

Image prediction by an inkjet printing simulator

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Abstract

A newly developed inkjet printing simulator which enables arbitrary settings of resolution, and shapes and concentration of ink droplets, simulates inkjet printing with resolution and number of shades very closely to actual print results. By applying the evaluation function to this simulator, the quality of the inkjet printing image can be predicted. In this paper, we describe the granularity of digital halftone images obtained by an inkjet printer.

Introduction

In recent years, the demand for high-quality images from low-priced inkjet printers has been increasing along with the rapidly growing popularity of digital images. In order to enable the output of images which can be appreciated, multiple image quality factors must be optimized from mechanical accuracy to image processing. These factors present a considerable obstacle for development.

This report introduces the development of a simulator which can predict images output by an inkjet printer, attempts made to quantitatively evaluate image output, and improvements in inkjet printer image quality.

Previous research papers[1,7] have reported on the relationship between resolution and gradation for the purpose of satisfying visual properties. Figure 1 shows the theoretical spatial-tone properties of a binary printer. However, these papers arguments were based on ideal printing and did not consider conditions of printing with an actual printer.

We developed a high-accuracy printer simulator and performed image predictions under conditions close to that of actual printing. The simulator developed for this research can be manipulated to freely set resolution, dot configuration and dot density.

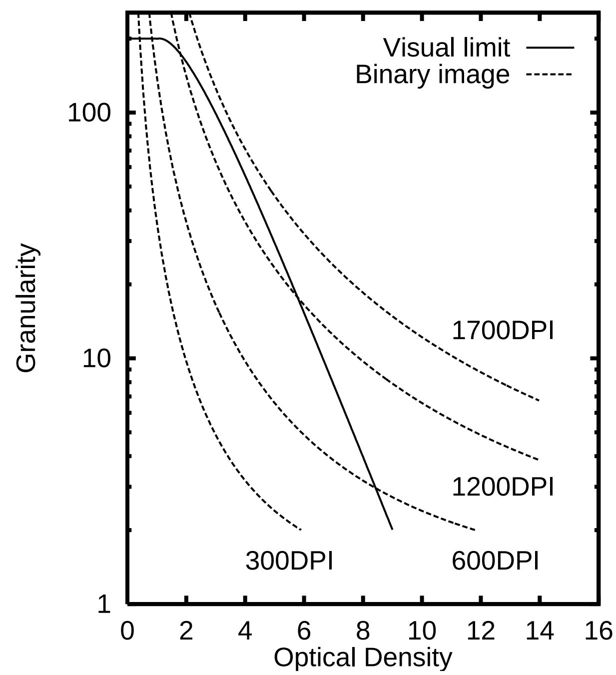

Figure 1. Binary image code limits (spatial-tone properties)

Simulation Tests

Tests were performed under the following conditions and image samples were prepared.

Resolution

While considering the conditions for satisfying resolution and visual properties of a representative printer, the following four resolutions were chosen:

- 300 DPI
- 600 DPI
- 1,200 DPI
- 1,700 DPI

Halftoning method

The following three methods were used:

- Error Diffusion Method (Jarvis et al. filter with random threshold)[2]
- Ordered Dither Method (Bayer's 16 x 16 matrix)[2]
- Blue Noise Mask Method (256 x 256 matrix)[3]

It is interesting to note that error diffusion method-like image quality was obtained with the blue noise mask method with a processing load equivalent to that of the ordered dither method.

Dot configuration, etc.

Circular dot configuration was chosen with a dot diameter equal to $\sqrt{2}$ x the dot pitch. The inkjet printer produces the kind of overlapping shown in Figure 2. Dot density was made 2.0 and the optical density of areas where dots overlap was made 20% greater than that of a single dot.

Evaluated images

Two types of natural images (ISO/JIS-SCID N1 and N5)[6] and images with seven levels of grey patch distributed were used.

Image Quality and Evaluation

An attempt was made to quantitatively evaluate image quality of the above-mentioned image samples. While tone reproduction, sharpness, graininess and color reproduction all influence image quality, in this case we focused on the evaluation of graininess. In this report, we used as reference the RMS granularity used in graininess evaluation of photographic images[4] and utilized the following evaluation functions. In these functions, P is the simulation image used to derive P' using a visual filter. G is the granularity set as the standard deviation within the pixel value in P'.

$$G = \left\{ \frac{1}{N^2 - 1} \sum_{i,j=1}^{N} (P'_{ij} - \bar{P})^2 \right\}^{1/2} \qquad (1)$$

$$\bar{P} = \frac{1}{N^2} \sum_{i,j=1}^{N} P'_{ij} \qquad (2)$$

$$P'_{ij} = IFFT\{FFT(P_{ij}) \Sigma V(f)\} \qquad (3)$$

$$V(f) = \begin{cases} 5.05\,(e^{-0.138 f})\,(1 - e^{-0.1 f}) & : f \geq 5 \\ 1 & : f < 5 \end{cases} \qquad (4)$$

f: Spatial frequency [cycle/degree]

above granularity G was measured at seven points from highlight to medium-density sections.

