Requirements for Printing Technologies in Digital Photo Finishing

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Introduction

Non-impact printing technologies have recently gained a high level of image quality - this allows to produce photo-like prints.

In the development of new printing technologies suitable for photo imaging applications, the question of the necessary image quality and the basic parameters affecting this quality, is of extreme importance.

Our investigation presented here addresses these questions by defining the minimum technical requirements for high quality amateur photo printing.

We derive data for visually perceived image quality levels using prints produced on a high quality digital printing system. In this system scan data were generated from colour negative film, passed through an exactly defined digital processing unit and outputted on a high quality colour laser recorder.

Several different parameter sets were used in the digital processing of natural images. The resulting prints of these images were then used in a survey to assess the perceived image quality. Using the same sets of parameters in the digital processing of test images, measurements of physical parameters affecting the image quality have been obtained. By correlating these measurement data with the results from the survey we now are able to rate the relevance of physical image parameters on image quality and to give design rules for alternative output technologies.

Conventional Photographic System

The well established conventional photographic system used by photo amateurs consists of color negative film, color negative paper and the appropriate developing processes. These components are well adjusted to each other thus providing a good image quality as well as a high robustness of the system under amateur conditions. This is the benchmark for all upcoming technologies – the quality of the final prints has to be at least as good as provided by the conventional photographic system.

The film material as the input part of the system has already some “image enhancement intelligence” built-in. In particular it provides a:

- low gradation (γ =0.65) to get a high exposure latitude,
- an enhancement in color differentiation and sharpness due to effects related with the latent image.

The photo paper is designed to convert the negative film image into the positive photography. The paper gradation is about γ =2.5 in order to achieve an overall gradation of the system of about γ =1.4. This results in:

- a high contrast of the prints,
- an improved sharpness of details, and
- an enhancement of color saturation.

It is an advantage specific to the 2 step process – film and paper – that the images can still be improved after exposing the film and before printing the photograph.

However, there are some shortcomings of the conventional system which can be corrected when processing the images digitally between these two production steps.

Generally spoken, the photo paper defines the possible range of parameters of the prints, but the actual achieved image quality is a result of all components of the imaging process ranging from the film via the processing to the printing unit.

Digital Enhancement of the Photographic System

Due to the steep paper gradation the exposure range of the paper is very narrow. Thus, when a high contrast scene is captured on film, one has to decide which part of the original dynamic range should be transferred to the print. This is one of many situations where digital image enhancement can improve the image quality. By applying digital dodging algorithms to the image the contrast in the details of the scene is maintained whereas the overall contrast can be balanced to result in a visually better image within the limited ability of the photographic paper.

Another scenario deals with underexposed photographs. Here the reduced gradation of the film material typically leads to shallow, colorless print results on paper even when the brightness is corrected. A digital photo finishing system can compensate for the low film gradation by computationally applying a steep correction curve to the digital data. The result is an improved image both in contrast and color saturation since the color separation can also be increased.

Images can also be sharpened by appropriate high pass filtering. However, although the sensitivity/ graininess relation of films has considerably improved in recent years, high speed films still exhibit a very high graininess. To a certain extent, this can be compensated by digitally applying a smart filtering of high spatial frequencies.

Another advantage of digital print systems is the enhancement of the limited color-contrast ability of the conventional photographic system. Very saturated colors are clipped when reproduced on paper, fine structures in highly saturated areas are lost. This artifact is reduced by smart mapping of the digital data to the gamut of the paper.

In general it is possible to improve conventional photographic images to an optimum image quality by digital processing. The imaging sequence therefore is separated into input (film, digital camera) and output components (printer) - but now input and output technology are no longer linked to each other. This opens up the way to replace the output technology by any other technology which meets the requirements. It should be noted here, that the output technology defines the maximum possible image quality, the actual achieved parameters of the prints are defined by all components of the total system, including the scanner / camera and the image processing.

Investigation of the Minimum Image Quality Requirements

Since image quality is expensive in terms of processing time and equipment cost, we have performed an investigation aiming at the definition of minimal requirements on some basic parameters affecting image quality.[1] The relation between physically measurable quality parameters and the visually perceived image quality was investigated by performing a survey.

Although very many values have influence on the image quality, the investigations were restricted to the most common parameters, namely sharpness, noise, color and contrast. A set of several test images was selected for the survey:

Figure 1. Test images for the survey

These test images combine various parameters like high contrast regions, neutral areas, skin tones, continuos color wedges, saturated colors, details, etc.

These images were processed by a digital image processing program which provides very flexible possibilities to change different parameters. The total image processing consists of the following steps:

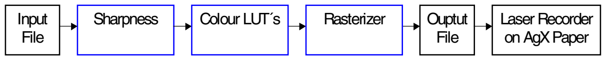

Figure 2. Image processing chain

1. Shooting the images on 35mm CN film 200 ASA,
2. digitizing the images with 2k x 3k pixels @ 12 bit / color on a digital Minilab scanner,
3. sharpening with 5 different sharpening levels @ 12 bit / color,
4. variation of the maximum color density in cyan, yellow, magenta at 4 different levels each by applying appropriate color LUT´s (Look-Up Tables). This also changes the maximum contrast of the prints.
5. Variation / Addition of noise at 3 different levels by screening the image data using an error diffusion algorithm with different quantization tables,
6. output on a digital Minilab on AgX paper @ 400 dpi,
7. and measuring the physical image parameters of test images digitally processed the same way.

