Design of Test Targets for Objective Image Quality Evaluation

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Abstract

Image quality is imperative in the design and selection of digital imaging systems and technologies. End-users typically evaluate image quality subjectively, while technologists prefer quantitative analysis to support objective and rational decisions. The concepts of objective image quality analysis and the use of test targets are not new. Unfortunately, the literature on the subject is generally quite scattered or specialized. In this paper, we present a review on the image quality requirements for different imaging applications, the basic concepts in objective image quality evaluation and the corresponding test target design principles and practical considerations. In preparing this review article, we draw on our experience as a practitioner and designer of instrumentation for digital imaging, as well as a broad scope literature review.

Introduction

What to measure, how to measure, and why to measure — the answers to these questions establish the foundation for objective print quality evaluation. Unfortunately, for a newcomer to the field, the literature on the subject is often difficult to comprehend due to an unfamiliar vocabulary, or the highly specialized subject. This paper presents a useful framework for the development of image analysis systems and test targets. Of course, in a short paper, a comprehensive treatise is not possible, but the author hopes, at the least, readers will find the basics provided helpful in their next image quality evaluation or test target design projects.

Imaging involves both input and output devices. In this paper, the focus is on output devices & their output, i.e., printers and prints. However, the principle of target design for output devices is generally applicable to input devices as well.

Image Quality Evaluation Methodologies

Image quality evaluation is a basic tool in the imaging industry for research, development, technology and product benchmarking, production quality control, process control, and troubleshooting. Image evaluation methods can be broadly classified in three categories:

1. ***Subjective evaluation of finished prints***: This type of testing, commonly practiced in the printing industry, uses a sample of the finished product with actual pictorial images, text, or graphic designs, and the evaluator decides on the acceptance of a product purely based on subjective judgment or by comparing with a proof. While this type of testing provides a "reality check," it is nonetheless subjective, qualitative, and subject to variability from person to person and from time to time.
2. ***Psychometric scaling***: this is basically a subjective method that uses "calibrated" test targets or "quality rulers"[1.2]. The results from such tests can be very effective in predicting user preference if the test targets are chosen carefully and the tests are conducted properly. In fact, some such methodologies have been standardized[3] or hold promise to become important standards[4]. Scaling experiments usually require special viewing conditions; proper analysis of the test results often demands the expertise of specialists; and designing good test targets for this type of testing is often difficult. All these factors limit the application of such methods.
3. ***Test target-based evaluation***: In this type of testing, print quality is evaluated with a specialized test target or targets (rather than on the finished product). The test target(s) may be one of many "standard" targets available commercially, usually based on industry standards[5-10], or proprietary targets designed for internal applications[11,12] or commercial purposes[13]. The majority of test target-based image quality evaluation to-date is performed by visual judgment; and to a lesser extent, by means of instruments such as a densitometer for optical density, or a spectrophotometer for color. While the use of visual test target evaluation is a major step towards process control and product quality assurance, it is nonetheless qualitative and its reliability suffers from variations due to all the pitfalls of subjective testing.

   Since its publication in 2001, the ISO/IEC 13660 international image quality standard[14] provides an alternative to visual image quality testing and has served as a cornerstone for a new generation of objective image quality analysis systems[15].

Test target design today generally falls under two categories: a) those concerned primarily with density and color measurements[16], and b) those focusing almost exclusively on print defects such as graininess, mottle, banding, streaking, … etc.[17,18]. Both categories are important contributors to overall image quality, and a good test target must therefore include all these attributes. Density and color alone do not guarantee adequate image quality. Similarly, the lack of defects in a print does not necessarily imply high image quality either[19]. Image quality is a complicated subject. Design of a good test target must begin with a basic understanding of image quality and an appreciation of a print user's requirements, i.e., "How to print pictures and please people?"[20].

User Requirements for Test Target Design

The answer to the above question lays the groundwork for choosing the proper test target elements and the corresponding analysis method. Since pictorial images are very important in print applications, we start by establishing the user requirements for pictorial images, and then design corresponding test targets and analysis methods to measure the prints with respect to such requirements.

At the highest level, pictorial image quality consists of 5 major categories of attributes:

1. Tone quality (tone reproduction)
2. Color quality
3. Sharpness and details
4. Image artifacts (defects)
5. Gloss and distinctness of image (DOI)

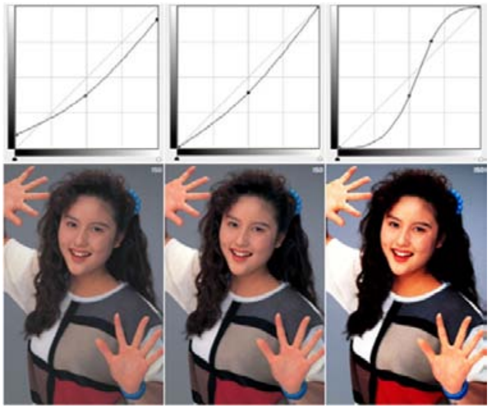
The author believes that the above list represents the order of importance in terms of image quality to most users of a print, as supported by the discussion in the rest of this paper.

