# Principles of system analysis of the characteristics of inkjet print media

Sergey Gnatyuk, Maxim Domasev, Sergey Shavkun, Andrey Lihache St. Petersburg State University of Cinema and Television

## Abstract

Authors established systematic approach to the quantitative estimation of print qualities of inkjet media based on the use of more than 20 parameters of print image quality.

Along the traditional parameters (mechanical, geometrical, optical, sorption value) a number of quantitative characteristics of print media were estimated. These are: multi-fractal characteristics of the media surface, tonal and color reproduction quality characteristics which were estimated by the means of unique methodologies that made it possible to characterize imaging system color gamut value and tonal reproduction range.

Cluster analysis allowed to classify all the number inkjet print materials from various manufacturers according to the distribution of the media physical, topological, colorimetric, and optical characteristics and correlations of these among each other.

To model each class of materials behaviour a number of discriminant functions were built which made it possible to predict qualities of inkjet print media and develop based on that systems of inkjet print quality management.

Development and research of qualitative characteristics of imaging system was always an important mean used in the production process for testing purposes of imaging media and equipment. Such characteristics as tonal dynamic range, sharpness, color reproduction accuracy, etc. are widely used for such purposes. However, in a number of cases it is rather difficult to interpret or compare results of imaging system or media tests because these tests do not produce clear figures or repeat each other. Also it is important to find crosslinks between various tests thus establishing connections between various natural quality factors of an imaging system and their influence on the quality. For example, color gamut of an inkjet paper depends on the morphological characteristics of the print media, from one side, and on the chemical composition of the media surface, from other side.

During the research authors took into account various characteristics of inkjet paper. These included: paper surface specification (plain, matte, glossy, super-glossy and semi-glossy microporous paper according to the manufacturer's specification), ink receptivity, fractal characteristics of the paper surface morphology, optical density of white (unprinted) and black (filled with 100% black ink) surface, characteristics of color reproduction quality.

Color reproduction quality, as authors believe, can be regarded as one of the most important characteristics of an inkjet paper, as most of images reproduced on an inkjet printer are color images. There is a common opinion that color reproduction quality is definite as color reproduction accuracy, i.e. as a color reproduction error measured in  $\Delta E$  units between etalon and printed colors. Extensive development and spread of color management systems resolved in much extent the problem of color inconsistency in inkjet image reproduction. So, given the ability to reproduce image color correctly on an inkjet printing device, next problem arises: because a large number of typical photographic images cannot be compressed into the color gamut of an inkjet printer without loss of out-of-gamut colors, color gamut becomes the defining factor that limits possibilities of correct color image reproduction and thus this factor becomes major factor that affects print image quality. With the change of print media, color gamut changes in wide extend.

To obtain numerical characteristic of color gamut of an inkjet paper authors used standard print targets used for printer profiling and measured color coordinates of samples from color target in CIE LAB color space (Fig. 1a). Using QHull algorithm [1, 2] authors obtained geometrical approximations of color gamut body (Fig. 1b), volume of which, definite in cubic  $\Delta E$  units, was used as the characteristic of paper color gamut.



**Figure 1.** Color gamut body of Lormond Glossy Photo Paper definite as distribution of color samples from GretagMacbeth RGB Target 1.5 plotted in CIE LAB color space (a) and its approximation body built using QHull algorithm (b)

For various types of analysed inkjet papers from various manufacturers this characteristic showed remarkable differentiation (Table 1, Fig. 2).

As the next step authors ranged papers according to the increase of their color gamut (Fig. 2) and used cluster analysis to divide papers into groups according to the change of this characteristic. The obtained result had high conformity with the distribution of samples according to their manufacturer's specification (Fig. 3). This also gave basis for futher discriminant analysis of data of various characteristics of inkjet papers.



Figure 2. Distribution of inkjet papers according to their color gamut volume



Figure 3. Clusterisation of inkjet papers according to the characteristic of their color gamut volume

To examine morphological characteristics of the paper surface authors used method of fractal modeling of the paper surface topology using coefficients of obtained using this method multifractal spectrums as measures of the paper surface uniformity and homogeneity. These coefficients serve as good mathematical values for characterisation of mechanical and physical properties of inkjet paper usually expressed by the paper manufacturer as the quality of paper coating (matte, semi-glossy, glossy, etc.).