The different levels of the parameter settings were chosen such, that the visual image quality was be tuned from “perfect” down to “bad” by each parameter.

In total the set of parameters would lead to:
5 images
x 5 sharpness values
x 3x4 color levels
x 3 noise levels
= 900 different test prints.

This number of test prints is impossible to be shown to a single participant in a survey. Therefore, a design of experiment (DOE) program was utilized in order to calculate a representative set of parameters and to limit the number of test prints to be evaluated to 57 in total.
In the survey, the participants had to place the prints along a ruler with respect to the image quality.

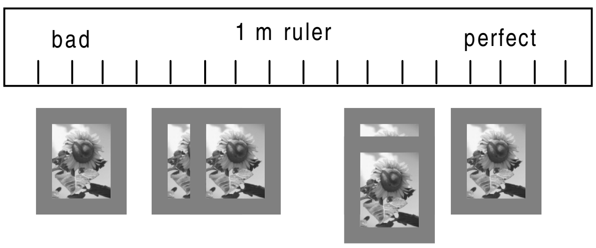

Figure 3. Experimental setup of the ranking

The perceived image quality was registered in terms of the ruler position of the print.

In the survey took part 126 participants - 26% female, 74% male. 25% of the participants were photography professionals, 33% ambitious amateurs and 42% amateurs.

An acceptable image quality is counted if 80% of the participants of the survey rate the print as good, i.e. ranking at > 80 cm at the ruler.

Results

In this chapter the results of the survey will be discussed in relation to measured image quality parameters.

Resolution, Sharpness

Sharpness is evaluated by the human eye at medium frequencies of 0.7 to 3.0 cycles/mm. The output system has to be able to provide a sufficiently high contrast at these frequencies. This can be obtained by using an output system with a resolution limit ν_{Nq} >> 3 cycles/mm. The used photo paper, laser recorder and sharpening procedure provides an upper frequency, which is sufficient to reproduce visually very sharp images. The sharpness can be expressed by measuring the total MTF of the prints and calculating the SQF acutance.

$$SQF = \frac{\int_{0.7}^{3} MTF_{System}(\nu)\, d\lg(\nu)}{2,3}$$

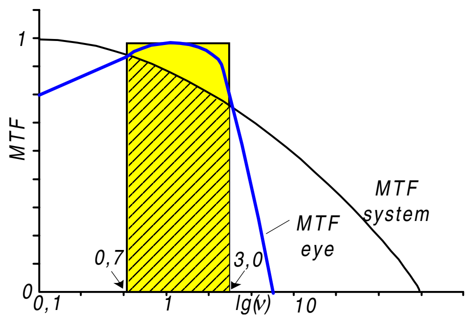

Figure 4. MTF of human eye and total system

The SQF is a measure for the dashed area in Fig. Nnm. From the survey was obtained, that very sharp images are obtained at SQF > 0.8, reasonable image sharpness is still obtained at SQF > 0.6. By appropriate digital enhancement of high frequencies, losses in sharpness can be compensated to the expense of noise.

Noise, Graininess

The noise can be expressed by the RMS value of the standard deviation of densities. Therefore, the local density of a homogeneous print has to be measured with a pinhole of 0.5 mm diameter (48 µm pinhole for film) at several spots and the RMS value is calculated by:

RMS = 1000 x σ, with

$$\sigma^2 = \frac{1}{n-1} \cdot \sum_{i=1}^{n} (D_i - \overline{D})^2$$

and

$$\overline{D} = \frac{1}{n} \cdot \sum_{i=1}^{n} D_i \quad \text{n = number of measurements}$$

Since the human eye is very sensitive to noise in light image areas, we measure the noise at low densities. Fig. 5 shows the noise expressed by the RMS value vs. the density of prints generated on a high quality laser printer. The noise of the test prints was artificially generated by screening the image data using quantization tables with 4, 16, 64 and 256 levels.

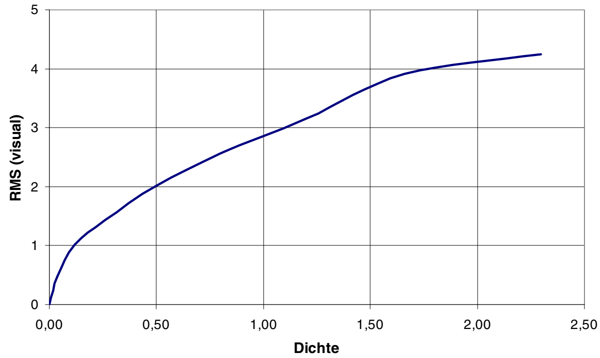

Figure 5. RMS vs. density of a laser printer on photo paper

Visually noise free prints are measured with RMS < 5 at densities between 0.3 D to 0.9 D. However it turned out as a surprising result of the survey, that images without any noise tend to be judged as to look artificial and not natural.

