Automated Print Quality Analysis in Inkjet Printing: Case Study Using Commercially Available Media

Ming-Kai Tse and Alice H. Klein
QEA, Inc.
755 Middlesex Turnpike, Unit 3, Billerica MA 01821 USA
Tel: (978) 528-2034 · Fax: (978) 528-2033
e-mail: info@qea.com
URL: www.qea.com

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Ming-Kai Tse and Alice H. Klein*
QEA, Inc.
Burlington, Massachusetts/USA

Abstract

A methodology for automated analysis of print quality in inkjet printing has been developed and tested on 32 commercially available media. The methodology is based on an understanding of the phenomenology of ink-media interactions and their impact on print quality and user perception. The automated print quality analysis system described has a comprehensive set of built-in tools for quantifying the fundamental image elements and their quality attributes. These include dots (dot gain, shape and size), lines (width, sharpness, edge roughness, optical density, contrast and modulation), and solid areas (media roughness, image noise, optical density, tone reproduction and color). Our case study clearly demonstrates the efficacy and advantages of the automated system, in particular the speed of data acquisition and analysis, and the objectivity and reliability of measurements. In this paper, the design of the system is described, the test results are presented, and applications of the system in product planning, research, development and quality control are discussed.

Introduction

As digital printer performance has improved in recent years and costs have come down, print quality has become increasingly important in consumer choices among printing products, from the printers themselves to the output media. Print quality is influenced by a great diversity of factors. Among these are: the input data (scanned images, digital photographs, application programs, CD, disk, internet); the printer, subsystem and component design; the printing technology (electrophotography, thermal, inkjet); the marking material (toner, developer, ink, ribbon); the media (paper, film, coating, laminate); the software/firmware (halftone method, color management, RIP, file format compression); and the environment in which printing supplies are stored and printing occurs. Each printing technology has its own set of variables. In inkjet printing, for example, factors influencing print quality include the composition, viscosity, surface tension, pH, and drying time of the ink; the design of the print heads; the method of firing; the contact angle of the ink with the paper; the surface attributes of the media; and the ink-media interaction.

Traditionally, print quality evaluations have been conducted by panels of judges ranking test samples by preference. These subjective evaluations have been used at all levels of decision-making in product development, production quality control, and marketing applications. Though the traditional approach capitalizes on the strengths of human vision in detecting and characterizing detail, it is also saddled with unavoidable shortcomings. Subjective evaluations are personal, inconsistent, and inherently qualitative. Being primarily descriptive, they are difficult to interpret and communicate. Preference scores can be disproportionately influenced by a particular image attribute such as color or content. By its nature, the approach is time-consuming and inefficient. Despite its limitations, subjective evaluation of print quality is an essential part of the process. Clearly, however, unnecessary reliance on it is to be avoided if other approaches offering greater accuracy, repeatability and productivity are available. What's needed is a well-designed, technology-independent, quantitative tool for understanding, communicating and controlling the effects of the many variables affecting print quality.

Available Systems

A number of image analysis systems have been reported in the literature.[1-9] Most of these, however, have been proprietary systems developed by manufacturers or research laboratories for in-house applications. They have not necessarily been designed to traceable standards and have not been intended for general use. A few commercially available image analysis systems designed specifically for

* Contact for inquiries

print quality analysis exist, but their number is still quite limited. More limited still are commercial implementations that take customer requirements fully into account in the system design. These requirements include compatibility with existing office systems; ease of use; integration of multiple test, analysis and reporting functions; flexibility and expandability; and consistent performance based on recognized standards. Recent advances in automated print quality analysis respond to these requirements.

A High-Performance Automated Print Quality Analysis System

The system described here uses a computerized machine vision system with a comprehensive array of built-in tools to quantify the fundamental image elements (dots, lines and solid areas) and their quality attributes (dot location, gain, shape, edge raggedness, and satellites; line width, edge sharpness, edge roughness, optical density, contrast, and modulation; image noise, tone reproduction, color, gloss, and other characteristics). Key components of the system include a computer-controlled x-y positioning stage for print samples, a CCD (charge coupled device) camera, high-resolution optics, a light source, and a computer to run the control software. A spectrophotometer is integrated into the system for color quantification in several color spaces. The system architecture is shown in Figure 1 below.

