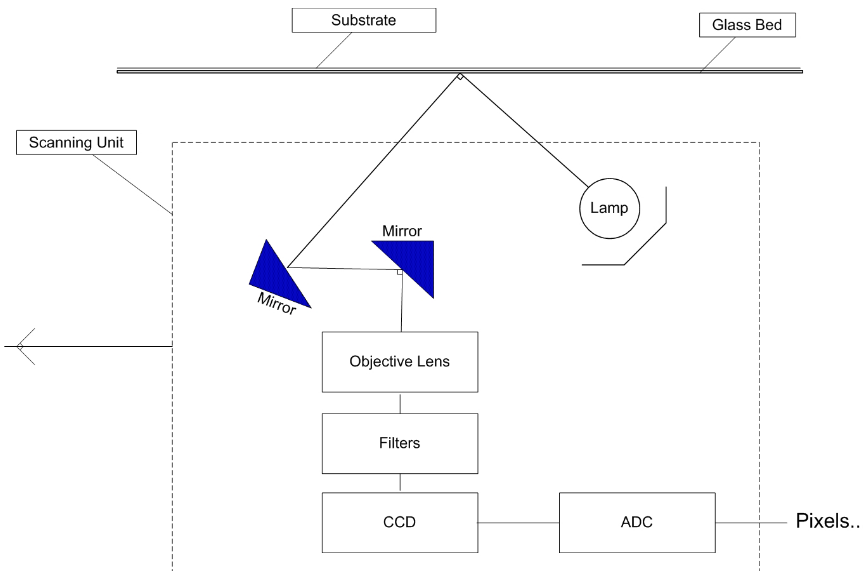

Figure 3. Schematic illustration of the scanning procedure of a flatbed scanner.

Scanner construction

The scanner should preferably be rigidly built and have a certain weight to withstand external vibrations and forces generated by the moving scanning unit. The rigid construction is an important factor since scanner-based systems for print quality evaluation are very often placed in environments with a lot of vibrations. Additionally, the scanner case should be almost hermetically airtight since dust in the optical system of the scanner quickly will lower the quality of the scanned images (Hobbs, 2000). In addition, keeping the glass bed of the scanner clean is a basic but essential part of the process to improve the image acquisition and thereby increase the possibility of obtaining precise measurements.

The scanner lamp

A consistent light source is required to produce precise results. Differences in the illumination characteristics over the scanned printed sample will affect the light that finally reaches the CCD sensor, thus decreasing the quality of the acquired image. The most commonly used lamp types are cold cathode fluorescent lamps and xenon gas discharge lamps. A cold cathode fluorescent lamp is a gas-discharge light source, which produces its output from a stimulated phosphor coating inside the glass lamp tube. The scanner lamp is combined with a light reflector to illuminate the printed sample more intensely. The shape of the reflector differs between scanner models. Some models are for example using two lamps and reflectors and therefore, it is hard to define any general standard geometry for the scanner illumination (Ng, 2001). Furthermore, what must be considered for scanners using cold cathode fluorescent lamps is the time required for the lamp to warm up. The warm up time differs between flatbed scanners, ranging from one minute up to 30 minutes or more for specific models. Xenon cold cathode lamps reach brightness faster and last longer than cold cathode fluorescent lamps, the two types of lamps also have different spectral distributions (Gann, 1998). An example of the intensity variations during warm-up for a scanner with a cold cathode lamp is shown in figure 4. An Agfa IT8.7/2 chart printed on photographic material was scanned 35 times in a row with an Agfa T1200 scanner starting with a cold scanner.

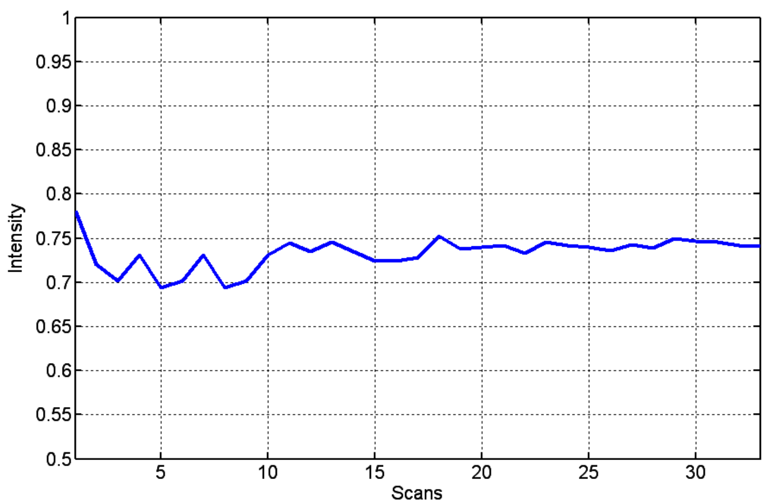

Figure 4. Intensity variations in the G-channel for one of the patches on the IT8 chart the during the warm-up stage of an AGFA T1200 flatbed scanner.

