Image Quality Metrics for Printers and Media

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Abstract

The most common computer peripheral used in office applications is the non-impact printer. The resolution, performance, and cost of these devices have improved dramatically during the 1990's with output image quality emerging as a significant differentiator between competitive products. Just as printer manufacturers have become more aware of these developments, paper manufacturers have also begun to develop special purpose papers formulated to accept ink, wax or toner with little or no substrate-induced image degradation or distortion.

These and other developments have created increased demand from imaging R&D and manufacturing quality engineers for precise tools to evaluate image quality in a non-subjective and repeatable manner. Just as importantly, these tools must be able to perform measurements in a timely manner in order to keep pace with ever shortening product development cycles.

This paper will present a series of specific metrics that can be used for quantifying printed image quality for printer and paper manufacturers. Specifically we will present a methodology for evaluating color registration, resolution, text quality, dot quality, line quality and other image quality attributes. In addition we will discuss methods by which manufacturers have achieved fully automated image quality testing and the benefits achieved by automated testing in the areas of process monitoring and production quality.

Typical Image Quality Tests

Among the multitude of image quality tests available, there are a few that are particularly well suited to evaluate media-dependent image quality issues. These tests include:

- Dot Quality (including tests for dot placement accuracy and variations in dot formation)
- Halftone Quality (including tests for area coverage)
- Line Quality (including tests for sharpness and edge noise as well as detectability tests for negative lines)
- Text Quality (including tests for connectivity and edge degradation)
- Color Quality (including tests for color registration and CIE L* a* b* measurements)
- Smear/Overspray
- Spatial Resolution

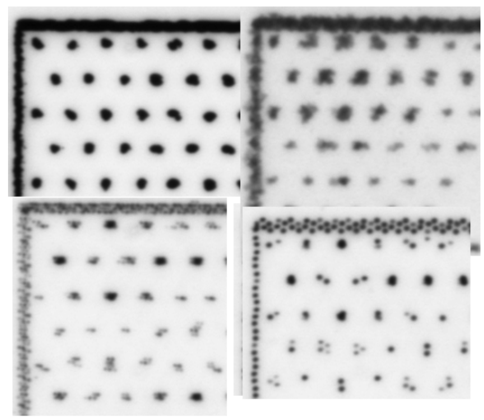
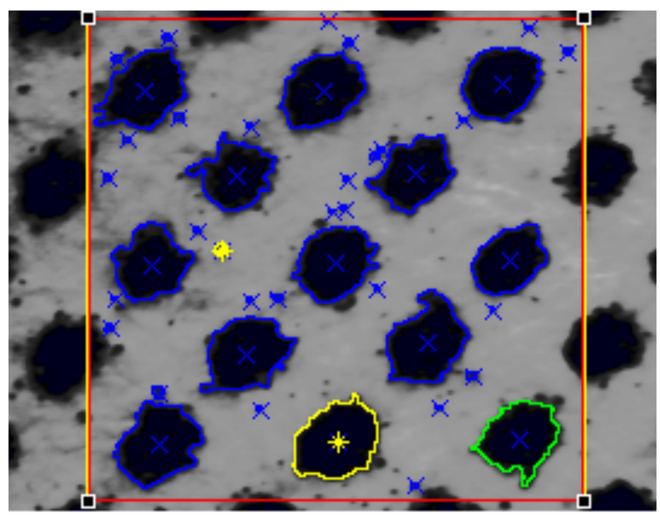


Figure 1a. Various levels of dot quality



Part Report: DOT QUALITY SQ

Stat	Measurement Name	Value
P	# OF SATTELITES	29.000
P	AREA AV.	739.846
P	AREA Area	75.405
P	GRAY AV.	8.195
P	GRAY STD.	1.700
P	AXIS RATIO	0.780
P	AXIS RATIO STD	0.070
P	ROUNDNESS AVG.	0.713
P	ROUNDNESS STD.	0.101