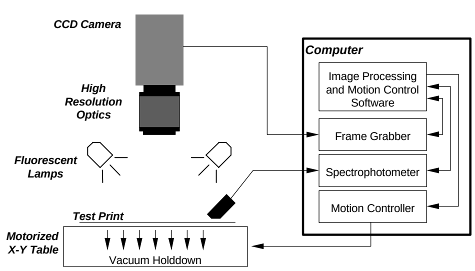

Figure 1 Automated Print Quality Analysis System Architecture

Using specially designed test targets, the system executes user-specified measurement sequences to quantify dot, line and solid area attributes. Measurement sequences can be of any length and degree of complexity. Powerful data analysis and reporting software make the scan results immediately available.

The system runs in Microsoft Excel® under Windows® 95. This design choice facilitates integration into existing environments and capitalizes on widespread user familiarity with the features and functions of the operating system and application software. Since digital printing technology is evolving fast, the system software and hardware configurations are designed to facilitate future modification as the needs of an application change. The open architecture allows users to add new measurement and analysis algorithms or modify existing ones. Similarly, the system includes ready-to-use report templates which the user can modify and add to as the need arises. The system can be operated in automated mode for optimum efficiency in production QC or large-scale data acquisition, or in interactive mode to investigate new problems, examine new test targets, develop new measurement functions or devise new test sequences. The system hardware and software are described in detail elsewhere.[10]

Application of the system in the case study

In a recent case study looking at print quality as a function of media type, we tested the effectiveness and practicality of the system for understanding relationships between objective print quality measurements and subjective preferences. In a typical office supply store, the choice of available media can be overwhelming, but how to choose among them is not necessarily clear. Our study aimed to shed light on this question.

We visited two local office supply stores and found a total of 32 media samples made by ten different manufacturers. We purchased all 32 samples for our study. The samples included 4 media types: uncoated papers of 2 different basis weights, matte finished coated papers of 2 different basis weights, glossy photographic grade coated papers, and film. We generated two sets of test prints, one for subjective and the other for objective evaluation, using all 32 media samples and printing all samples with three inkjet printers from three different manufacturers.

We asked a panel of judges to rank text and photographic test prints by preference, ranking them both by media type and by sample within type. Concurrently, we used the automated print quality analysis system described here to quantify print quality attributes on test targets specially designed for this purpose. The print quality attributes evaluated with the automated system were dot quality (dot size, dot uniformity, and dot gain), line quality (line width, edge sharpness, edge raggedness, optical density, and resolution), and solid area quality (optical density, tone reproduction, color gamut, and image noise). Representative results of these analyses are shown in Figures 2-7.

Our results clearly showed the importance of the media surface in ink-media interactions in inkjet printing. For example, Figure 2 provides a qualitative picture of the relationship between media roughness and dot quality. As shown, the smoother glossy coated papers and film tended to limit dot gain, producing consistent, well-formed dots. The much rougher uncoated papers were subject to irregular dot formation due to wicking of the ink along the cellulose fibers of the paper. These papers produced inconsistent dot size and substantial dot gain. Matte coated papers exhibited significantly more dot gain and more irregular dot formation than glossy coated papers and film, but considerably less than uncoated papers.

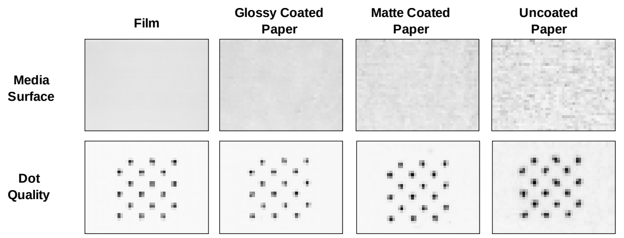

Figure 2 Effect of Media Roughness on Dot Quality

Using the automated print quality analysis system, the dependence of dot quality on media surface roughness was quantified as shown in Figure 3. The surface roughness, or noise, of the media was measured by setting the light source at a grazing angle of incidence. The graininess metric defined in the ISO-13660 draft standard was used to provide a quantitative measure of the media noise.[11]