Tone Quality

Tone quality or ***tone reproduction*** in prints refers to the overall appearance (including brightness and details in the highlight, through midtone, to the shadow) and the contrast in a pictorial image. Correctness in tonal quality is of fundamental importance in determining the perceived quality of a pictorial image[20-22]. In photography or printing, tonal quality is considered by many as the most important appearance quality attribute. The great American photographer, Ansel Adams, is well known for his Zone system[23], which provides a method to guide a photographer to visualize and compose an image and to set the exposure or the processing for good tonal quality. Indeed, if the tonal quality in a pictorial image is "off", nothing else matters. For example, a print does not look good if the *contrast* (gamma) is too low, leading to a "flat" and "uninteresting" image as shown in Fig.1a; or too high, in which the image looks posterized, over-saturated or cartoon-like as in Fig.1c. Similarly, if the highlight and shadow are not right, such as the "blown" highlight and "plugged" shadow, also evident in Fig. 1c, the image is not pleasing either. Overall, for an image to appear pleasing and natural, it needs to have not only a sufficient dynamic range (i.e. the range between D_{min} and D_{max}), but also a "properly shaped" tone curve from light to dark through highlight, mid-tone and shadow. The optimum tone curve shape, however, depends on the application and the user preference.

The emphasis on the shape and the details in the tone curve as a determinant of image quality is a strong departure from the classical emphasis on measurement of D_{max} (maximum optical density) as the sole judge of image quality.

Characterization of the tonal quality can be accomplished by measuring a tone scale, for example, with 11 tint steps from 0 to 100% in equal increments of 10%. This step wedge is typically included in a basic test target design. In a more advanced design, finer steps may be added, often to the shadow to better characterize this end of the tone scale. In addition, equal increments in lightness (L*) can be used instead of equal tint increments to better simulate how human perceives the gray world. An example of such a design can be found in the Kodak Q60 test target[27].



a. Low Contrast   b. Original   c. High Contrast

Fig.1. Importance of Tonal Quality on Image Appearance

Measurement of the tone scale can be done using a densitometer, spectrophotometer or a calibrated image analysis system. A standard methodology is provided by ISO 13660.

Note that in the testing of image input devices, tonal quality is characterized in terms of OECF, the Opto-Electronic Conversion Function as detailed in the international standard ISO-13524[24].

Color Quality

Color tone reproduction can be analyzed by extending the gray tone scale to include the different color separations such as C, M, and Y in the print. These tone scales serve to evaluate the tonal quality in color similar to that in the gray or lightness scale.

In addition to color tone reproduction, another critical attribute in perceived quality is ***gray balance*** (to a printer, or ***white balance*** to a photographer). The eye is extremely sensitive to the neutrality of gray. If the gray balance in a photograph is not right, it is not "neutral" and will not look natural or pleasing. An example is shown in Fig. 2, in which R, G, and B color casts are introduced intentionally to simulate poor gray balance. This example demonstrates that in a portrait, a greenish color cast is particularly objectionable in the skin tone. Maintaining gray balance is in fact central to the G7 calibration methodology, an industry standard in commercial printing to achieve appearance matching from proof to print[6].

To analyze gray balance, a gray tone step wedge composed of the "balanced" process colors (CMY or CMYK) should be included as an integral part of a test target. Such step wedges are shown below each portrait in Figure 2.

Measurements of gray balance can be done by means of a spectrodensitometer, a spectrophotometer, or a calibrated image analysis system to obtain a*-b* data as shown in Fig. 2. For the Neutral image with proper gray balance, the a*-b* values are all zero. But for the images with color casts the a*-b* measurements deviate from the ideal value at the origin.

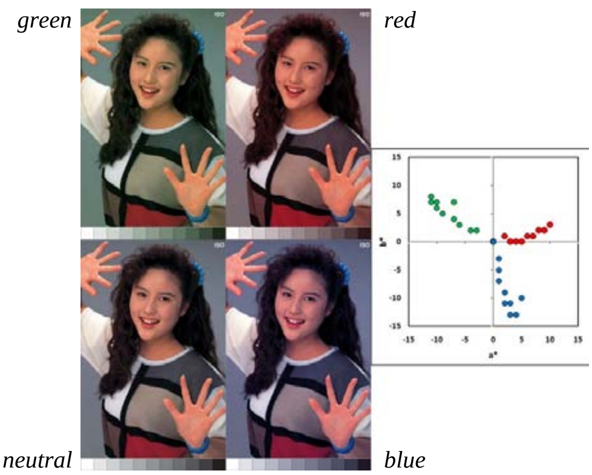


Fig. 2 Perceived Image Quality due to Color Cast

In rendering color, several other attributes are considered very important; these include: ***contouring***, ***color gamut*** and ***color fidelity***[25,26].