Figure 1b. Example of a dot quality test report

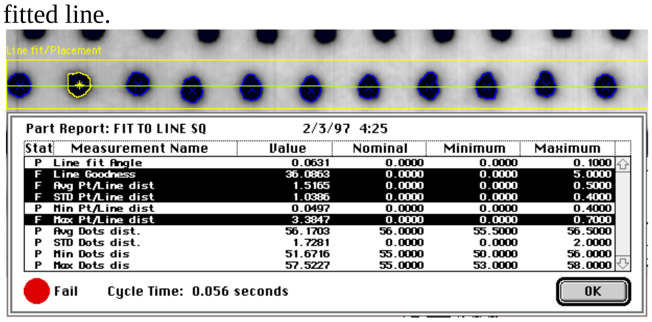
Substrate characteristics can affect image quality in a variety of ways. Line, dot and text quality as well as spatial resolution can be affected by variations in surface topography, wicking characteristics of substrate surfaces and coatings, and differences in adhesion/diffusion of the marking media with the substrate surface. Color can be affected by the substrate color and substrate/marking medium interactions. Substrates of different finishes and weights may react differently to paper handling systems as well as marking mechanics which may result in registration problems, smear and over-spray.

Dot Quality Test

Dot quality can be influenced by the printer mechanism, the characteristics of the ink or other marking medium, and the properties of the substrate. The dot quality test provides information about the spatial and morphological variations of the dots within the field of view of the camera. The dot quality test calculates a specific set of statistics based on the dots that are included in the FOV (Field of View). This test provides information about the number of satellites (extraneous spots within the FOV) as well as variations in dot formation, dot placement, and dot integrity.Dots that are uniform in darkness, shape, size and placement (in the case of amplitude modulated screens) are perceived as being of better quality than areas with dots showing greater amounts of shape and placement variation.

Fit To Line Algorithm

This algorithm detects the dots contained within a user-defined ROI (region of interest), fits a line through the centers of the dots, and calculates the displacement of the dots from the best fitted line. The values obtained from this algorithm include: The line angle, goodness-of-fit (a criteria of how well the dots fit the line), the average distance of the dots to the line, the standard deviation of the distances, and the minimum and maximum distances of the dots to the best fitted line.



Stat	Measurement Name	Value	Nominal	Minimum	Maximum
P	Line fit Angle	0.0631	0.0000	0.0000	0.1000
F	Line Goodness	36.0863	0.0000	0.0000	5.0000
F	Avg Pt/Line dist	1.5165	0.0000	0.0000	0.5000
F	STD Pt/Line dist	1.0386	0.0000	0.0000	0.4000
P	Min Pt/Line dist	0.0497	0.0000	0.0000	0.4000
F	Max Pt/Line dist	3.3847	0.0000	0.0000	0.7000
P	Avg Dots dist.	56.1703	56.0000	55.5000	56.5000
P	STD Dots dist.	1.7281	0.0000	0.0000	2.0000
P	Min Dots dis	51.6716	55.0000	50.0000	56.0000
P	Max Dots dis	57.5227	55.0000	53.0000	58.0000

Figure 2. Fit-to-line test report

As you can see from Figure 2, this set of algorithms provides information about screen angle as well as the accuracy of individual dot placement with respect to the best fit line.

Dot Placement Algorithm (Center-to-Center)

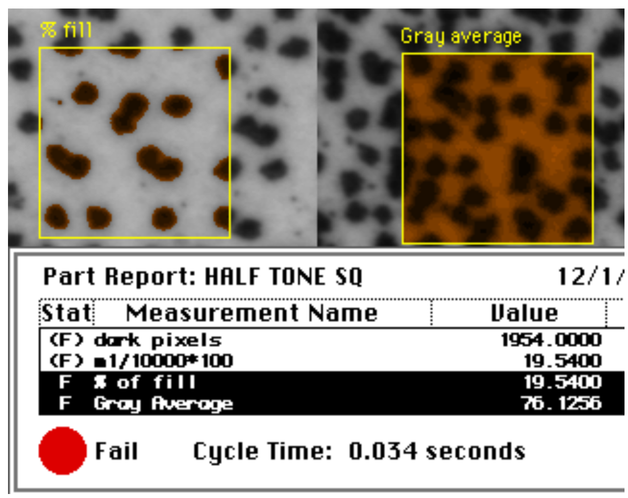
The dot placement algorithm provides information about the accuracy of dot-to-dot spacing within a user-defined ROI. Results of this algorithm include: the average distance between adjacent dots, the standard deviation of the distances between adjacent dots, and the minimum and maximum distances between adjacent dots.

