The Importance of Objective Analysis in Image Quality Evaluation

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Abstract

It can be stated that image quality is in the eye of the beholder. After all, the human observer is the final arbiter for an imaging device whose output is intended for human consumption. However, it is difficult to distill objective data about specific image elements and attributes from image evaluation processes and procedures that rely on human observations. Quantification of image quality attributes is confounded by the inherent subjectivity of human judgment, and the fact that human perception is a complex mixture of psychology, physiology, and environment. In spite of these difficulties, the need for quantitative image quality analysis still exists. Quantification provides the basis for inter-system comparisons, evaluation of performance against specifications, and it can be a critical component in process control and failure analysis.

Objective image quality evaluation systems can provide the repeatability and reliability lacking in subjective processes. A machine-vision-based system can provide detailed information about individual attributes that contribute to the overall perception of image quality. Line quality, dot quality, and color reproduction are just a few of the many elements that can be characterized in detail by such a system. In general, it is important to maintain a correlation between measured attributes and the human visual response. However, a machine-vision-based system has an additional benefit in that it can provide additional information that can be used to differentiate between multiple possible causes for a single defect.

If, in addition to being objective, a measurement system is also automated, the capabilities and resulting benefits of the system increase dramatically. A well designed, automated system can support the evaluation of a large volume of prints and a large number of image quality attributes, as well as a wide variety of test targets.

In this paper we will be discussing the importance of objective analysis in image quality evaluation. We will discuss several key image quality attributes such as dot and line quality, color registration, and tone reproduction, as well as address some technology-specific image quality attributes. We will present some of the metrics that can be used to quantify these attributes. We will also discuss how an automated, objective image quality measurement system can be a critical component in statistical process control and failure analysis.

Quantitative Analysis

Quantitative analysis provides repeatable, reliable data that can aid in performance tracking and failure analysis. However, the specific metrics used to characterize a device are not necessarily the same for each application. It is important to identify the figures of merit that should be measured to determine or verify the performance of a specific system. The next several sections will introduce a few of the possible metrics that can be used to evaluate some basic image quality attributes that are important figures of merit in many marking systems.

Dot Quality

Dot quality relies on how well a marking process can control dot formation. Unintended variations in dot shape, size and, in the case of amplitude modulated screening ("AM"), position.

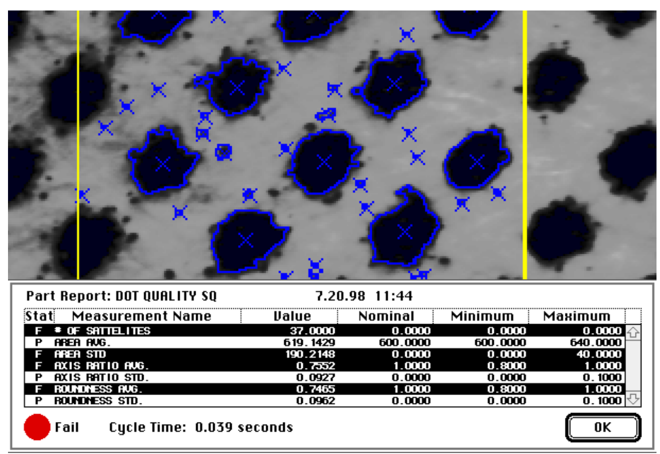

Figure 1. Dot Quality

The quantification of dot quality used to be relatively straightforward. Dot shape, size and position can all be measured with great accuracy and precision. However, since digital halftoning has grown to include techniques that are based on changes in dot position rather than dot size ("frequency modulated" or "FM" screening), variable dot sizes and shapes within an evenly toned area, dot quality analysis has become more challenging.

Line Quality

The perception of line quality is based on a number of factors. Some components of line quality are the average line width, line width variation, edge raggedness and line sharpness. Edge raggedness is measured by taking the mean deviation of the edge points from the best-fit line through those edge points. Line sharpness is evaluated by measuring the average rise time along an edge.

