Dot and Line Quality Analyses Using Commercially Available Measurement Systems

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Abstract

Printed dots and lines (edges) are the basic elements of printed output, and the quality attributes of these elements directly affect the visually perceived quality of a printed image. The use of commercially available devices designed to provide quantitative measurements of these elements would enable the industry to make and communicate performance comparisons between output systems. Two such measurement systems, the ImageXpert and the QEA personal Image Analysis System, will be evaluated for measuring absolute or perfect targets as well as 'real world' or imperfect targets.

Introduction

Having quantifiable metrics to complement visual judgements of image quality is essential to technology development, setting technical specifications, and production verification. Without numerical values to properly describe the quality of the basic imaging elements, it would be difficult to precisely communicate the impact a single component change might have on an entire system. It would be equally difficult to set specifications and tolerances for media or printhead manufacturing processes. Being able to quantify system interactions has become especially important in recent years as technology partnerships have become commonplace: one company formulates the ink, another produces the media, another fabricates a printhead, and yet another makes the printer hardware. Each component manufacturer needs the ability to evaluate and communicate the component performance using a common set of metrics. Moreover, in product commercialization, product claims based on measured values have been proven to be a valuable marketing tool.

Historically, metrics and measurement systems were developed "in-house" because significant expertise had already been invested, a high level of product competition existed, or extensive psychometric testing was involved. Within the last ten years, however, the number of precision measurements systems that have become commercially available for purchase has grown significantly. Measurements obtained from a purchased "off the shelf" system have the advantage of potentially greater acceptance, as anyone who wishes to verify another's data is able to do so by purchasing an identical measurement system. Moreover, if the measurements from a purchased system are defined in a standard such as ANSI, ASTM, ISO or any others developed and documented jointly by a representative group, the acceptance of the results becomes even more universal.

In output image quality, color, and tone are generally primary quality drivers, and measurements for those image attributes are well established in spectrophotometers and densitometers. When images are produced using an inkjet printing system, however, the image structure elements, i.e., the dot and edge qualities, become equally significant contributors to (visually) perceived image quality. Image structure metrics are measured on a microdensitometer or a high-resolution scanner, and the spectrum or profile is analyzed with a given algorithm. In recent years, there have been numerous papers presented at the IS&T PICS and NIP conferences, which cite measurements made with the instruments commercially marketed by ImageXpert, Inc. and Quality Engineering Associates, to name a few. Comparing these off-the-shelf measurement devices and the measurements they provide (both to each other and to an absolute standard), is the next logical step as the need for these devices continues to grow.

This paper documents the comparison of capabilities and output values from a single ImageXpert Quality Analysis System and two individual QEA personal Imaging Analysis Systems, hereafter referred to as IX, QEA1, and QEA2. The ImageXpert and the QEA personal IAS are similar but not identical in features and capabilities. The methodology used for comparison consists of measuring known targets (standards) to evaluate accuracy and measuring size series to see how each instrument type responds to changes.

The choice for different instrument types merely reflects the intent to sample commercially available measurement systems: there is no intent to endorse one over the other.

Dot Measurements

The dot is the most basic element of halftone technologies. In the inkjet market particularly, as manufacturers drive to reduce ink drop volumes to less than three picoliters, the resulting dots are becoming smaller and smaller and increasingly difficult to characterize. However, accurate characterization of these smaller dots is essential to understanding dot gain, ink/media interactions, and even hardware anomalies. Even though the two-dimensional dot is the most fundamental element of a printed image, a standard that addresses dot measurements and the process by which these measurements should be obtained has yet to become issues by ISO or other standards committees.

The authors discovered early on that the most significant challenge to accurate characterization of (inkjet) dots is the threshold setting, i.e., the point at which background transitions to printed feature. The two devices analyzed here, the IX and the QEA instruments, handle "threshold" very differently; in the absence of a standard, neither method is necessarily right or wrong.

The IX captures images in gray scale mode only, and it reports lightness/darkness in terms of a gray value ranging from 0 to 255. To determine the threshold gray level value, a line that is laser-engraved on a ceramic media (KDY INC603-598-2500 P#K100-PRINTER) is measured. The threshold setting is varied until the line measures 0.1000 mm in width (±0.005 mm). A scaling factor that will determine the threshold value for other measurements (frame captures) is calculated using the following formula:

$$Threshold = Gray_{min} + (scaling\ factor)(Gray_{max} - Gray_{min})$$

Thus the threshold setting used to obtain IX measures is an absolute gray value calculation that is tied to a fixed standard.

