ANTI-COUNTERFEITING FEATURES OF ARTISTIC SCREENING

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1. Introduction

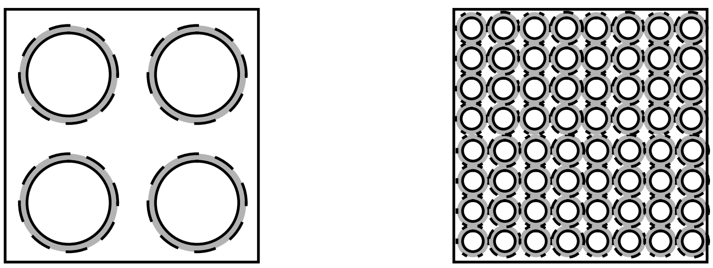
In a recent publication [Ostromoukhov95], a new image reproduction technique, Artistic Screening, was presented. It incorporates freely created artistic screen elements for generating halftones. Fixed predefined dot contours associated with given intensity levels determine the screen dot shape's growing behaviour. Screen dot contours associated with each intensity level are obtained by interpolation between the fixed predefined dot contours. A user-defined mapping transforms screen elements from screen element definition space to screen element rendition space. This mapping can be tuned to produce various effects such as dilatations, contractions and non-linear deformations of the screen element grid.

Although Artistic Screening has been designed mainly for performing the creation of graphic designs of high artistic quality, it also incorporates several important anti-counterfeiting features. For example, bank notes or other valuable printed matters produced with Artistic Screening may incorporate both full size and microscopic letters of varying shape into the image halftoning process.

Furthermore, Artistic Screening can be used for generating screen dots at varying frequencies and orientations, which are well known for inducing strong moiré effects when scanned by a digital colour copier or a desktop scanner. Moiré effects due to scanning of frequency modulated dots and lines have been discussed by Spannenburg [Spannenburg91].

However, it is less known that frequency-modulated screen dots have at each screen element size a different reproduction behaviour (dot gain). When trying to reproduce an original by analog means, such as a photocopier, the variations in dot gain induce strong intensity variations at the same original intensity levels (Fig. 1). In this paper, we present a method for compensating such variations for the target printer, on which the original security document is to be printed. Potential counterfeiters who would like to reproduce the original with a photocopying device may only be able to adjust the dot gain for the whole image and will therefore be unable to eliminate the undesired intensity variations produced by variable frequency screen elements.

Surface increase due to dot gain: 5%



Surface increase due to dot gain: 40%

Fig. 1. Intensity variation due to dot gain at two different screen periods

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2. Generating frequency-modulated halftone screens

In order to generate varying dot shapes capable of representing figurative or decorative motives, we define the evolving screen dot shape by a description of its contours. For this purpose, we introduce fixed predefined screen dot contours which are associated with specific intensity levels. By interpolation between the fixed predefined screen dot contours, described for convenience as Bézier splines, we can generate intermediate contours at all required intensity levels.

Once all fixed contours have been designed in the screen element definition space, one merely needs to define a transformation between screen element definition space and screen element rendition space. This transformation enables both screen element morphing [Ostromoukhov95] and screen dot frequency modulation.

Figures 2 and 3 show examples of halftone images generated using a sinusoidal screen dot period variation both in the x and y directions, according to the following formula:

$$x' = k_1 \cdot x + k_2 \cdot \sin(k_3 \cdot x)$$

$$y' = k_4 \cdot y + k_5 \cdot \sin(k_6 \cdot y)$$

where k_1, k_2, k_3, k_4, k_5 and k_6 are parameters characterizing the current transformation t_s.

Once the fixed predefined contour parts have been transformed from screen element definition space to rendition space, discrete screen elements may be generated for each discrete intensity level. For reproducing 256 intensity levels, the intensity interval between $z = 0$ and $z = 1$ is divided by 255 and intermediate screen dot contours are successively generated at intensity levels $z=0, z=1/255,..,z=255/255$. At each discrete intensity, the screen dot contours are rasterized by applying well known shape rasterization techniques [Foley90].