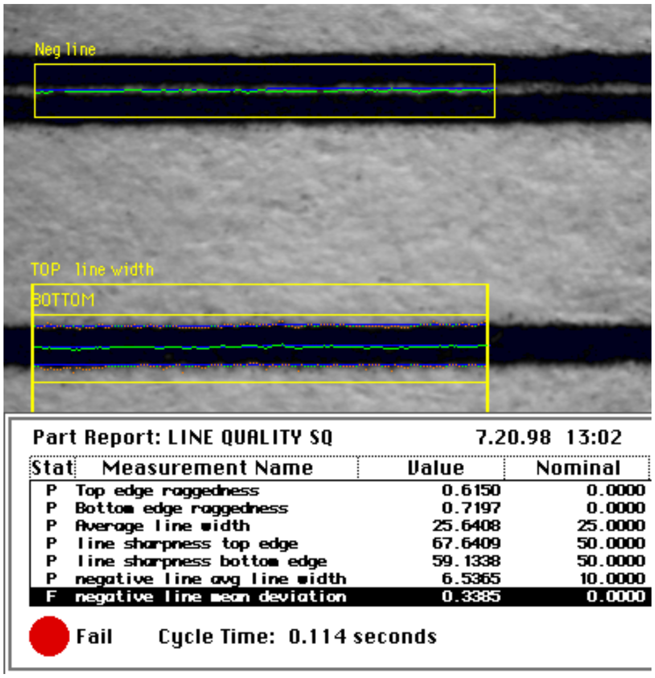

Figure 2. Line Quality

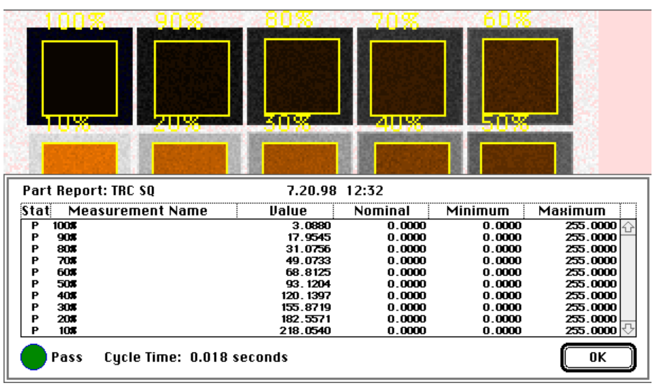

Figure 3. TRC

Color Registration

Color registration is critical to the perceived quality of a color print. One measure of color registration is to compare the width of a "registration" line (C+M+Y) to a black-only line of the same intended width. Measuring both horizontal and vertical lines will provide some information about the total amount of mis-registration as a function of distance. However, this metric does not provide information about which primaries are out of register. A second metric is needed to determine the horizontal and vertical offset of each color.

Tone Reproduction

Tonal response is a fundamental characteristic of an imaging system. Analyzing the tone reproduction curve (TRC) for each primary can be quite informative.

Determining and verifying this relationship can provide information on the status of a marking engine either during set-up or during service.

Technology-Specific Attributes

Inkjet: Bleed

Bleed occurs between adjacent and abutted areas of wet ink. The inks mix along the border between the areas. This can be quantified by measuring the width of the border line as well as quantifying the extent of the intrusion of each ink into the other. The degree of intrusion is measured by locating the points that make up an edge, finding a best-fit-line through those points and then measuring the deviation of each point from the best fit line. The mean deviation provides some measure of the extent of the intrusion, as does the maximum deviation.

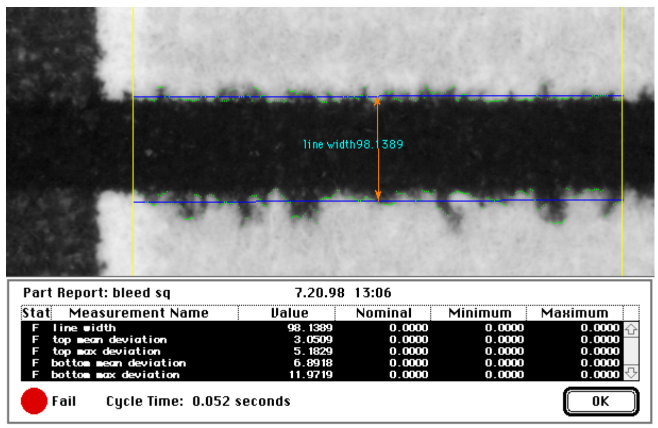

Figure 4. Bleed Between Yellow and Black

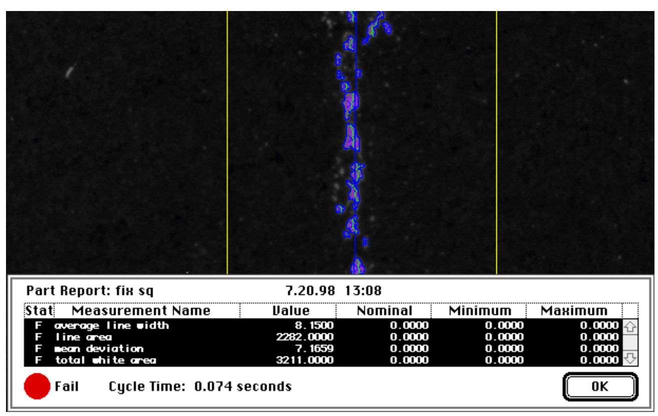

Figure 5. Fix/Crease

Electrophotography: Fix/Crease

Fix/crease is a measure of how well toner has adhered to the substrate in a solid region of a print. Often, the sample is folded ("creased") and then either wiped or blown free of any toner that was disturbed during the creasing process. Fix can be quantified by measuring the width of the line formed from the disturbed toner along the crease as well as the area and gray level.

