A New Class of Print Quality Tests

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Abstract

Designers and manufacturers of printers need quick and easy methods of measuring the print quality capabilities of printers. This paper describes a class of print quality tests which systematically stress the writing system until print quality failure. The tests allow product designers to visually scan printed pages to determine what level of stress causes print quality failure. These tests help product designers quickly qualify new designs, or isolate the source of print quality problem during product developments.

Print Quality is a System-Level Attribute

The writing system is the collection of printer parts that contribute to formatting and making marks on the media. Print quality is dependent on the interaction of many subcomponents of the writing system. These include the mechanics that move media and place colorant, the electronics and control systems that drive those mechanical parts, the colorant properties, the media properties and the rendering algorithms that prepare the data to be printed. These subcomponents work in concert to create text, graphics, and images on paper or other media. The interaction between the subcomponents is highly complex and often unpredictable.

Designing for Print Quality

Print quality is not a directly designed attribute of a writing system, nor is it easily measured during product development. Subsystem designers design and modify their components to meet or exceed design criteria they can measure. If designers do not have good tools to measure print quality during the design process, they will focus on more easily measured criteria, such as cost, size, speed, and durability. Changes to any subcomponent can affect the behavior of the writing system, and ultimately, the print quality. Seemingly innocuous changes to the writing system subcomponents can have significant impact on the print quality.

If engineers are assigned to print quality, there is no "print quality subcomponent" to design. Engineers responsible for print quality must convince subcomponent designers to make changes to their respective subcomponents in order to improve print quality.

Subcomponent designers resist changing their design, unless the evidence is timely and compelling, and the qualification of design changes is fast and easy. Traditional print quality testing generally requires a fully functional formatting and marking system. Some tests also require machine vision systems to measure and quantify print quality. This can result in infrequent testing, delayed test results, all of which occurs too late in the product development cycle to effectively respond to problems.

The Role of a Writing System Test Suite

The solution is to provide a suite of easily-interpreted, phase-appropriate writing system tests that can be easily integrated into the printer development process.

Early testing of the writing system provides print engine designers with the means to quickly identify deficiencies in the writing system. These same tests aid designers in quickly judge how well a candidate countermeasure addresses an identified writing system problem.

The test suite is also useful to monitor the state of the writing system to identify if intentional design changes may have unintentionally affected the quality of the writing system.

The test suite is a means to continually and quickly monitor writing system quality, in order to detect any other unanticipated changes.

By putting the "smarts" into easily implemented and interpreted tests, the reliance on specialized engineering skills is decreased, and the speed and quality of product development is improved.

Note that printers often have built-in diagnostic pages which can be printed through a diagnostic menu from the front panel or driver. Diagnostic tests are intended to be used by end users to perform calibration, or diagnose print quality issues encountered during normal operation. In contrast, writing system tests are intended to be used by product designers during product development. Writing system testing is standardized across printers, examines the raw capabilities of the writing system and is designed to stress the writing system until print quality failure.

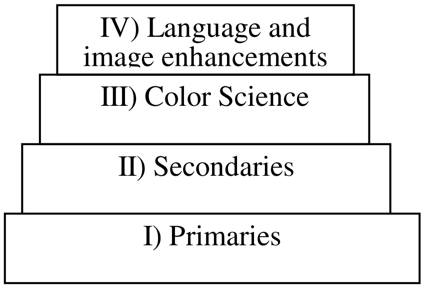
Test Suite Attributes

Here are some important attributes that are necessary to make the tests useful:

- **Easily implemented**
  The tests must be easily incorporated into the printing environments of early product development. This typically means the test files are in planar raster format. .
- **Easily interpreted**
  Writing system tests must be easily interpreted, ideally without aid of specialized measurement equipment, or significant imaging science expertise. This allows testers and designers to incorporate print quality testing into quick experimental cycles.
- **Provides a meter, not just pass/fail status.**
  Good tests stress the writing system until print quality failure. This provides designers with a good understanding of the limitations of the writing system.

Test Coverage: Four Logical Levels

There are four levels of testing where each level builds on top of the previous level.



I) The first level measures the behavior of each primary color of the writing system, including halftoning. This is the most fundamental property of the marking system.

