MODELING AND QUALITY EVALUATION BASED ON VISUAL PERCEPTION OF HALFTONE REPRODUCTION

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Abstract
This paper introduces model of halftone image reproduction based on TVI of printing process and human visual perception. That gives opportunity to generate images for dataset and to calculate loss function without printing images after each epoch of neural networks training which can be used for creating new algorithm of digital halftoning. In this paper quality of modeled AM and FM screens is compared to offset prints on uniformity, sharpness, noise level and structural similarity. This quality metrics can be used as loss function for neural network training. The adequacy of the model presented was verified. Neural networks nowadays wildly used for image processing and they can be also used for digital halftoning algorithms in relation to printing. Dataset of images and loss function are required to train neural networks.
Key words: *digital halftoning, screens, visual perception, image quality metrics*

Introduction

The combination of different raster structures on one image in the printing reproduction allows to create an security element for product protection [1], but also to improve the quality of reproduction in terms of detail transfer and smoothness of gradients by using the most suitable structures for particular image area.

There are algorithms for combining two structures on one image: hybrid structures and, for example, Screening Esko DeskPack software.

The approach without the use of traditional threshold matrix halftoning can be implemented through machine learning. The use of machine learning algorithms in digital halftoning and the training approach with print analysis are discussed in the article [2].

The basis for machine learning algorithms is the image dataset and evaluation criteria - the loss function. The article proposes a method of image generation for dataset and evaluation criteria. The main task is to model the printing process using different structures, considering the visual perception of the print. Using real prints with their subsequent digitization by scanning or photographing to form a dataset of images is costly, since this must be done after each epoch of training.

Another reason why the model was created, is the need for a program that creates halftone images, models printing process and visual perception, evaluates the result and learns in a single environment. This will also improve computational speed.

Digital halftoning model with TVI and visual perception

The proposed model of digital screening for now implements algorithms with regular and irregular structures based on threshold matrices. A round dots are used for the regular structure, the first-order structure is used as an irregular one. An example of a raster dot with 0%, 20%, 50% and 100% dot area rate is shown in Figure 1.

Fig 1. Raster dots with 0%, 20%, 50% and 100% dot area rate: left — regular, right — irregular

Tone value increase (TVI) is used to model the printing process. The data for model is taken from TVI curves, which are described in the standard for offset printing for regular and irregular structures respectively [3]. Model increases the area of the dot by the corresponding value from the TVI curve by changing the threshold matrix. An example of modeling raster dot with 50% dot area rate is shown in Figure 2.

Fig 2. Raster dots with 0%, 20%, 50% and 100% dot area rate after printing model: left — regular, right — irregular

Modeling the visual perception of the print is carried out according to the method described in article [4] by blur parameters adjustment for Gauss filter based on the properties of the final image: its size and resolution. An example of a raster dots with 50% dot area rate with increased tone and visual perception modeling is shown in Figure 3.

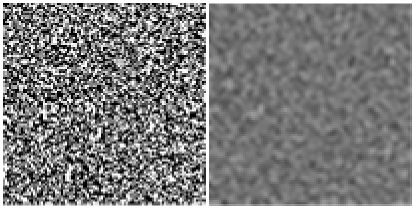

Fig 3. Irregular dot with 50% area rate: left — before visual perception model, right — after visual perception model

Model testing

The adequacy of the obtained model was verified by comparing the digital images generated with our model with scanned offset prints. Printing was produced under PC2 conditions. For comparison, we took regular structures with a round dot rotated by 45 degrees and frequencies of 150, 175 and 200 lines per inch; and irregular structures: Creo Turbo FM and Super Fine, because visually they were closest to first-order structures. For modeling we created patches from 0% to 100% with 10% step of increase in dot area rate and image of box.

The parameters of model are taken according to the standard and printing conditions: TVI curve B for regular structure and E for irregular. In the modeling of the visual perception of a print for the Gaussian filter $\boldsymbol{\sigma}$ is set to 6.

Using the proposed model, images were generated from chosen patches and image considering the printing conditions. Further, a model of visual perception of a print was applied to generated images and scanned prints. Comparison was made with MS-SSIM (Fig. 4), uniformity of the images through entropy (Fig. 5), noise level through SNR (Fig. 6).

By the parameter MS-SSIM the modeled structure is close to prints in highlights, but after a dot area rate of 50% there is a drop in image similarity. This is due to the problems with meeting the printing conditions, especially dot gain, and paper structure, that adds noise to scanned images.