For dot measurements in the QEA devices, the threshold is user-defined, and two modes of calibration are possible: absolute calibration based on a standard reflectance (e.g., status A) or relative calibration based on the feature reflectance and media reflectance

Two distinct dots engraved on a glass medium (manufactured by Applied Image Inc.) were measured using the three devices of interest. The QEA measurements were taken with relative calibration at 65% threshold. The IX calibrations and threshold scaling factor were verified. The following values were results for dot diameter:

Target	IX	QEA1	QEA2
0.9975 mm	1.0110 mm	0.9921 mm	0.9937 mm
0.8081 mm	0.8236 mm	0.8015 mm	0.8009 mm

ISO13660:2001 describes hardware compliance as the ability to measure to within 21 microns (or .021 mm) of the feature's declared dimension. Both instruments provide measurements well within this tolerance. In fact, perhaps ISO 13660 may be generous in its requirements

A second absolute target was measured using the same three devices with similar calibrations and thresholds. This target was the KDY, Inc. laser-engraved ceramic standard used for calibrating the IX (described earlier in the thresholding discussion). The dots appear to be perfect circles and ranged in size from 250 micron to 1600+ micron. The purpose of measuring these dots was to demonstrate capability of the measuring device over a range of dot sizes. The diameter, area, and perimeter for six selected dots were measured as follows.

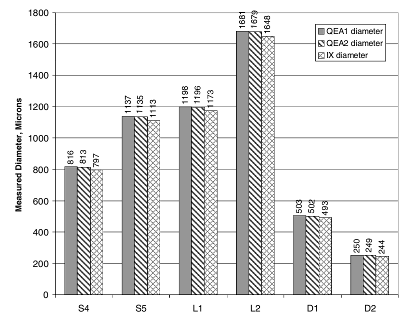

Figure 1. Measured dot diameter

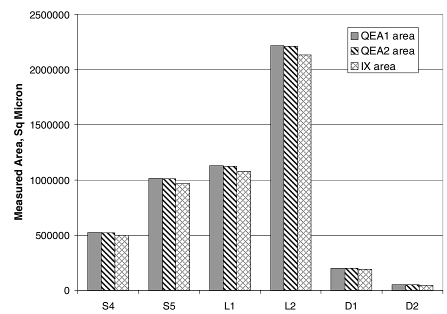

Figure 2. Measured dot area

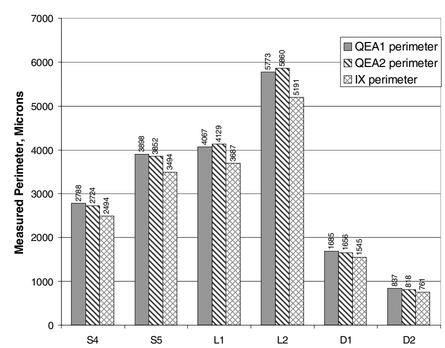

Figure 3. Measured dot perimeter

The IX and QEA units give nearly identical measured values for diameter and area. However, the QEA perimeter consistently read longer than the IX by approximately 10%. As there are several algorithms for determining perimeter from boundary pixels, the two instruments likely employ different algorithms for determining the length of the perimeter. We believe the pixel pitch to be very similar between the two instrument types.

Besides the more common geometric attributes of area and perimeter, these devices have the capability to measure or calculate values for a number of other interesting parameters:

Table 1. Dot Parameter Comparison

Dot ID	QEA1 Box Ratio	QEA2 Box Ratio	IX Axis Ratio	QEA1 Circul-arity	QEA2 Circul-arity	IX Round-ness
S4	0.99	0.99	1.00	1.18	1.13	1.00
S5	0.99	1.00	1.00	1.19	1.16	1.00
L1	1.00	100	1.00	1.17	1.20	1.00
L2	1.00	0.99	1.00	1.19	1.23	0.99
D1	1.00	1.00	1.00	1.13	1.10	1.00
D2	1.00	0.98	1.00	1.13	1.09	1.00

The reader will note that several parameters are similar in name, but they may, in fact, describe very different measurements. For example, the IX "Axis Ratio" is defined as the minor axis length divided by the major axis length. The QEA "Box Ratio" is defined as the maximum height divided by the maximum width. These two measurements may or may not be the same. Similarly, consider the attributes of "roundness" and "circularity." Both are intended to measure how a dot differs from a perfect circle. However, there are conflicting formulae in the technical community and the two instruments use different algorithms for this calculation. The QEA "circularity" value is calculated as Perimeter^2/4 Pi Area. A perfect circle would have a value of 1.00, and an imperfect circle would have a value greater than 1.00. The IX "roundness" value is a ratio of the perimeter of the perfect circle that would result using the average radius of the dot(s) in question divided by the actual measured dot's perimeter. Which measurement is "right?" The user of these devices is merely cautioned that seemingly similar parameters may differ significantly, and one would be well advised to take the time to understand how a device performs a measurement or calculates a value before the data is widely published.