Contouring refers to the lack of smoothness in a color gradient. Human vision is very sensitive to jumps or steps in a tone gradient, e.g., the sky. Contouring can be analyzed by adding a set of color vignettes (CMYK) to the test target and is best measured by using a calibrated, scanner-based image analysis system.

Color gamut and color fidelity of a printing system are always very important. For serious color gamut measurement, the test target must contain many color patches covering the entire color space (typically on the order of 1000 patches). An example of such a target is the IT8.7/3 or IT8.7/4[27]. In case of test target space limitations, a reduced set that maintains a broad range of lightness, hue and chroma (Lch) such as those in IT8.7/2[27] is a possibility. For color fidelity, the basic idea is to select color patches that are a good representation of the color content in the application. Some of the color bars based on industry standards[5-10] provide guidance on the choice of color patches. Measuring large numbers of color patches by hand is not practical. Therefore, an automated scanning system is essential for accurate color gamut characterization.

Sharpness and Details

Tone and color deals with the contents in an image in terms of lightness, hue and chroma. Another attribute fundamental to image quality relates to the spatial content, or sharpness and details in the image, which are critical in, for example, photos, text and barcodes. Sharpness and details are controlled by the resolution of the imaging system and the interaction of the marking materials (ink and toner) with the print substrate.

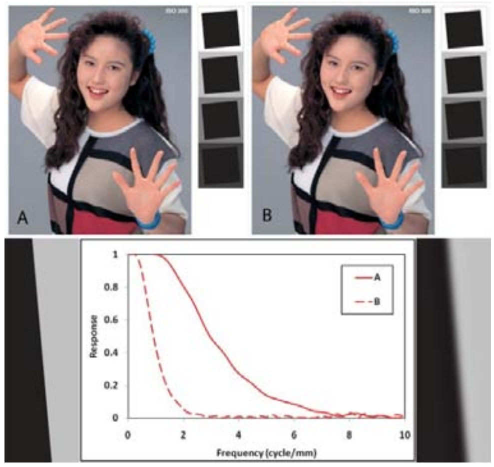


Fig. 3. Use of Slant Edge Spatial Frequency Response (SFR) Method For Printer Resolution Analysis

Historically, resolution in an imaging system is measured using resolution targets consisting of line patterns of increasing frequency such as the USAF 1951 target[13]. A relatively new approach to determine the resolution of an imaging system is to measure the Spatial Frequency Response (SFR) using the slanted edge technique as specified in an international standard (ISO 12233)[28]. The basic target design is deceptively simple – a rotated square (typically at 5 deg). A major advantage of the SFR technique is its simplicity in execution and its potential for automated measurements. Figure 3 provides an example where image A is sharper as clearly quantified by the SFR measurement.

In addition to SFR, line quality analysis is a common and useful technique to measure the ability of an imaging system to reproduce sharp features and details. ISO 13660 provides an excellent foundation for the design of line test targets and analysis of line quality.

Text quality is also affected by a printing system's ability to produce sharpness and details. Text quality analysis is much more complicated than the analysis of lines and in fact a new appearance based standard is currently under development[4,26].

Image Artifacts

The previous image quality attributes measure the "signal" in an image. Unfortunately, "noise" (image defects) is often unavoidable in real imaging systems. This is a category that covers a broad range of defects, some are generic in printing systems in general, and others are specific to an individual technology. Generic noise types include graininess, mottle, banding, streaking, ghosting, and color mis-registration. Technology specific noise types include satellites and inter-color bleed in inkjet; and background, deletion, and blistering in electrophotography. The design of test targets for different image defects are well-covered in the literature [15,17-18] and are not detailed in this paper due to space constraints. Two new international standards are also under development to address many image noise measurement issues. These include ISO 24790[29] as an update of ISO 13660, and ISO 19751 with an emphasis on appearance based image quality evaluation (including text quality analysis)[4,26]. Image defect testing may require the use of large target areas and multiple test pages.

Image artifacts are best analyzed by means of camera or scanner-based image analysis systems[15].

Gloss and DOI Gloss

The latest international image quality standard on gloss measurement is ISO 19799[30], which details the target design and analysis methodology for differential gloss measurements[30].

For Distinctness of Image (DOI) Gloss, there is no need for special target design - measurements are made on the actual sample, printed or un-printed[15].

Summary

Built on an understanding of the basic print user requirements, supported by relevant literature, industry standards, and international standards, this paper presented a framework for the design of test targets for instrumented, objective print quality analysis.

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