The intensity and characteristics of the lamp will change throughout its lifetime. Therefore, all scanners that are to be used for print quality measurements should have an internal calibration routine compensating for changes in the illumination. The internal calibration is usually implemented with a calibration target located under the scanner glass. Before an image is scanned the calibration target is measured and used to compensate for lamp degeneration. It is important that the calibration target can resist fading after long-term use since the cold cathode lamps have long lifetimes, typically 10000 hours. If the calibration target fades with time, the internal calibration will be less successful.

The image sensor

For each color channel, the CCD elements are coated with a channel-specific filter, hence separating the incident light into the three primary components of a color image. The filter characteristics differ between sensors used on different makes of CCDs (and scanners) thus making the obtained RGB-coordinates device-dependent (Hardeberg, 1999). The color separation is not only dependent of the filter, but also on the entire optical system that is involved prior to the filters, from the characteristics of the illumination to the quality and properties of the objective lens.

Optical density range

The quality and capacity of the scanning unit will set the limit for the optical density range (or dynamic range) of the scanner. The dynamic range of the scanner will depend on the brightness of the lamp, the quality and precision of the ADC and the capability of the optical system and the CCD (Hobbs, 2000).

Color Depth

The ADC (analog-to-digital converter) converts the output from the CCD array to digitally represented data. The bit depth is the number of bits allocated to store the color information for each color channel and pixel. Basically, higher bit depth gives higher image quality. The quality of the ADC will determine the true bit depth. The resulting image can be represented in 16 bits but if the ADC only manages to resolve 12 bits, the last four bits will only consist of noise. In practice, distortion in the scanning unit will further reduce the number of reproducible colors (Hobbs, 2000).

Optical resolution

The number of CCD elements in combination with the properties of the mirrors and lenses determine the optical resolution of the scanner. That is, the optical resolution is the number of elements in the CCD array divided by the width of the operational area. High quality in the mirror and lens system is required to obtain high quality in the acquired image. The optical resolution is an important parameter when selecting a flatbed scanner for print quality measurements. Scanner resolutions are often presented as a double number like 1200 x 2400, where the first number represents the optical resolution and the second represents the mechanical resolution. The mechanical resolution is determined by the resolution of the stepping motor that moves the scanning unit and it is usually higher than the optical resolution. However, there are very few, if any print quality measurements where images with higher resolution in one direction are required. It is not recommended to scan with a resolution higher then the optical. If this is done, an interpolation will be performed to calculate the intermediate pixel values. The interpolated pixel values will not deliver any additional information to the print quality algorithms; they will more likely introduce noise in the measurements.

Scanning unit linearity

The scanning unit is a linear electro-optical converter. It converts the energy of the incoming light into proportional amounts of electric signals. These are digitized and presented as digital RGB values. In practice, the scanner RGB values are not proportional to the spectral energy; the non-linearity can be caused by several factors. Due to leak currents, the CCD sensor produces a small electric signal even in the absence of incoming light, the problem is called black offset. Uneven illumination, stray light and unsatisfactory gloss trapping and inclusion of ultraviolet and infrared light in the detector are other factors that will have an influence on the linearity of the scanning unit and the quality of the scanner measurements (Hardeberg, 1999). It is fundamentally important that the optical density range of the scanner is enclosing the density range of the printed substrate that is scanned. An example where the printed density range of the substrate is wider than the optical density range of the scanner is presented here. A grayscale was printed with inkjet on a high-quality mattcoated substrate and measured with an Agfa T1200 scanner. Figure 5 shows how the scanner is saturating for the lowest tone levels (close to paper white) in the printed grayscale. It can also be observed that the curve levels out considerably for the highest tone levels and in addition, there is also more noise in the intensity values for the highest tone levels. The scanner is not capable of resolving the darkest levels of gray in the printed grayscale.