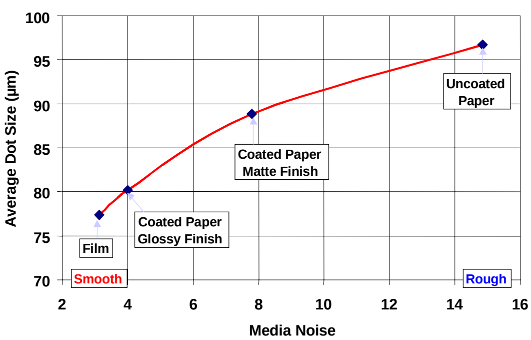

Figure 3 Effect of Media on Dot Size

Similarly, Figure 4 demonstrates the effects of media surface roughness on line width, which was shown to be

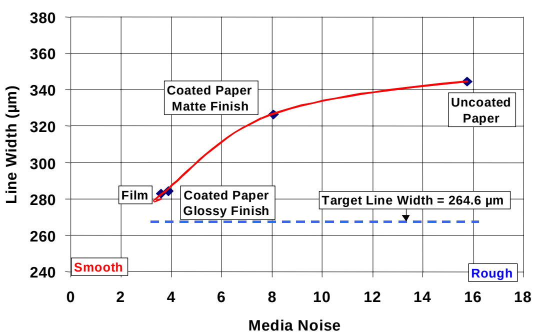

Figure 4 Effect of Media on Line Width

directly proportional to media noise. Similar observations were made of other line quality attributes such as tangential edge roughness, line density and line contrast.

Figure 5 demonstrates the dependence of modulation (resolution) on media surface characteristics. Uncoated papers produced the poorest dot and line definition and hence the most pronounced drop-off in modulation as line-pairs per mm increased. Predictably, films and glossy coated papers showed the least degradation.

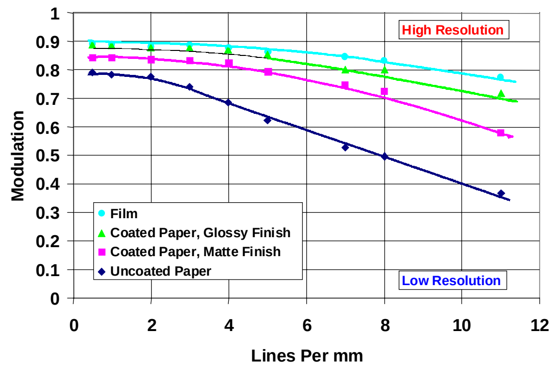

Figure 5 Effect of Media on Modulation (Resolution)

Figure 6 shows the effects of media on tone reproduction. Output optical density, relative to the gray scale percentages specified in the input file, is significantly higher for glossy coated papers and films than for the other media at high gray input levels. On the other hand, uncoated papers shows the smallest dynamic range, with significantly lower output optical density at gray scale values above 50 percent. Visually, images on the glossy coated papers and films appear significantly more saturated than those on the uncoated paper.

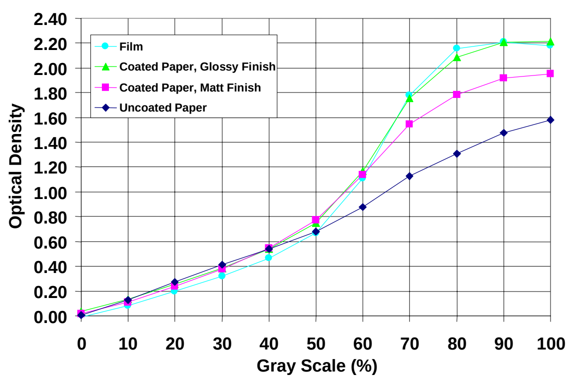

Figure 6 Effect of Media on Tone Reproduction

Figure 7 shows the effect of the media surface on color gamut to be just as dramatic. As the graph shows, uncoated papers have the smallest gamut while films have the greatest gamut, with matte coated and glossy coated papers in between.