Together with these authors measured paper ink/water resistance, sharpness and local contrast (measured from resolution target), optical density of white and black points, density dynamic range, whiteness of white and black points. For futher estimation of color reproduction quality chroma coordinates of primary cyan, magenta, yellow color samples and their mixture as red, green, and blue color samples were measured. The latter gives important information on color rendering ability of a given material for various groups of colors in an image.

To find influence of each of these factors on the color gamut volume, two-dimensional correlation analysis was performed. It was noted that all characteristics had strong correlation with color gamut volume (Table 1).

#### Table 1. Characteristics of inkjet papers

Paper	Paper sur- face*	Water/ Ink recepti- vity, h	Surface fractal spec- trum coeff. D(0)	Sharp- ness	Local contrast	Chroma C*						Lightness L*			
						R	G	в	С	М	Y	к	w	DL*	Color gamut V, ΔE³
Plain paper	1	3.25	1.917	66.70	0.2706	65.25	47.92	25.83	38.84	64.27	85.48	27.55	92.94	65.39	249590
ProfLine MT	2	2.12	1.973	45.20	0.4544	81.96	51.34	35.75	43.33	76.20	103.19	18.03	94.96	76.93	454910
Canon Matte Photo Paper	2	1.90	1.978	43.00	0.4218	86.49	50.58	38.82	45.38	78.86	108.65	14.69	95.47	80.77	528750
Lomond Matt Inkjet Photo Paper	2	1.98	1.983	43.70	0.4154	87.20	56.29	40.51	48.66	79.74	106.43	12.97	94.40	81.43	544050
ProfLine GL	4	1.86	1.990	31.30	0.5309	84.66	58.84	39.69	49.53	79.70	106.95	10.75	95.43	84.68	553300
Epson Matte Paper Heavyweight	2	1.75	1.988	44.60	0.4658	89.24	52.66	38.41	45.47	79.99	110.76	13.42	96.03	82.62	553980
Slavich Design Plus Matte	2	1.67	1.990	43.70	0.5571	87.92	56.55	38.37	47.48	78.83	110.97	12.79	96.46	83.66	577430
Kodak Glossy Picture Paper	4	1.29	1.996	31.80	0.4702	84.71	69.96	51.25	51.01	78.93	107.42	8.23	95.89	87.66	605220
Slavich Print Photo Satin	3	1.16	1.994	36.80	0.6121	88.04	68.96	49.09	52.79	82.47	106.68	5.53	94.57	89.04	628440
HP Premium Plus Photo Paper Matt	3	1.05	1.996	36.00	0.5297	93.52	71.44	53.78	49.95	79.95	107.30	5.80	94.63	88.82	646120
Epson Photo Quality Glossy Paper	4	0.90	2.000	31.30	0.6030	94.37	62.02	48.35	49.79	82.57	114.28	4.36	94.66	90.30	653370
HP Premium Glossy Photo Paper	5	0.68	2.000	29.40	0.6346	104.63	80.35	64.69	51.42	85.25	111.65	1.56	93.95	92.39	755600
Lomond Super Glossy	5	0.60	2.000	30.00	0.7041	99.30	81.52	60.76	52.68	84.91	114.18	2.63	93.75	91.12	771530
Slavich Photojet Plus Glossy	5	0.57	2.000	32.10	0.6020	103.41	86.00	65.95	53.19	85.31	112.47	2.84	94.20	91.35	786044
correlation coeff. to color gamut V.	0.8601	-0.9804	0.8965	-0.8896	0.9006	0.9654	0.8797	0.9402	0.9178	0.9519	0.8642	- 0.9689	0.0195	0.9622	1.0000

\* 1 = uncoated paper, 2 = matt paper, 3 = semiglossy paper, 4 = glossy paper, 5 = super glossy paper

Highest correlations were found in chroma coordinates of red, blue, cyan and magenta color samples, and also in lightness coordinates of black sample, which tells about interconnectivity of these characteristics giving us possibility to use color gamut body volume as integral characteristic of color reproduction quality.