Halftone Test

One of the essential attributes of a halftoned region is its area coverage (also referred to as the "percent fill"). The area coverage of an image is determined by taking the ratio between the dark areas (the marked areas) and the total image area. This ratio can be measured in two different ways:

- Calculate the ratio between the black area contained within the FOV and the total area of the FOV.
- Calculate the average gray value of the area contained within the FOV.

In a monochrome system, each of the above tests will determine the blackness of the image. In both cases, the user can define the acceptable criteria for the level of blackness for a given image area. Changing the dot size or density in a given area will result in a different area coverage and gray average.



Stat	Measurement Name	Value
(F)	dark pixels	1954.0000
(F)	■1/10000*100	19.5400
F	% of fill	19.5400
F	Gray Average	76.1256

Figure 3. Halftone quality test report

These tests of halftone quality allow for the comparison between the desired area coverage or gray level and the actual area coverage of an image. This comparison provides information about the tone response performance of the system. This test can be used to evaluate both traditional amplitude modulated halftone screens and frequency modulated screens.

Line Quality Test

A few of the most common line quality problems that are caused by printing devices and media are smear, overspray and wicking.

Three important measurable quantities are used to assess line quality:

1. Stroke width
2. Raggedness - TEP (Tangential Edge Profile)
3. Sharpness -NEP (Normal Edge Profile)

Stroke width is a measurement of the average width of the line within the user-defined ROI. If an image is blurred, the width of the line increases in size.

Raggedness (TEP) is determined by the displacement of the black-white boundary from the ideal boundary line. The ideal boundary is determined by calculating the best fit line through the boundary points.

Sharpness (NEP) is quantified by analyzing the profile of the black-white boundary itself. A low NEP indicates a sharper transition and a correspondingly sharper line. A blurry looking, softer-edged line would result in a higher NEP value since the transition from black to white would be more gradual. Ideally the boundary would have a NEP of zero.

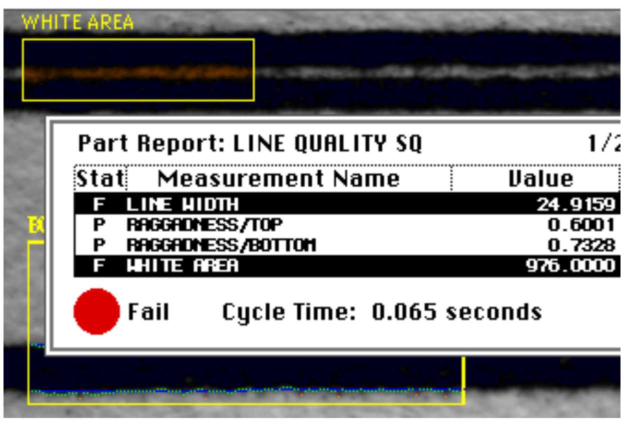


Figure 4a. Example of a line quality test report

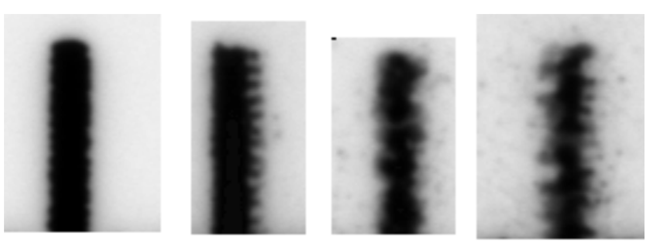


Figure 4b. Various levels of line quality

Figure 4b shows four lines of decreasing quality. As you can see, line width variations, line edge noise and lack of edge sharpness have negative impacts on the perceived quality of the lines.