II) The second level examines the interactions of the primaries.

III) The third level adds the color science compromise of gamut mapping, and interaction with typical source data to be printed.

IV) The fourth level adds rendering from a language, data compression and any built-in image processing such as anti-aliasing, alternate rendering of neutral axis, etc.

Construction of Writing System Tests

All test pages are designed as objects, in a common language such as PostScript® and are rendered in one of the following ways, depending on what is being tested:

Level I and level II testing: Test pages are rendered from object to raster form using simple algorithmic color separations and simple binary halftones, and printed using a test harness. To test the effectiveness of printer halftoning, the same test pages are rendered through simple algorithmic color separations and the printer halftones, then printed using a test harness.

Level III testing: Test pages are rendered from object to raster form using printer gamut mapping and printer halftoning, then printed using a test harness

Level IV testing: Language level test pages are sent directly to the printer. The printer renders and prints the test pages.

Printing the Writing System Tests

Test pages are created in a language form, such as PostScript. To prepare PostScript files for printing, they must be rendered from object form into raster form. For Level IV testing, this rendering operation is performed by a software driver and/or the formatter of the printer.

For Level I, II and III testing, the Postscript file is rendered into raster format using a software rendering tool. The rendering tool takes four input files: a Postscript file; a halftone file; a gamut mapping file and a parameter file.

The software rendering tool uses the halftoning file and gamut mapping file to create a raster file from the Postscript file, as specified by the parameter file. The specified parameters include raster file format, resolution, image dimensions and so forth. These parameters are needed to tailor the final raster file to be print-ready for the printer test harness.

The printer test harness accepts the print-ready raster file, and drives the print mechanism to create the finished printed page.

The software rendering tool can be a standardize tool used across many printers and print vendors. Alternatively, some printer vendors may choose to use their own proprietary tools to render raster files from the language-level test pages.

The printer test harness must be provided by the printer vendor, since the file formats and operational algorithms are unique and often proprietary to each printer vendor.

Interpreting the Writing System Tests

Test pages typically consist of a grid of rows and columns on the page. (See Appendix II for example pages) Each cell contains a test pattern that is derived from a single base pattern. The pattern in each cell is altered to create a certain level of stress on the writing system. The variation in patterns is organized such that the stress increases or decreases from left to right and top to bottom. This allows observers to visually scan the page and easily identify stress levels that cause print quality failures. If desired, the patterns may also be measured by machine vision systems.

Broad Test Applicability

The test files are designed to stress all writing systems, irrespective of the printing technology (laser, LED, inkjet, dye sublimation, liquid toner etc.). The tests challenge writing systems to print things that are universally difficult to do well: Resolve small details, create smooth gradients, uniformly fill areas, hide gamut compression and halftoning artifacts, preserve crisp boarders between colors and so forth. By applying the same stress test across different printing technologies, the relative strengths and weaknesses of the technologies can be easily demonstrated and quantified.

The Test Suite

Level I Tests: Primaries

These tests examine the basic operation of the primary colors of the writing system. Each primary is tested in isolation. Pages are rendered with a standard numerically linear binary halftone to provide a common comparison point. Test pages are also be rendered through the printer's halftoning algorithms to judge how well the algorithm compensates for the writing system's native behavior. Table 1 provides an incomplete list of level 1 tests.

Table 1: Selected Level I tests

Test	**Comments**
Area fill uniformity	Examines general uniformity, ghosting, thermal and voltage sags, developer starvation and other similar phenomena.
Color plane registration	Accentuates and quantifies absolute registration errors across the printable area
Resolution of details	This test stresses the ability of the writing system to resolve objects and edges as a function of object size and spacing.
Tone curve	This test demonstrates how each primary responds to a numerically linear halftone, and the printer halftones.

Level II Tests: Secondaries

These tests combine two or more primaries to stress the basic interaction of the primary colors of the writing system. Pages are rendered with a standard numerically linear binary halftone to provide a common comparison point. Test pages are also be rendered through the printer's halftoning algorithms to judge how well the algorithm compensates for the writing system's native behavior. Table 2 is in incomplete list of level II tests.