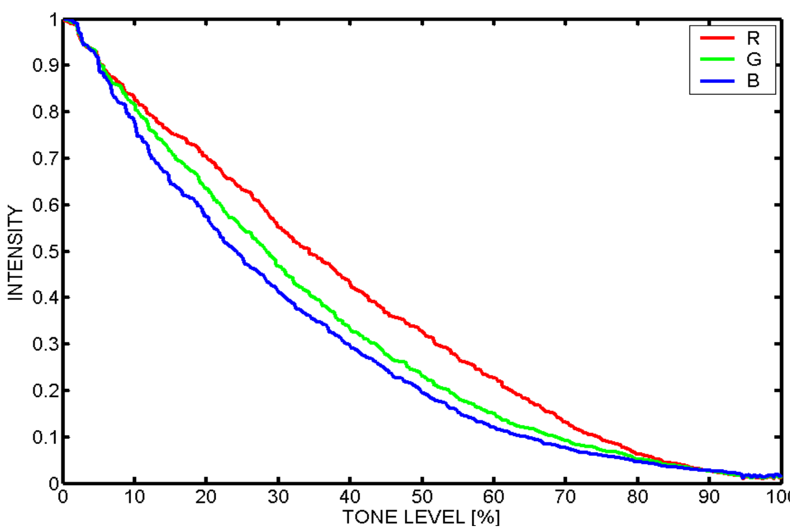

Figure 5. The optical density range of the scanner is not wide enough to entirely cover the density range of the printed substrate.

Controlling the scanner

Scanners need instructions, weather it is run by an operator or if controlled from a print quality measurement software. Scanning parameters as the size and position of the scanned area, the image format, the tonal range, tone curve adjustments, pixel depth and resolution must be set to the correct values associated with the print quality algorithm that is to be applied to the acquired image. For repetitive print quality measurements, it is necessary that correct scan settings are being used every time a measurement is executed. Therefore, it is strongly recommended that all algorithms for print quality measurements include the correct scanner settings for that specific algorithm. For each measurement, the specific scanner settings associated with each algorithm must be sent to the scanner. Figure 6 shows the workflow of a scanner-based system with a controlled image acquisition.

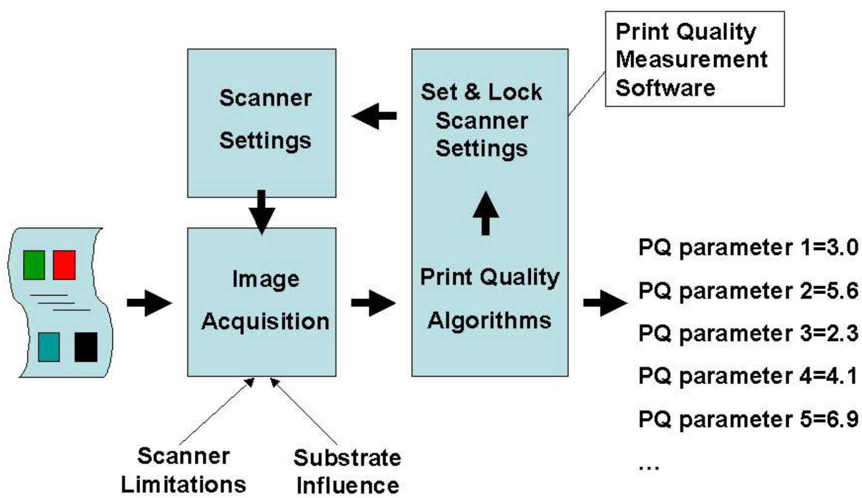

Figure 6. Controlled image acquisition in a scanner-based system for print quality measurements.

TWAIN

The majority of the scanners that are manufactured today are TWAIN-compatible, thus providing good possibilities to control the scanner from software for print quality measurements. TWAIN is a standard programming interface for scanners, which has become a widely used standard for software applications and operating systems to communicate with image acquisition devices. It was initiated by a consortium of scanner and software manufacturers with the purpose of providing a universal public standard which links applications and image acquisition devices. It defines a standard software protocol and API (application programming interface) for communication between software applications and image capturing devices.

Figure 7 illustrates the three key elements in TWAIN.

1. The application software
2. The source manager software, which handles the interactions between the application and the source. (In this case, between the print quality measurement software and the scanner).
3. The source software, which controls the image acquisition device.