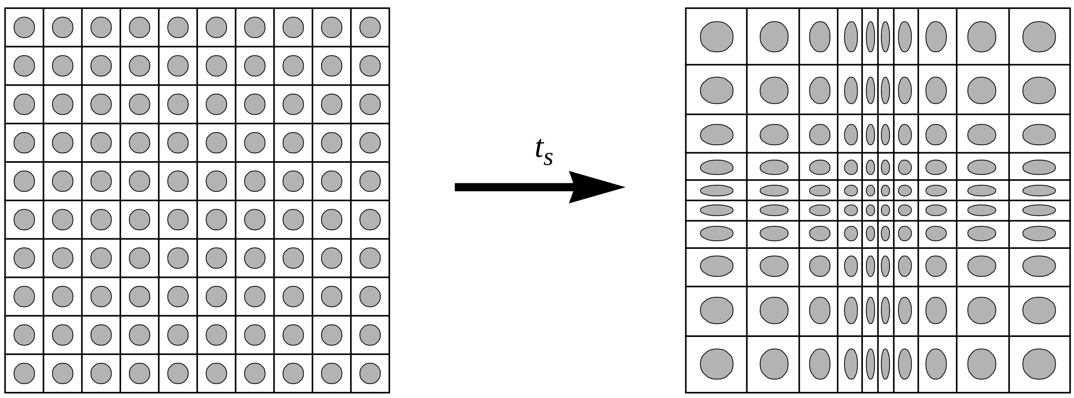

Fig 2. Transformation of a rectangular screen into a sinusoidally modulated screen