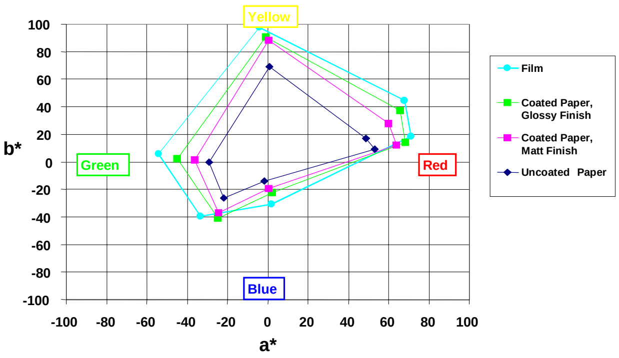

Figure 7 Effect of Media on Color Gamut

Correlating Objective and Subjective PQ Analyses

Turning our attention to the preference ratings of the panel of judges, we observed good correlations between the subjective evaluations and the objective analyses performed with the print quality analysis system. For example, when we plotted objectively measured modulation and optical density in photographic test samples against panel preferences, it was apparent that objective improvements in these attributes corresponded to higher preference ratings by the judges. This correlation is shown in Figure 8 below.

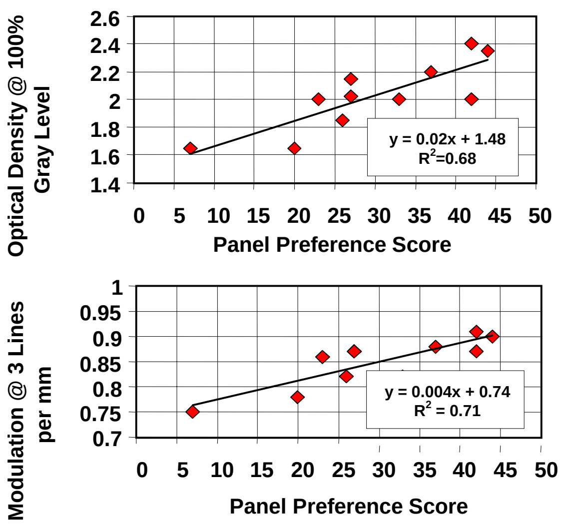

Figure 8 Modulation and Optical Density vs. Subjective Scores

It should be noted that when we used black text test samples and plotted the same quantitatively measured attributes against panel preferences, results were slightly more scattered. This suggests that other attributes may be at play in this case.

Overall, correlations between subjective and objective evaluations were strong enough to suggest that a well-designed quantitative print quality analysis methodology can anticipate consumer preference to a significant degree.

Summary

The automated print quality analysis system described here has been shown to be a practical tool for large-scale objective studies of print quality. In our case study, we analyzed a total of about 100,000 data points. Total data acquisition time was about 24 hours. Due to the speed of the system and its integrated data analysis and reporting features, we completed the entire study in less than 2 weeks of part-time effort. We were able to demonstrate the effects of ink-media interactions and show that objective measurements made with the system described here generally correlate well with subjective print quality preference ratings. This shows that much of the work traditionally done by subjective evaluations can be performed by well-designed objective methodologies like the one described. Further, while our case study looked at issues relating specifically to inkjet printing, the same print quality analysis system can be used to investigate variables of any printing technology, as similar studies in electrophotography and thermal printing have shown.[12-14] The system allows many tasks previously requiring the ongoing attention of technical experts to be executed by technicians, freeing scarce resources for other tasks. The system offers benefits to R&D, manufacturing and marketing applications, generating data in volumes large enough to ensure statistical reliability and ensuring a dependable basis for decisions at all levels. Further, it offers a needed tool for setting industry standards for printers, papers, marking materials and digital printing products in general.

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Biography

Dr. Ming-Kai Tse founded QEA, Inc. in 1987. The company designs and manufactures automated quality control test systems for manufacturing and R&D applications in digital printing. Dr. Tse was a professor of Mechanical Engineering at the Massachusetts Institute of Technology between 1982 and 1989. At MIT he specialized in the areas of manufacturing, non-destructive testing, and quality engineering. Dr. Tse received his BS degree in Mechanical Engineering from Cornell University and his MS and PhD degrees, both in Mechanical Engineering, from MIT.