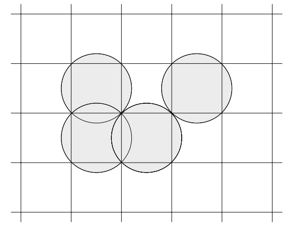

Figure 2. Circular dot model.

Results

Binary printer resolution

Subjectively speaking, individual dots could be confirmed at resolutions of 600 DPI and lower, and the graininess from highlight to medium-density sections is not good. Since at 1,200 DPI and above, individual dots become indistinguishable and highlight image quality improves. However, grittiness still remains in the medium-density sections.

Figure 3 shows changes in granularity due to differences in resolution. The halftoning method here is the error diffusion method. These results show that the subjective evaluation and the results obtained from spatial-tone properties match up well.

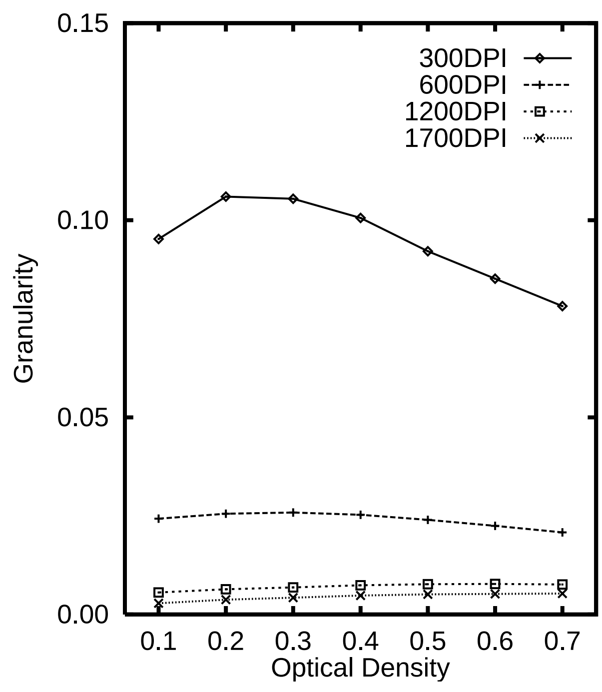

Figure 3.Comparison of the granularity in various resolutions.

Halftoning method

Figure 4-6 shows changes in granularity due to differences in halftoning method.

On the whole, granularity under the ordered dither and blue noise mask methods was comparatively smaller than that under the error diffusion method. In actuality, when viewed at the patch, the grittiness produced by the error diffusion method can be detected strongly .

Under the ordered dither method, some pseudo contour can be seen in the area where optical density changes smoothly and the overall impression worsens. This is due to the fact that since granularity varies according to optical density, these changes are recognized as a pseudo contour.

For natural images, especially those with low resolutions, image quality under the error diffusion method is clearly superior to that of both the ordered dither method and the blue noise mask method. This is thought to be due to factors other than graininess.

At this point, an evaluation of halftone images using spatial frequency was attempted. The evaluation function used for this paper was a radially averaged power spectrum[2] which enables a two-dimensional spatial frequency to be handled one-dimensionally. With a visual filter V(f) the power spectrum was transformed into a psychophysical value and evaluated.

Figure 7 shows spatial frequency response of images with optical density of 0.2 under each halftoning method. The ideal frequency response for reproduced images is 0 for all frequencies.

At 300 DPI, all methods exhibit power at lower frequencies which is perceived as noise. The power is greatest under the error diffusion method. This is consistent with the result of the granularity evaluation which also found the power of the error diffusion method to be the greatest. Several peaks can be seen under the ordered dither method. These peaks correspond to periodic noise which appears in images. A slight noise remains at 600 DPI. At 1,200 DPI, all methods exhibit virtually no excess power and it can be observed that ideal reproduction has been obtained.