Detectability

Detectability is a measure of "negative" line quality. Fine white lines on black backgrounds are very susceptible to fill-in defects that affect their visibility. Wicking, line edge noise, toner scatter and smear are among the many possible causes of degraded negative line quality. The quality of negative lines is affected by many of the same issues as positive lines. Increased line edge noise ("raggedness") and blurred edges (lack of "sharpness") degrade image quality. Figure 5 shows three different levels of negative line quality. The sample with the least edge noise and with the sharpest edges is the most visually detectable.

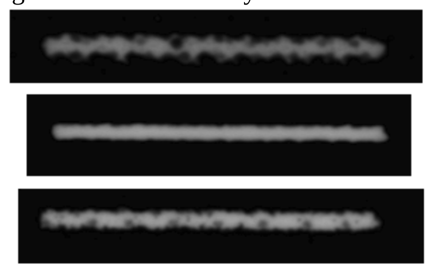


Figure 5. Various levels of negative line quality

Text Quality Test

The text quality test provides information about touching, broken or smeared characters. In this test, a connectivity algorithm is used to detect the number of characters within a user-defined ROI. A broken character or spill of toner will result in an increase in the number of "characters" detected. If two characters are touching, the number of discrete "characters" detected will decrease. Length of perimeter tests can be performed on any given character and will indicate if smear or some other spreading mechanism has altered the text (the range of allowable perimeter values for that specific character needs to be known).

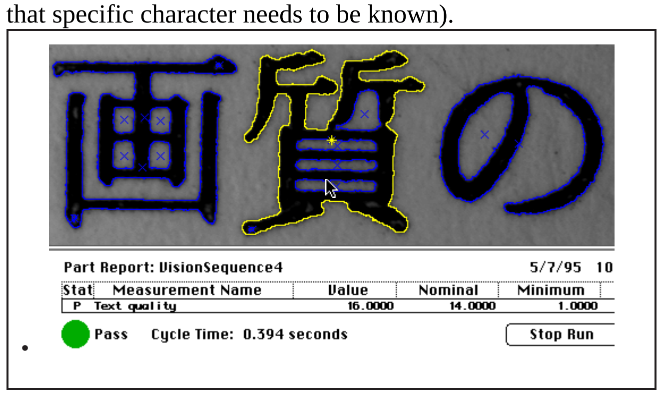


Figure 6. Character quality

Color (CYMK) Registration Test

In an ideal printout, all four separations (CYMK) of a line should collapse into one line. Any consistent deviation of the line width indicates color mis-registration. The color registration test can be performed in both the horizontal and vertical directions. It can also be repeated and compared at different locations on the target.

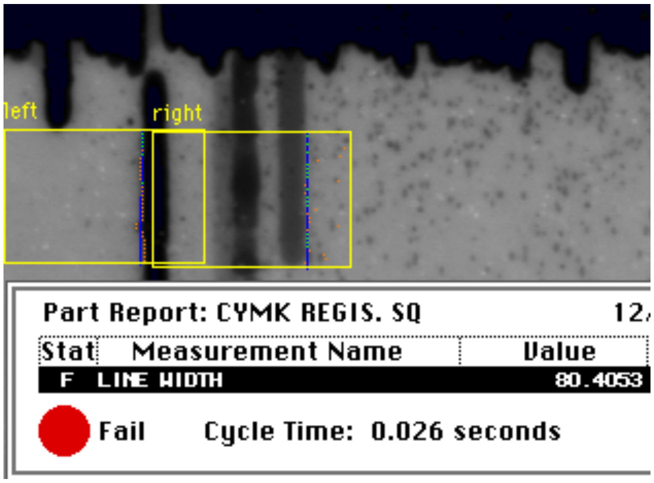


Figure 7. Color registration test

The results of this test are compared with the tolerances (in microns) of the printer.

Color Measurements (CIE L* a* b*)

Automated verification of the color performance of a printing system can be performed by using a measurement system that includes a spectrophotometer. Actual color rendering performance can be compared with expected performance to determine the tone response characteristics of the printing system. Since we are evaluating image quality of printed output, CIE L* a* b* is used because of its correlation to human visual perception.

Smear Test / Overspray

Dots that are adjacent to a solid line or to the edge of a solid area could be the results of image smear or any one of a number of other causes (depending on the printer technology). One example of a technology-dependent cause is toner spill-over (also called toner "scatter").