Table 2: Selected Level II tests

Test	**Comments**
Adjacent primaries edge behaviors	This test stresses interactions between primary colors adjacent to each other. Tests are designed to be relatively insensitive to color plane misregistration.
Small area fills	Small fills of one color surrounded by fills of other colors.
Secondary mass limits	This test stresses the ability of the writing system to mix two colorants and maintain print quality. This identifies secondary color mixing rules used in gamut mapping.
Multi-primary mass limit	This test stresses the ability of the writing system to mix three or more colorants and maintain print quality. This identifies tertiary color mixing rules used in gamut mapping.
Color dependent moiré	This test stresses the full range of the secondaries and selected tertiary colors to identify moiré related to scatter, bleed, halftone cell design, etc.
Halftoned edges	This test stresses the full range of colors and angles and object sizes to identify combinations that produce visible artifacts.

Level III Tests: Color Gamut Mapping.

These tests combine two or more primaries to stress the basic interaction of the primary colors of the writing system. Pages are rendered with a standard numerically linear binary halftone to provide a common comparison point. Test pages are also be rendered through the printer's halftoning algorithms to judge how well the algorithm compensates for the writing system's native behavior. Table 3 is in incomplete list of level III tests.

Table 3: Selected Level III tests

Test	**Comments**
Gamut mapping interpolator artifacts	These tests stress gamut mapping algorithms in areas where interpolators are most prone to color errors, such as near-neutrals, and gradients along gamut surfaces.
Tolerance to image noise	These tests stress the interaction between gamut compression artifacts and the data noise typically present in natural images captured with scanners and digital cameras.
Color consistency	These tests are composed of secondary and tertiary colors that are prone to objectionable shifts in hue and saturation when the tone curves of the contributing primaries shift.
Color compression and expansion tests	Gamut mapping requires compression and expansion of color spaces. This test visually indicates regions of significant color compression and expansion.

Level IV Tests: Full printer imaging pipeline

These tests stress the full printer rendering system. Many levels I, II and III test pages can also be use as level IV tests by simply printing the test files through the printer driver. Table 4 is an incomplete list of additional level IV tests.

Table 4: Selected Level III tests

Test	**Comments**
Small object rendering	Identifies how languages render lines and small objects.
Edge improvements	The printer rendering may include forms of edge enhancements algorithms
Lossy compression artifacts	Printers have limited memory, and generally perform lossy compression on complex pages.
Object-dependent rendering	Printer rendering algorithms can assign different halftoning and gamut mapping to different objects o the page. This test accentuates any differences in rendering by placing different object types (text, graphic, raster adjacent to each other to accentuate any differences.

A Level I Test Example: Resolving Detail

Test Page Description

The test page is sectioned into 64 cells. (Figure 1) Each cell contains a test pattern. The test pattern is composed of three sections: horizontal lines, parallel lines, and squares. Each cell of the test page contains a variation of the test pattern. The pattern in the upper left-hand cell consists of one pixel-wide lines, one pixel wide gaps and one pixel squares with one pixel gaps between the squares. The test patterns in the remaining cells are laid out the same fashion, except for changes in the dimensions of the gaps and lines. The size of the gaps increases by one pixel per main column, and the width of the lines and squares increase by one pixel per main row.

This results in a test page where each of the 64 cells differs slightly from the neighboring cells. The lines and squares are thin at the top of the page, and thicker towards the bottom of the page. The gaps between the lines and squares are small at the left side of the page, and large at the right side of the page.

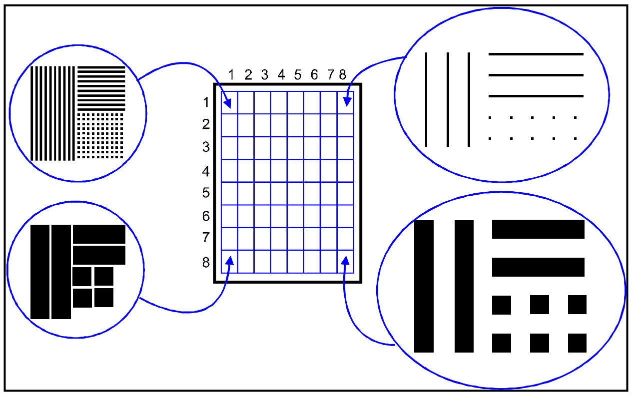


Figure 1. Test page layout for an example level I test.