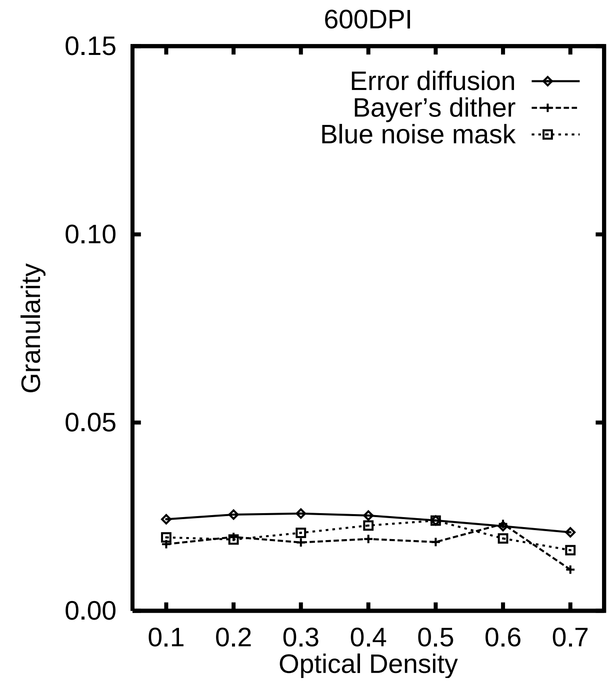

Figure 5. Comparison of the granularity in various halftoning (600DPI).

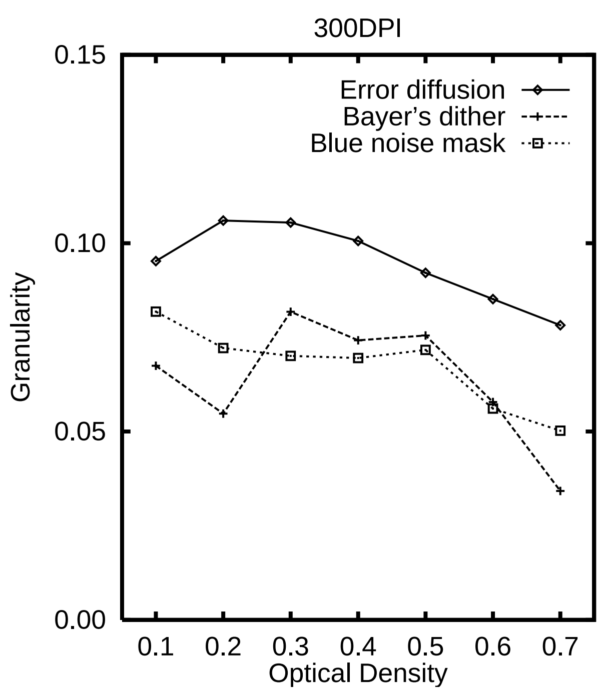

Figure 4. Comparison of the granularity in various halftoning (300DPI).

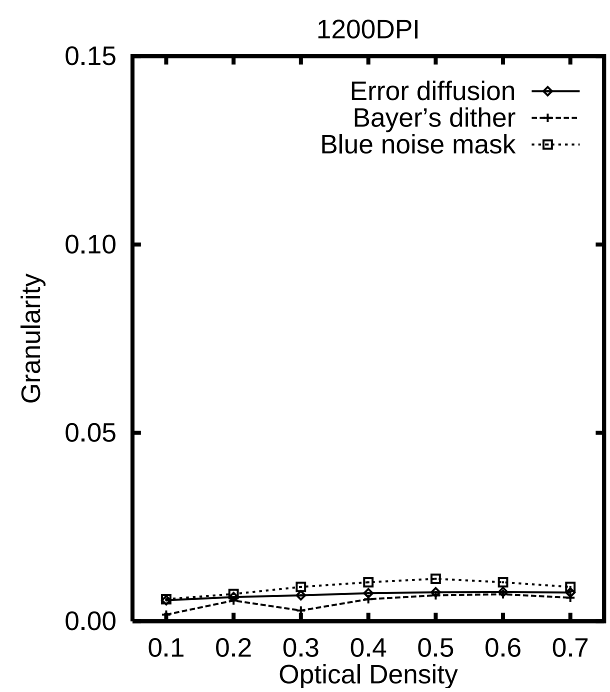

Figure 6. Comparison of the granularity in various halftoning (1200DPI).