Yet other paper characteristics, mainly morphological characteristics of the paper surface, did not show that high correlation as, for example, ink receptivity of the paper. It was also noted that differentiation of morphological characteristics among each morphological class of paper was not that high as differentiation of the characteristic of color gamut volume in the same class.

This gave authors hypotheses that color reproduction quality is not solely depended of the morphology and mechanical quality of the paper, and is much influenced with other factors, among which one of the most important factors, as authors believe, is chemical composition and structure of the ink receptive layer of the paper.

To verify this hypothesis authors decided to use technique of the direct precise modification of the chemical structure of the paper surface based on the method of molecular layering (see Sergey Gnatyuk, Maxim Domasev, Sergey Shavkun, "Nanotechnologies in application to digital print media development", report on 6th International Conference on Image Science and Hardcopy). This method showed increase of paper color gamut with the change of chemical structure of the paper receptive layer while retaining paper morphology unchanged.

#### Methodology and formulas

Ink/water resistance was measured according to Klemm.

Fractal characteristics of paper topology were measured as coefficient of fractal models built from microscopy images of the paper surface (Fig. 4). Explanation of this methodology can be found in [3].



Figure 4. Microscope images of uncoated paper (a), coated matte inkjet paper (b), coated glossy inkjet paper (c) (60X magnification)

Sharpness and contrast were measured using test resolution targets printed on the paper surface as follows [4]:

— sharpness was definite as function of brightness of two points located on the edge of black (printed) (point a) and white (unprinted) (point b) zones of the test target (Fig. 5):

$$R_o = \frac{\int\limits_{a}^{b} \left(\frac{df}{dx}\right)^2 dx}{f(a) - f(b)},$$
(1)

where f(x) – print image brightness at point x;  $\left(\frac{df}{dx}\right)^2$  — brightness

change velocity;

 — contrast was measured as the characteristic of local contrast from the same test image:

$$C_{ij} = \frac{L_i - L_j}{L_i + L_j},\tag{2}$$

where  $L_i$ ,  $L_j$  — lightness of *i* and *j* elements.



Figure 5. Test target for estimation of paper resolution and contrast and its reproduction on different kinds of papers: uncoated paper (a), coated matte inkjet paper (b), coated glossy inkjet paper (c)

Chroma and lightness values were estimated as CIE C\* and L\* coordinates using CIE 2° standard color observer and D65 standard illuminant [5] (the choose of D65 instead of D50 was determined with the fact that in inkjet print the use of D65 gives better result, than D50). To measure color gamut volume standard GretagMacbeth RGB Target 1.5 was used (Fig. 6). Color gamut body volume was calculated from distribution of 288 color samples measured from this target in CIELAB color space using MATLAB convhulln function [6].



Figure 6. GretagMacbeth RGB Target 1.5 used in evaluation of the paper color gamut volume

#### Conclusions

Using color gamut volume characteristic calculated with Qhull algorithm on the base of data of distribution of uniform color samples in CIELAB color space as a strict mathematical measure for color reproduction quality showed good results in performing of the task of quality estimation of inkjet print media.

High correlation rates of this characteristic with other quality characteristic of inkjet print media allows to use this characteristic as an integral measure of paper quality.

This characteristic shows dependance both from morphological, adsorption, mechanical characteristics of the print media and from its chemical composition and structure.

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#### Author's Biography

Sergey Gnatyuk born in 1956 in Moldova. In 1979 graduated from Leningrad Technological Institute and in 1982 received PhD in chemistry. Since 1987 works in St. Petersburg State University of Cinema and Television. Assistant professor. Among the theme of his scientific interests are system analysis and digital processing of information and nanotechnology. Author of several original study courses. Master of martial arts. One of leading Aikido masters in St. Petersburg.

Maxim Domasev born in 1977 in Leningrad, in 1999 graduated from St. Petersburg State University of Cinema and Television, specialisation digital image processing. Professional landscape photographer. Works as graphic designer and pre-press engineer combining professional work with scientific studies in color and digital imaging. PhD student.