We include here measurements of three "real-world" targets, using just area, perimeter and diameter, as these parameters are concepts that are well understood. Measurements on the QEA devices were based on absolute calibration because there is not a large enough feature ROI to do relative calibration. The threshold was chosen at 50% because higher or lower thresholds for these targets resulted in incorrect detection of the features.

Table 2. Measurements of Imperfect Dot Targets

Dot Target	Device	Area sq mm	Perimeter mm	Diameter mm
magenta	IX	0.0009	0.109	0.035
magenta	QEA1	0.0006	0.079	0.027
magenta	QEA2	0.0006	0.082	0.028
K-Black	IX	0.0051	0.272	0.084
K-Black	QEA1	0.0051	0.266	0.081
K-Black	QEA2	0.0051	0.261	0.080
Process Black	IX	0.0039	0.264	0.076
Process Black	QEA1	0.0036	0.252	0.068
Process Black	QEA2	0.0035	0.259	0.067

The three instruments showed similar measurements, with the largest difference in measured diameter between instruments, within the same target, being less than 9 microns. This level of agreement is quite amazing as there are possible sample variations in the printed target. Note that this time the perimeter measurements from the QEA devices were closer in value to those measured by the IX than before. This could be attributed to both the threshold values used on the QEAs to read these targets and to the physical size of the dots. Thus, the two instrument types are capable of producing similar results for "real-world" targets.

Line Measurements

Printed edges and lines are the next basic image elements to examine. They should be thought of as transition points or "zones," from unprinted to printed media or from one color to another color. Measures that describe these transition zones include "blur" and "raggedness" which ultimately describe perceived visual (image) sharpness. For analysis purposes, lines can be thought of as parallel or back-to-back edges. The distance between these edges is the line width, and the most significant attributes of line width are dimensional accuracy and consistency. Fixed width lines are frequently used as leading indicators of text quality, color registration, and hardware performance, to name a few. ISO 13660 features a standard for line measurement and analysis

As was the case with measuring dots, the most significant variable in measuring edges is the threshold setting that determines the actual transition from dark to light (or vice versa). The threshold setting for the IX is determined in the same way as described in the previous section. The QEA units automatically calibrate the light and dark thresholds as the measurements are performed.

The IX ceramic standard target (603-598-2500 P#K100) features two lines of known widths. These lines were measured using each of the devices.

Table 3. Line Measurements

	0.5 mm line	0.1 mm line
QEA1 linewidth, *u*	497	94
QEA2 linewidth, *u*	497	93
IX linewidth, *u*	500	100
QEA1 blur, *u*	102	91
QEA2 blur, *u*	102	87
IX blur (ISO def.), gray levels	21.6	17.8
IX Avg. Gradient Sharpness	139	128
QEA1 rag, *u*	0.15	0.34
QEA2 rag, *u*	0.47	0.10
IX mean deviation, *u*	0.37	0.40

The IX and QEA instruments are both well within the tolerance recommended by ISO 13660 for linewidth.

ISO 13660 defines the edge quality attributes of "blur" and "raggedness". IX and QEA both use the ISO 13660 definition of "blur", which is based on 10% and 90% thresholds. However, where the QEA results are in units of microns, the IX measure is in units of absolute gray level. It was also noted that this IX measure is highly variable depending on the height and width of the ROI. The author has determined that the measure of average gradient[1] is a more robust parameter for characterizing edge sharpness with the IX. Although the QEA value for blur and the IX value for average gradient describe the same attribute of a transitional edge, they are very different measurements. Both QEA and IX use the ISO 13360 definition of raggedness to measure that attribute, however the QEA calls this measure "raggedness" but the IX calls this measure "mean deviation."

On the same ceramic target used previously (603-598-2500 P#K100), there is a line size series with line widths ranging from 10 to 23 line pairs per mm (50.00 to 21.74 micron width lines). Both devices produced measurements within the ISO 13660 recommended tolerance. With the QEA devices, the measurements were not always consistent within the series. The manufacturer has recommended a minimum line width of 25 microns, and this appears to be the maximum capability of the fixed lens system. The IX unit in this study has the benefit of several cameras, one of them has high resolution and "zoom" capability, so the narrower lines on the ceramic standard could be measured consistently.