Interpretation of Results:

An ideal writing system would render each of the test cells with lines and squares as they are depicted in Figure 1. However these test patterns stress writing systems in ways that typically cause failures in some regions of the test page. The page has been organized to allow a user to visually scan across the printed page and identify where the print quality deviates significantly from the ideal.

A Level II Example Test: Secondary color mixing rules

Test Page Description

The test page is divided into 36 cells. (Figure 2) Each cell contains a test pattern. The test pattern is composed of three sections: horizontal lines, vertical lines, and a solid square. (Figure 3) Each cell of the test page contains a variation of the test pattern. Note that this test pattern contains a range of line widths (detail section of Figure 3). The physical dimensions of the test pattern in each cell are the same, and every test pattern is composed of two primary colors. However the amount of each of the two colors varies as indicated by the row and column headings shown in Figure 2. There is one test page for each combination of primary colors. In a CMYK printer, this means 6 test pages: CM, CY, CK, MY, MK, YK.

Interpretation of Results:

An ideal writing system would render each of the test cells with lines and squares as they are depicted in the test file description. By visually scanning over the page, a user can quickly identify regions of anomalous behavior compared to surrounding regions. This information is useful in optimizing the writing system.

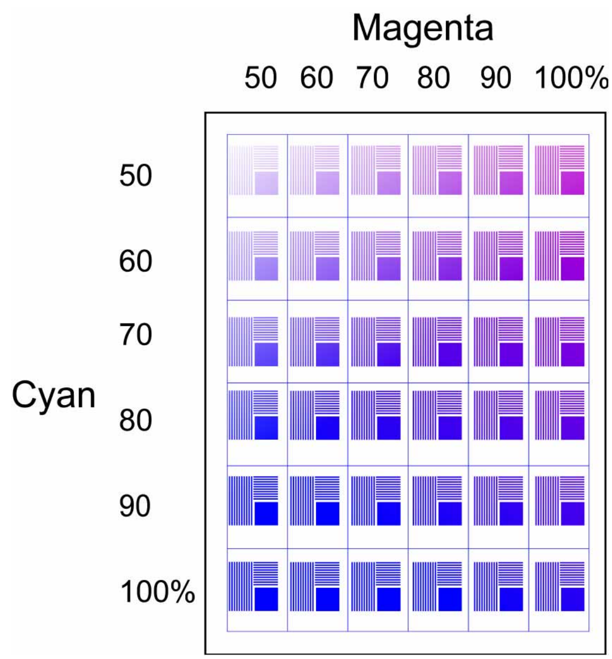


Figure 2. Test page for secondary color capabilities of a writing system

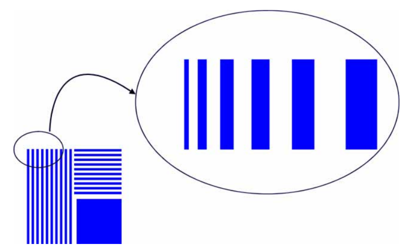


Figure 3. Detail of the patterns from figure 2

Summary

This new class of print quality tests provides printer designers with an easy way to incorporate print quality measures into the design verification process of a printer's writing system. This improved visibility of cause and effect will result in faster and more certain printer design cycles, with improved print quality.

Author Biographies

David A. Johnson received a BSME from the University of Utah, and an MSME from Brigham Young University. He worked for Hewlett Packard Company for 21 years in R&D Labs developing color inkjet and color laser printers. He is currently consulting, and is involved with technology start-up companies.

Steve Kang received a BS/MS in Computer Science from University of California and USC respectively. He also received an MBA from UCLA and currently is the Director of Engineering at QualityLogic. Previously, Steve was a consultant and VP of Engineering at AHT and Colorbus leading their color controller/RIP development projects. He also worked for Xerox as a manager in the development of the DocuSP controller for high end production systems, including the Xerox IGen3 presses.