Gamut, Color Spectra

At recent photo paper dyes with wide spectral primaries at 450 nm, 550 nm and 650 nm are utilized, resulting in a gamut shown in Fig. 7.

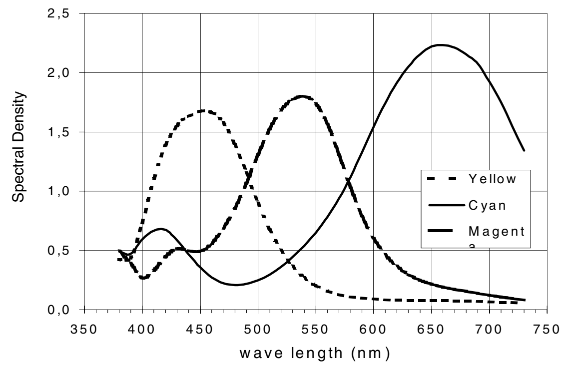

Figure 6. Spectral characteristic of photo paper

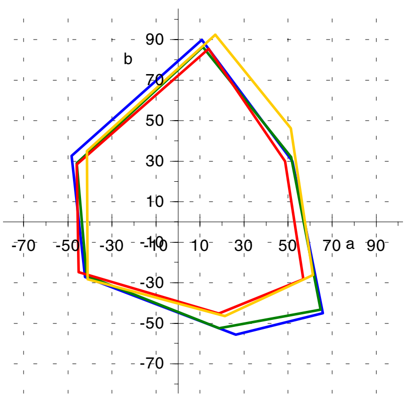

Figure 7. Gamut of different types of photo paper

The gamut is sufficient for the representation of well accepted color photographs, however, there is still room for improvement by utilizing more pure dyes. I.e. the side absorption of the cyan dye in blue and green leads to a reduced maximum cyan saturation. Although the maximum color saturation is limited by this gamut, the visible color differentiation of the photograph can be improved by smart rendering the image data to the color space provided by the output technology

Contrast, Minimum and Maximum Density

Recent photo paper provides a high contrast of more than 2.1 densities. The fog density Dmin is a critical parameter in particular with respect to the brilliance of high lights, it should be less then 0.12 D.

The maximum density Dmax is an important parameter for the contrast and for the perceived brilliance of shadows. In order to measure the minimum level of Dmax required for a minimum acceptable image quality, the maximum density of the prints was reduced by applying a cut-off LUT to the image data.

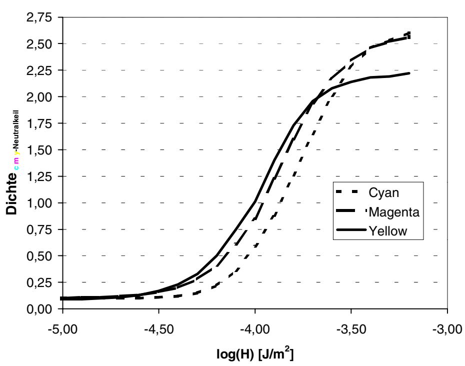

Figure 8. Gradation curve of photo paper

For the survey, prints were produced with Dmax between 1.4D up to 2.4D, measured with a status A densitometer on glossy paper. The survey showed, that prints with Dmax > 2.1 D are well accepted whereas Dmax < 1.8 D leads to not acceptable print quality.

Conclusion

The conventional photographic system provides a good image quality setting the benchmark for new technologies for the production of photographic pints. In order not to overstress the specifications of the alternative technologies, an image quality survey was performed .

In the survey the following results were obtained for an acceptable and for a good perceived image quality:

- Sharpness: SQF > 0.8 for very good images SQF > 0.6 for acceptable images
- RMS between 3-5 for very fine images, RMS < 8 for good images
- Contrast > 2.2D for brilliant images, Dmax > 2 for acceptable images
- Gamut > 3000 ab (in Lab values), not smaller than the gamut of photo paper for well accepted image quality. In particular a color cast is much less accepted than a neutral reduction of the gamut in all colors.

Acknowledgement

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References

1. Carola Bolte, Diplomarbeit, FH Köln, Germany, 2000

Biography

Dr. Tobias Damm studied physics at Jena University, Germany. He took his diploma in 1981. In 1985 he received a PhD in physics and the Dr. rer. nat. habil. in natural sciences in 1991. His scientific work included laser physics, spectroscopy and scanning microscopy.

Dr. Damm joined Agfa in Leverkusen in 1990, where he started as a busienss development manager for new systems and businesses for the photo market. In 1993 he moved to the Agfa business unit lab-equipment in Munich where he managed projects to introduce digital technology for major applications. Since 1996 he has been head of basic research of the lab-equipment division. He is a member of the IS&T and since 1999 he is the Vice President of the European Chapter of IS&T.