This test quantifies the amount of extraneous dots in a user-defined area located at some distance from an edge of a solid or line. The results of the measurement are compared with a reference measurement of an area known to be in an unprinted location that is not adjacent to a solid.

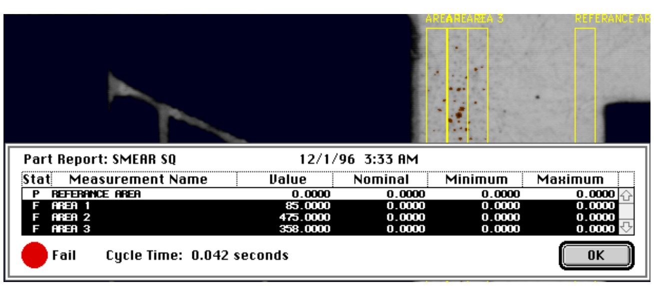


Figure 8. Overspray test

Smear/over-spray measurements taken at various distances from the line or edge can provide insight into the severity and spatial duration of the defect.

Resolution; Test

The resolution test measures a printers ability to print high frequency line patterns. The test produces information about the detectability of the transition area between adjacent black lines. Images from a printer exhibiting good resolution will have clearly discernible lines. A system with lower resolution will have images where the transition area is not well defined and in some cases is somewhat or mostly filled in. The degradation of resolution can be a result of different mechanisms including wicking, scatter and too much line growth. This test gives a good indication of how well a particular system will be able to legibly represent high frequency details in an image. Resolution can be evaluated by a variety of methods.

One method is to use a connectivity algorithm after binarizing the image to a set threshold. Compare the number of discrete objects detected within a user-defined ROI with the expected value. If the lines within the ROI are touching each other (which would indicate lower resolution), the number of detected objects in that area will be less than expected.

Another method is to calculate the average gray value of the image contained within the ROI. A lower average than expected means that the image is darker than expected (which is a result of having less white space between lines). As you can see in Figure 9, darker output images of the same target correspond with cases of lower resolution.

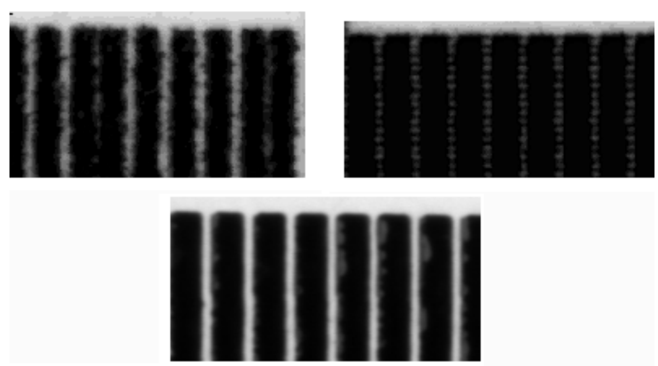


Figure 9. Various levels of resolution

Benefits of Automated Measurement of Image Quality

In the previous sections, a few image quality metrics were discussed that can provide quantitative analysis of media-dependent image quality performance. Both printer companies and media companies can benefit from this type of automated analysis. Automated measurement systems can provide the means for repeatable, non-subjective evaluation of the performance of a printer system or printing medium. Automated measurements can be used during the product development process as well as during manufacturing verification.

In a high volume manufacturing environment, ImageXpert^{tm} users have achieved improved consistency in the quality of their product throughout the life of the product. They have gained better control over their vendors by using SPC to identify variations in subsystem performance. Based on the results of the statistical analysis made possible through the use of an automated evaluation and verification process, the manufacturer found that the warranty cost for the product could be lowered substantially. Another benefit of using a high speed, automated image quality measurement system is that it leads to a higher inspection rate with improved accuracy and repeatability when compared with manual methods. There is an additional benefit for the manufacturer which minimizes staffing requirements: A technician who is not an image quality expert can maintain the automated image quality evaluation operation.

The benefits of integrating the use of an automated image quality measurement system such as ImageXpert^{tm} into product development and manufacturing are myriad. Improved measurement accuracy, repeatability and speed are just a few of the benefits to expect.