Thermal Transfer: Streaks

Thermal transfer marking technologies have historically been prone to streaks. These streaks can be the result of many different mechanisms, but most are due to the presence of debris on the thermal print head, or the failure of one of the elements on the print head to operate properly. Quantifying the number and severity of streaks on a print can provide information on print head performance.

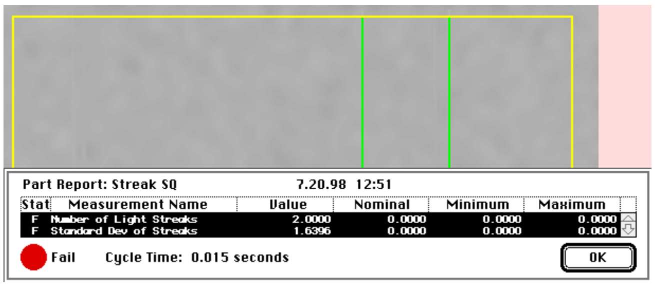

Figure 6. Streaks

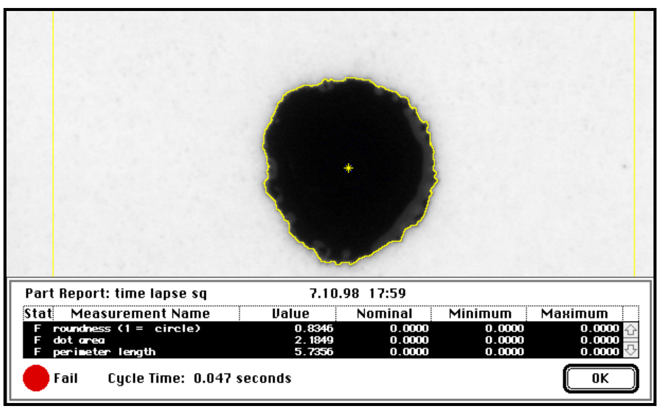

Figure 7a. Time Zero

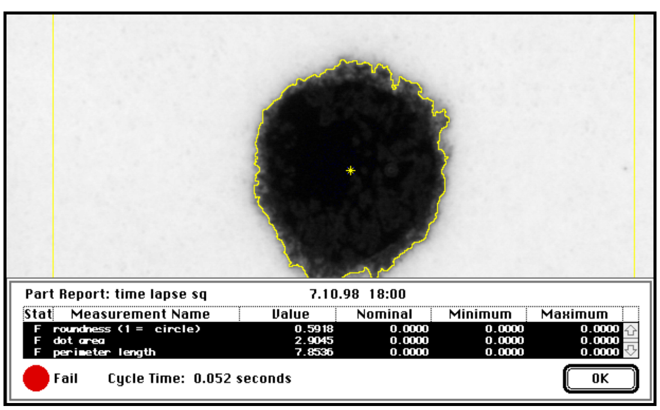

Figure 7b. Dot After 5 Min. 30 Sec.