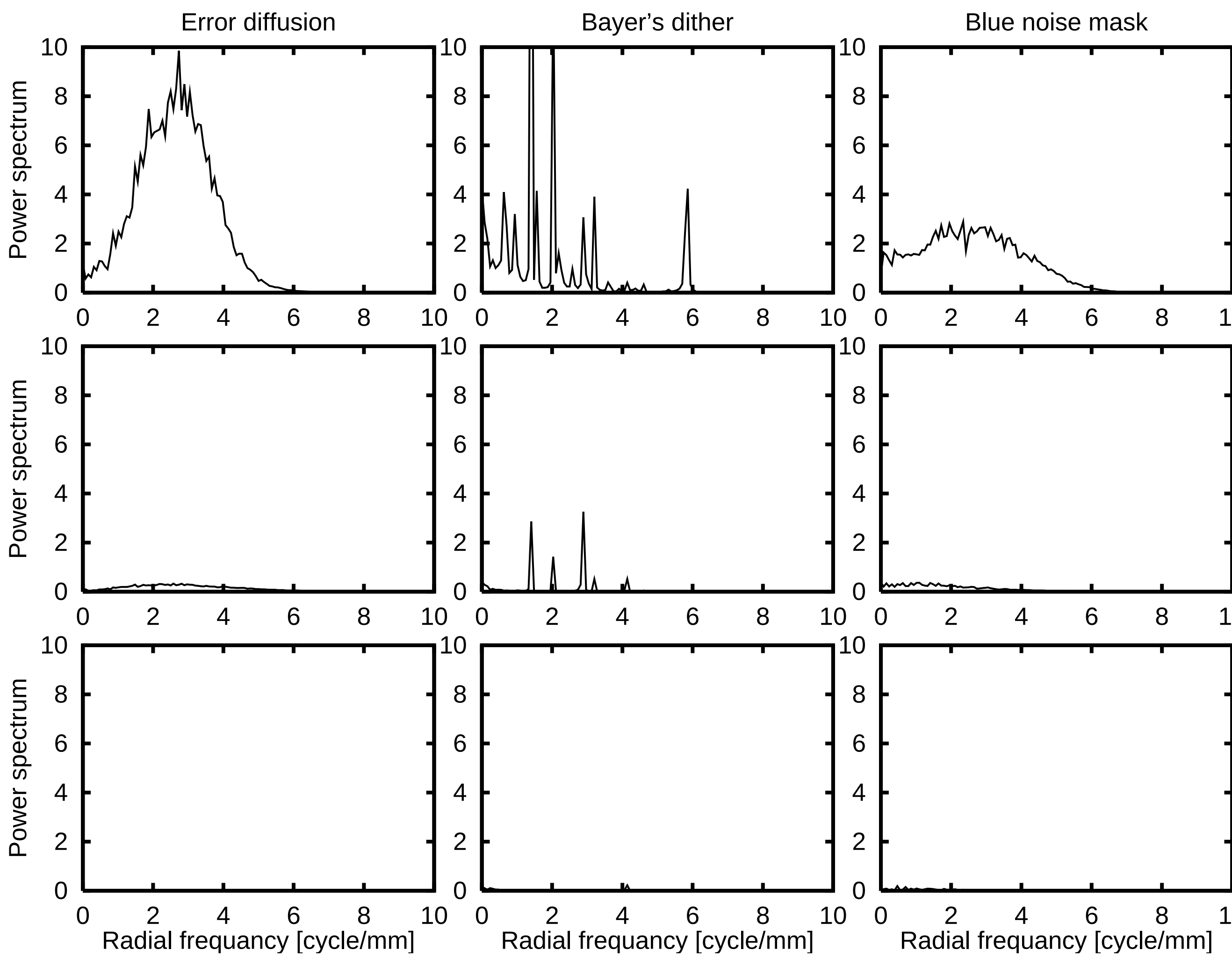

Figure 7. Comparison of the radially averaged poewr spectrum on various halftoning (O.D.=0.2).

Conclusion

Using a high-accuracy inkjet printer simulator, we predicted output images under a variety of processing methods. As a result, the relationships between resolution/gradation and image quality were found to be consistent with results obtained from spatial-tone properties, even in the inkjet printing system.

In addition, we found that as resolution approaches the limits of vision, differences in image quality obtained by processing using the ordered dither and error diffusion methods begin to fade.

In evaluating graininess, by incorporating visual spatial tone response into RMS granularity, we obtained results consistent with subjective evaluations. These findings were also backed up by the spatial frequency responses of the images. From the standpoint of graininess, the ordered dither and blue noise mask methods produced better results than the error diffusion method.

This evaluation method cannot be used to measure images with a frequency structure such as texture and moire. However, we expect that a valid evaluation method will be obtainable in the future by incorporating auto correlation functions and other two-dimensional variables.

References

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