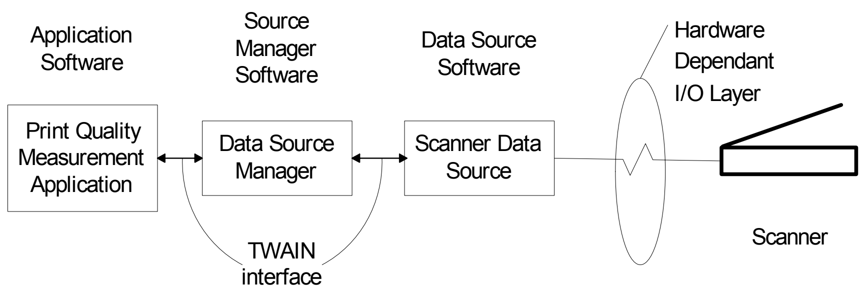

Figure 7. Using TWAIN to control the scanner.

The influence of gloss variations on the scanned image

Method

The aim with this study was to investigate how the gloss level of the printed substrate would influence the image acquisition. A print trial was performed on a DICO xerographic press where a test form consisting of square color patches was printed whereas the temperature in the gloss enhancement unit was varied, thus changing the gloss level in the printed color patches The print trial was carried out with the purpose to obtain printed substrates with the same color but with varying gloss level. The printed samples were measured with a spectrophotometer to validate that the colors were kept relatively constant as the gloss level was varied. Finally, the printed samples were scanned and an image processing routine was applied to extract the mean intensity level of each color patch.

Test forms

The A4-sized test form consisted of square color patches (9 x 9 mm) as shown in figure 8. It was produced in PostScript and converted to Adobe PDF 1.2 format without any color adjustments. The test form contained 475 test patches and was designed to have colors randomly distributed in the CIELAB color space with colors inside the gamut as well as colors on the edge of the gamut for the combination of print engine and substrate used in this study.

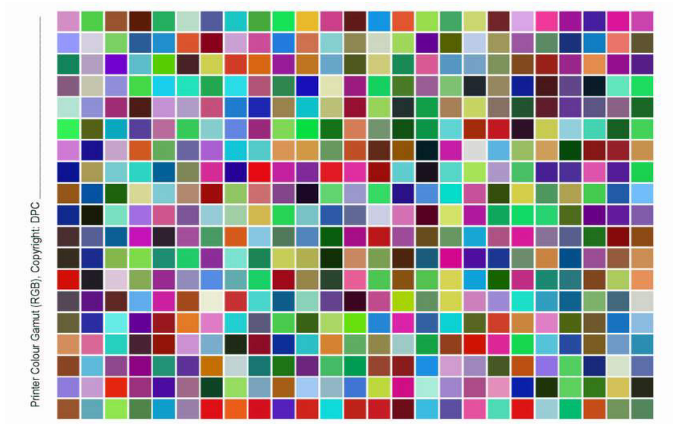

Figure 8. The A4-sized test form.

Printing

The temperature *T,* in the gloss enhancement unit (two nips, heated silicon rolls) of the printing press was increased from 40°C to 120°C in steps of 10°C, thus increasing the gloss level in the print. Only the substrates printed with a gloss enhancement unit temperature *T* between 60°C and 100°C was selected for the study. Below 60°C, the amount of print mottle was too high to allow consistent color reproduction. For temperatures above 100°C, the print started to crack for some of the color patches, which made it impossible to obtain a consistent color reproduction. No color adjustments were made to the test form that was printed on a mattcoated 115g paper. The printing was performed in a room with a controlled temperature of 21°C and a relative humidity of 40%. The difference in gloss level between the samples printed with T=60°C and T=100°C was clearly visible to the eye, where the sample printed with T=100°C had the higher gloss level.

Spectrophotometer measurements

The printed substrates were measured with a GretagMacBeth Spectrolino spectrophotometer. The measurements were carried out using D50 illumination, and 2° standard observer. The samples were measured twice, once with a neutral filter a second time where a polarization filter was used (see Appendix 1). The color difference between the sample printed with T=60°C and the sample printed with T=100°C was calculated for all the 475 color patches using the CIE 1976 color difference (Equation 1)

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \qquad (Eq.1)$$

The color differences were considered to be at acceptable levels, the results from the color difference calculation are shown in table 1.

	Filter	
	Polarization	Neutral
Maximum ΔE	3.4	4.5
Mean ΔE	1.8	2.2

Table 1. Color difference between the samples printed with T=100°C and T=60°C for the 475 color patches.

Scanner measurements

The printed samples were scanned with 150 ppi and a pixel depth of 12-bits per channel on an Agfa DuoScan T1200 flatbed scanner. All samples were scanned with the same scanner settings. The tonal range was fixed with the minimum set to 0.0D and the maximum set to 2.3D (In practice 0-1,9D, see Appendix 1). No tone curve adjustment or sharpening was used.