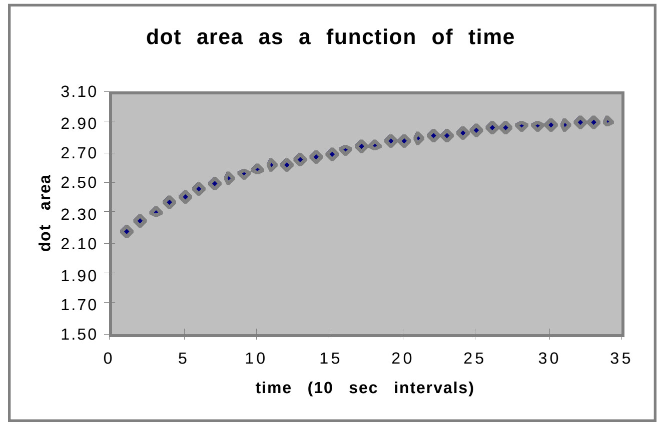

Figure 8a. Dot Area

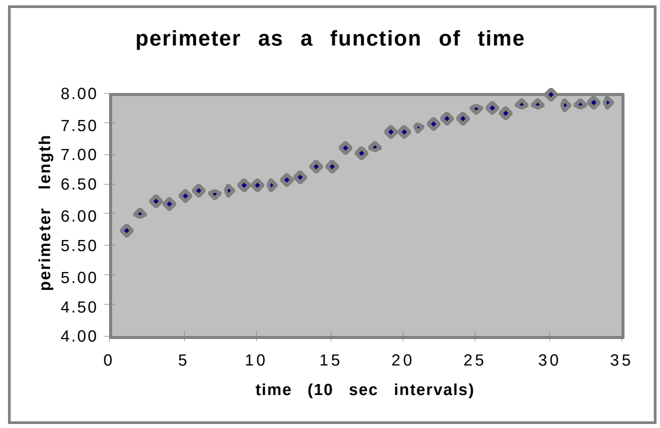

Figure 8b. Perimeter Length

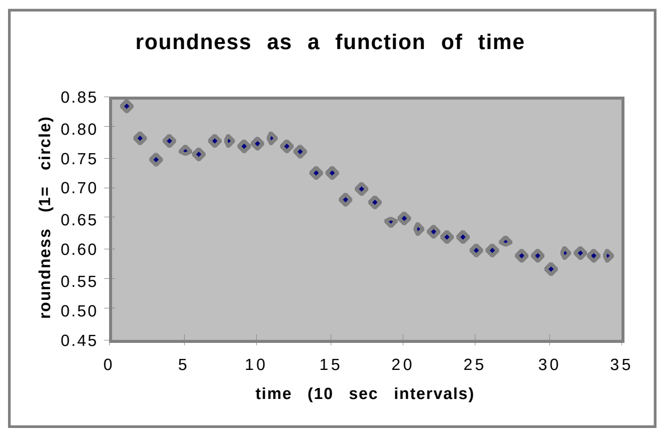

Figure 8c. Roundness

Media: Time Lapse Analysis of Wicking

Characterizing media performance is difficult because print quality is a function of the complex inter-relationships between marking and receiving media and the print engine. One example of a media specific characteristic is seen in inkjet printing. The effect is called "wicking" and it is due to the flow of ink along paper fibers. This results in unintended line and dot growth, which then affect the quality of everything from halftoned areas to text. One way to measure the severity of wicking as well as to get information about the wicking process is to evaluate dot quality characteristics of some number of dots from soon after being printed to when they are dry. In order to perform this type of investigation, some time-lapse imaging and evaluation need to be used. The next figures show an image of a just-deposited ink dot followed by an image of the same ink dot taken after five and one half minutes.

Analysis took place in real time at 10-second intervals. The following graphs show the changes in some fundamental dot characteristics during this time frame.

Correlation Between Subjective and Objective Measurements

One of the most critical steps in developing objective measurements of image quality characteristics is to fully understand the relationship between the figures of merit being measured and human perception. Since each application is a different marking technology or a different target market, there is no way to have one set of correlation functions that will work for everyone. The needs of a barcode printer are quite different from a printer intended for pre-press proofing.

Failure Mode Differentiation

Quantitative analysis can also directly feed failure analysis. Often, similar defects can be caused by several different mechanisms. Sometimes the differentiating characteristics are very subtle or very small. Machine-vision-based systems can measure subtle image characteristics that the human visual system cannot perceive and use these details for differentiation between multiple failure modes. These methodologies are repeatable and objective, which can enable performance tracking as well as increase throughput, and decrease troubleshooting time.

The Role of Automation

The role of automation is simple: automation increases measurement repeatability, reliability and throughput. In the context of image quality measurement systems, automation can refer to the integration of a high-precision X-Y translation stage, one or more computer driven auxiliary instruments such as a spectrophotometer and glossmeter, and an automatic document feeder. In order to minimize the need for operator intervention, the system should enable automatic compensation for sample or image misalignment as well as for variations in illumination and substrate intensity. A system that automatically checks measured values against user-defined tolerances can speed-up inspection and verification in production environments.

Conclusion

Objective image quality analysis results in repeatable, reliable, quantitative data to be used in performance evaluation, tracking, verification, and failure mode differentiation. Automation can increase the power of an objective image quality measurement system by enabling increased throughput while decreasing the need for operator intervention. It is important to remember that each application will have its own set of image quality requirements. The decisions regarding which measurements to perform and what the tolerances to apply to those measurements are not universally applicable. Different technologies, even those competing in the same market, will have different characteristics that need to be taken into account when deciding what measurement set is appropriate.

Objective measurements and measurement devices are not intended to take the place of human observers. Correlation between objective and subjective evaluation is essential if the objective data is to have meaning and relevance.

Biography

Dave Wolin received his Bachelor's degree in Physics from Cornell University, and has spent the last twenty years working in the field of imaging. He has been involved in the development and production of imaging sensors and systems for a variety of applications. Since joining KDY Inc. as Technical Marketing Manager, he has been working on image quality metrics for print and media analysis.