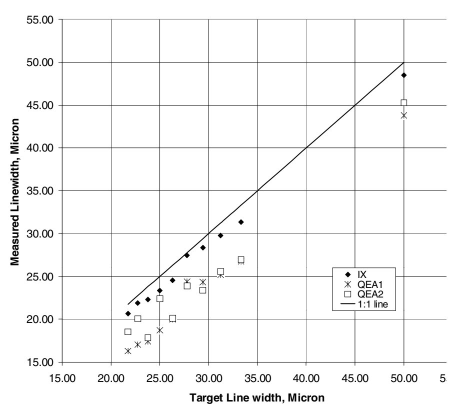

Figure 4. Measurements of very narrow lines

A second series of lines was measured using both devices, however the second target was a "real world" print from a digital silver halide writer. The line edges featured more subtle transition zones than those on the ceramic standard target. Lines at different code values resulted in increasing widths because of increasing exposures. Both the horizontal and vertical (transport direction) lines were measured.

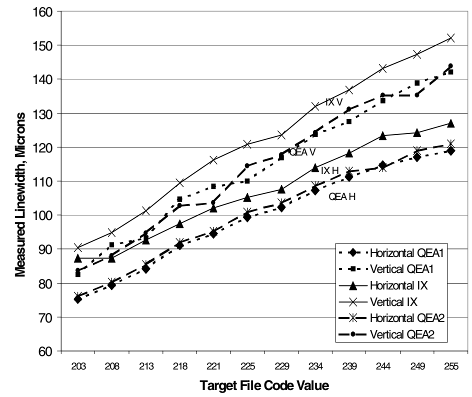

Figure 5. Measurements of a linewidth series

The IX measurements of the linewidths are greater in value than those yielded by the QEA devices. These differences can be attributed to the operational difference in calibrations and, again, in threshold setting methods. Vertical lines are noisier because of the writer's transport motion. Vertical lines are wider than the horizontal because of writing spot geometry and spot overlap in the line direction.

Conclusions

Both the ImageXpert and the QEA personal IAS are capable of accurately measuring well defined, absolute dot and line targets, at least in the range of dot sizes and line widths covered by this comparison study.

- In measuring standard dot targets, both systems measure similarly for dot diameter and dot area, but the QEA seems to read a longer perimeter. When measuring very small dots (area <0.005 square mm), both instruments yielded similar size measurements.
- Both instruments can read line widths to within the margin of error defined in the ISO 13660 standard; however, there is a consistent offset between the values yielded by the two devices, this offset being attributable to device calibration.

It was noted that between the two devices of concern, there are many dot parameters with similar names; the user cannot assume that the similar parameter names equate to identical measurement definitions between the two systems. This may be true of other parameters that are not discussed in this paper. Clear industry standards for additional image quality type measurements, such as dot parameters, could only help to reduce confusion when comparing measurements obtained from different systems.

Although a user can obtain many numbers rather quickly with either system, the authors must emphasize that it is very important to understand how the instrument determines feature boundaries. Should one see that the instrument is not determining the feature boundary properly, or the image shows some artifacts, the resulting measurements should be questioned. This was one of the most significant lessons from this comparison study.

As a matter of best practices, all measurement devices should be calibrated and verified against known standards. If a constant offset from a known standard is encountered, it does not mean that the measuring device is "wrong;" rather, it is the responsibility of the user to understand the sources of variability that contribute to this difference or offset. It is also the user's responsibility to understand the maximum precision of the measurement device, particularly when an optical system is involved, and report measurements accordingly. For example, if the maximum resolution of an optical device is 100 microns per pixel, one should not report data to single micron precision even if the device provides these numbers. If the sources of variability can be eliminated or at least understood and acknowledged, and the precision of the instrument is understood, the user can report resulting data with increased confidence in its validity.

Acknowledgment

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References

1. P. Hill, K. Suitor, and P. Artz, "Measurement of Humidity Effects on the Dark Keeping Properties of Inkjet Photographic Prints", *Proc IS&Ts NIP16 Conference*, 70-73(2000).

Biography

Mamie Kam-Ng is a Technical Associate in the Systems Technology Division of Eastman Kodak Company. Her current interests are in the areas of media formulations, digital AgX writing technologies, and cross technology benchmarking. Mamie holds 11 US patents and a BSChE from Pennsylvania State University.

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