Printed density range

A print trial was performed to ensure that the density range of the printed substrates used in the gloss level study would be within the scanners optical density range. A grayscale test form was created in the same way as the one shown in figure 8, it consisted of 475 grayscale patches ranging from 0% to 100% in tone level. The grayscale test form was printed on the same substrate used in the gloss variation study under the same controlled conditions. The grayscale test form was printed and samples were selected when the temperature *T* in the gloss enhancement unit was at 60°C and 100°C respectively. The two printed grayscales were scanned and it could be confirmed that the printed density range of the two samples were both within the optical density range of the scanner.

Scanner noise and warm up time

A test was carried out to determine the time required for the scanners cold cathode fluorescent lamp to warm up and stabilize. An Agfa IT8.7/2 chart containing 308 color patches printed on photographic material with very even color reproduction was scanned 25 times in a row starting with a cold scanner. The measurements showed that after five minutes, the variations in the intensity values had decreased to a magnitude in parity with the intensity noise levels for a warm scanner that are shown in table 2. To analyze the noise level for the warmed up scanner it was powered and repeatedly used for two hours and then the IT8 chart was scanned every five minutes for another 25 measurements. Furthermore, an image processing routine was used to extract the mean intensity from each color patch. Finally, the standard deviation of the mean intensity over 25 scans was calculated for each color patch. The results are presented in table 2.

Standard deviation in mean intensity [%]			
	R	G	B
Mean	0.09	0.07	0.08
Max	0.23	0.20	0.21

Table 2. Noise in intensity values for the 308 color patches on the IT8 chart.

Results

The study indicates that as the gloss level increased in the printed color patches, the intensity levels in the scanned color patches decreased. Figure 9 shows the intensity change in the G channel for the 475 color patches when the temperature in the gloss enhancement unit was increased from 60°C to 100°C, thus increasing the gloss level in the color patches.

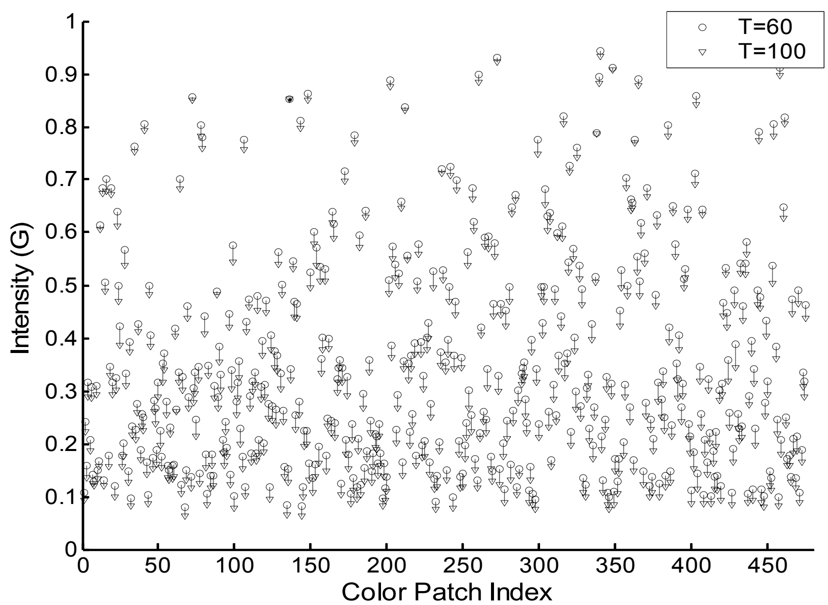

Figure 9. Intensity change in the G channel for the 475 color patches on the test form as the temperature in the gloss enhancement unit was increased from 60°C to 100°C.

The intensity level decreased for all color patches, and the maximum changes in intensity was 0.05 with the intensity ranging from 0.0 to 1.0. Furthermore, the relative change in intensity was as large as 25% for some of the color patches.

It was also observed that the effect was most noticeable for vivid colors. Similar result could also be observed for the R and B channels. Figure 9 illustrates how the intensity of the color patches move towards black [R, G, B] = [0, 0, 0] as the gloss level increases. The starting points of the arrows indicate the intensity levels for T=60°C and the endpoints of the arrows indicate the intensity levels when the temperature in the gloss enhancement unit was increased to 100°C.