The lower the value of entropy, the more uniform the patch is reproduced. Points on a graph where entropy value equals 0 are a modeled dots with 100% dot area rate. For a round dots with frequencies of 150 and 175

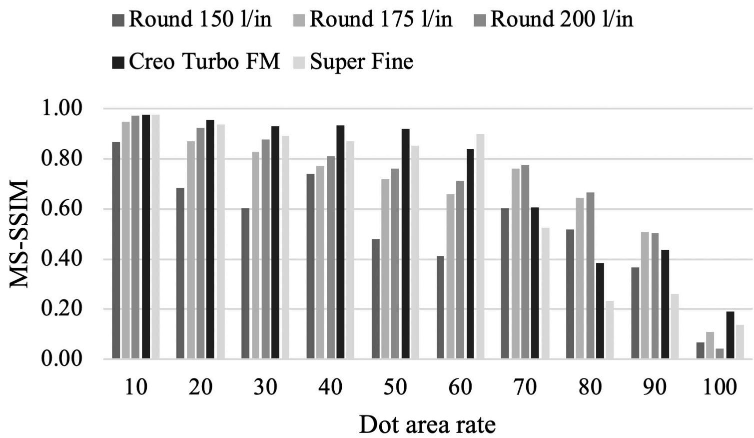

Fig 4. MS-SSIM comparison of patches with different dot area rates between modeled and printed patches with 5 structures

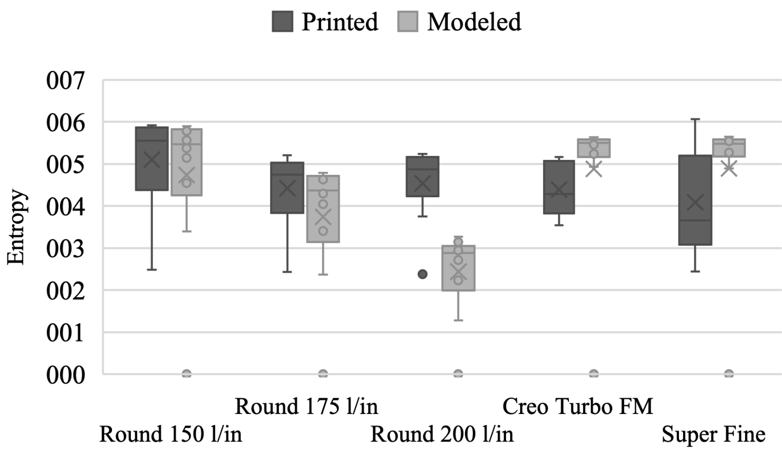

Fig 5. Box plots of entropy for modeled and printed patches with 5 structures

lines per inch, the results of the model and real prints are close. For a frequency of 200 lines per image, the model shows more uniform pattern.

In the future, for example, based on such a result machine learning algorithm may choose such a structure for reproducing uniform areas of an image. For an irregular raster, uniformity is lower, but the deviation is less.

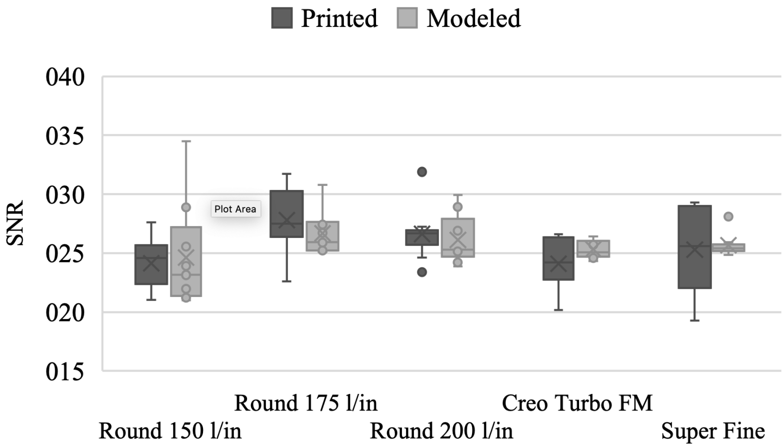

Fig 6. Box plots of SNR for modeled and printed patches with 5 structures

Single/noise ratio in the images is close to each other, which, therefore, shows the similarity of the model to the real process of reproduction.

Image of box was used for sharpness evaluation (Fig. 7), due to high amount of details in it. Sharpness was evaluated by full reference image blur measure described in article [5]. The results are presented in table 1. Entropy and SNR are close to each other, but percentage of blur is much higher for scanned print. The reason for that is additional blur in the scanner optical system.

Fig 7. Test image with smooth background and sharp details

Table 1. Metrics for printed and modeled image with frequencies 150 and 200 l/in

l/in	MS-SSIM	SNR printed	SNR modeled	Percentage of blur printed	Percentage of blur modeled
150	0,93	14,72	15,73	0,50	0,25
200	0,93	14,03	15,68	0,21	0,01

In the future, the model will be supplemented with regular structures with a different dot shape, second-order stochastic structures, and these metrics will be used as components of the loss function for machine learning.

Conclusions

Digital halftoning model with TVI and visual perception of the print is proposed, and the adequacy of the model presented. Modeled patches and image were compared to prints and they show similar results: for images structural similarity equals to 0.93, for patches with dot area rate below 60% average structural similarity equals to 0.84, above 60% structural similarity significantly dropped to 0.47 due to the problems with meeting the printing conditions in real printing process.

Model can be used to produce image dataset for future machine learning in digital halftoning.

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