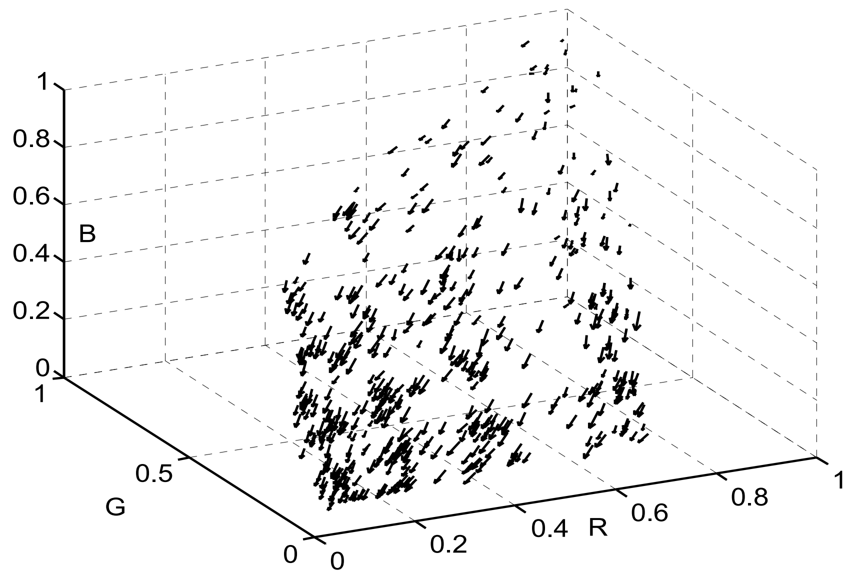

Figure 10. Intensity change for the 475 color patches on the test form when the temperature in the gloss enhancement unit was increased from 60°C to 100°C.

Conclusions

The findings of this study indicate that gloss variations influence the image acquisition for the scanner used in this study. The intensity in the acquired image decreases as the gloss level increases, thus indicating that the geometry of the scanning unit allows the gloss reflection from the illuminated substrate to be at least partially deflected away and thus not reaching the CCD array. This is one example of how the properties of the printed substrate will influence the image acquisition by means of a flatbed scanner, and this is something users of scanner-based systems for automated print quality measurements should be aware off. Furthermore, to calculate print quality parameters from images obtained from an uncontrolled image acquisition situation is to take an unnecessary risk of producing inferior measurements. Consistent image print quality measurements requires a consistent image acquisition. Therefore, it is important to be aware of scanner limitations and the influence of the printed substrate on the image acquisition as well as to use the proper scanning settings. Finally, it should be mentioned that the scanner used in this study is no longer commercially available. New flatbed scanners with higher optical resolutions, higher bit-depths and wider optical density ranges have been introduced on the market. However, though the capability of the scanners has increased, it is still imperative to have a well-controlled image acquisition when the scanners are used in systems for print quality measurements.

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Appendix 1

GretagMacbeth Spectrolino Specification:

Spectral Analysis: By holographic diffraction grating
Spectral Range: 380 to 730 nm
Physical Resolution: 10 nm
Measurement geometry: 45°/ 0° ring optic, DIN 5033
Measurement aperture: 4mm
Light Source: gas-filled tungsten, type A illumination
Density Range: 0.0 to 2.5D, DIN 16536
Physical Filters: D65, Polarization and Neutral
Short term repeatability: 0.03 ΔE (D50, 2°)

D50 and D65 illuminations can be simulated from the tungsten light source. Two standard observers are available, 2° and 10°. Additionally, there are three different mountable physical filters:

1. Neutral filter; measuring colors without any alterations.
2. Polarization filter; reduces the amount of directly reflected light, thus decreasing the effect of gloss in the measured sample. It also has a reducing effect for light with shorter wavelengths than 380 nm.
3. D65 filter; lowers the transmission within the visible range, which modifies the emitted light to approximate daylight.

In this study, all samples were measured using D50 illumination and 2° standard observer.

Agfa DuoScanT1200 Flatbed Scanner specification:

CCD: Tri-linear Coated, 5000 elements
A/D Conversion: 12 bits per Channel
Output pixel depth: 12 bits per Channel
Optical Resolution: 600 ppi
Density Range: 0.1 to 1.9 D for reflective scanning)
Scanner Lamp Type: Cold Cathode Fluorescent Lamp
Warm-up Time: 180s

In this study, the printed samples were scanned with 150 ppi and a pixel depth of 12-bits per channel. All samples were scanned with the same scanner settings. The tonal range was fixed with the minimum set to 0.0D and the maximum set to 2.3D. No tone curve adjustment or sharpening was used.