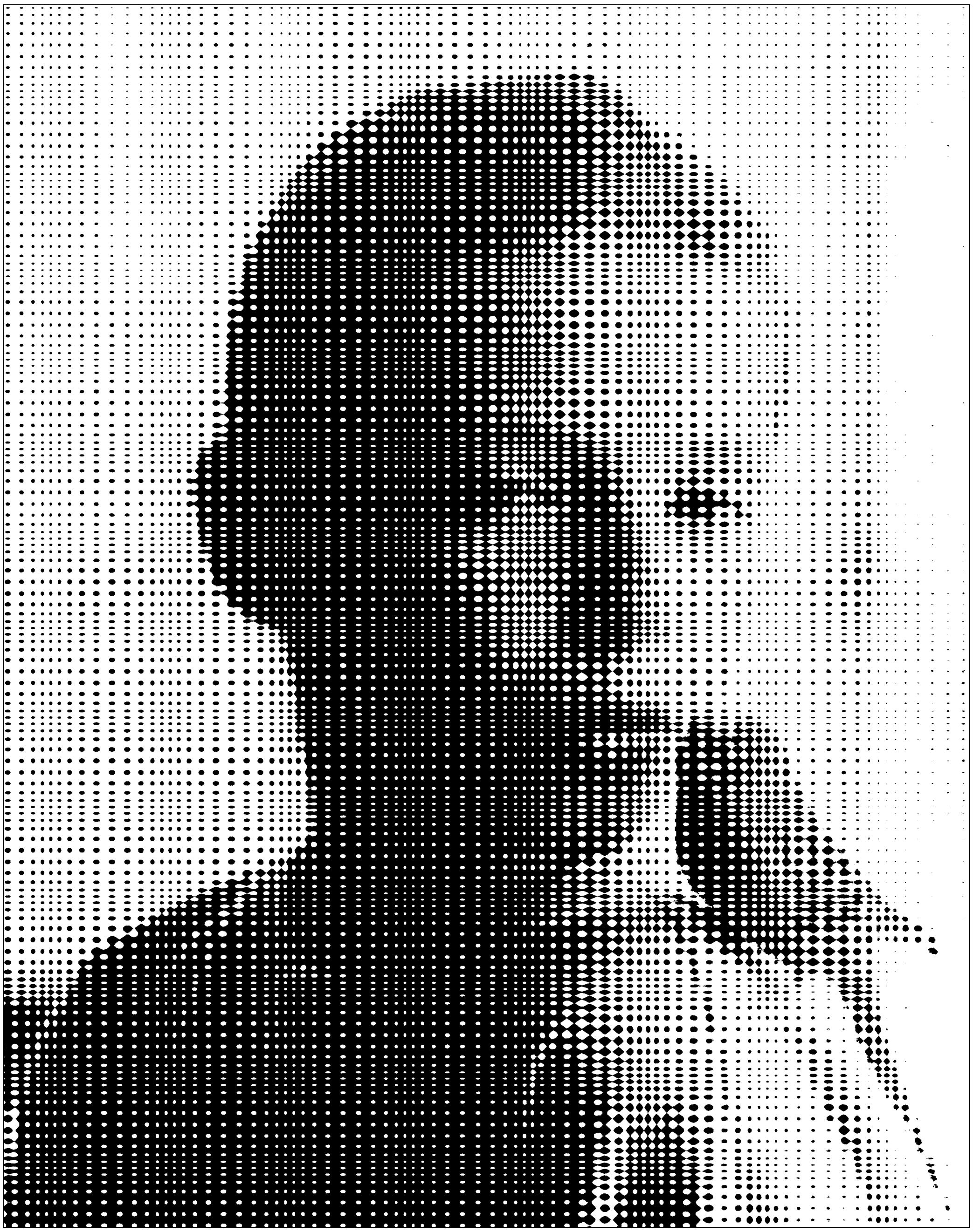

Fig. 3. Image of young girl, halftoned with the screen dot shown in Fig. 2.

Once discrete screen elements have been generated for all intensity levels, the halftoning of an input image requires scanning all output bitmap pixels, pixel by pixel and scanline by scanline, finding for every single output pixel its corresponding input image pixel intensity, and selecting in the discrete screen element at the corresponding intensity the pixel value (black or white) which is to be copied into the output bitmap (Fig. 4).

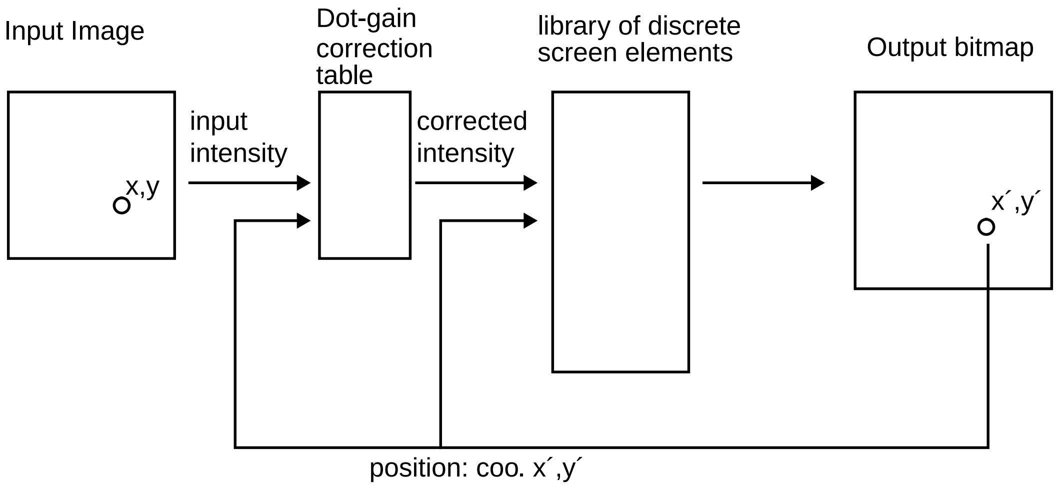

Fig. 4. Mapping input pixels and discrete screen elements into the output bitmap

A dot gain compensation stage can be incorporated into this halftoning algorithm by using instead of the source image intensity the corrected image intensity in order to select the discrete screen element used for the current output pixel setting. In order to access the dot gain correction table, both the current source image pixel intensity and the current output pixel position are needed. The current output pixel position determines the period of the current screen dot. Fig. 4 shows how the halftoning scheme is to be modified in order to obtain the position-dependent dot gain compensation.

Position-dependent dot gain compensation is not specific of artistic screening and can also be used in other halftoning algorithms, for example in dithering algorithms.

3. Compensating dot gain in frequency-modulated halftone screens

Thanks to the flexibility introduced by the mapping between screen element space and screen rendition space, the frequency of halftone screens can be modulated with any desired function. For the sake of simplicity, we present here a method for compensating the dot gain for a sinusoidal halftone screen period modulation along the x-axis, according to the formula

$$x' = x + a \cdot \sin(b \cdot x)$$

$$y' = y$$

In order to consider all values of a sine function, it is sufficient to consider half of its full period interval, for example the interval from π/2 to 3π/2 (Fig. 5). This interval can be divided into a certain number of subintervals, for example, 4 distinct subintervals separated by 5 discrete frequency values f_0, f_1, f_2, f_3, and f_4.

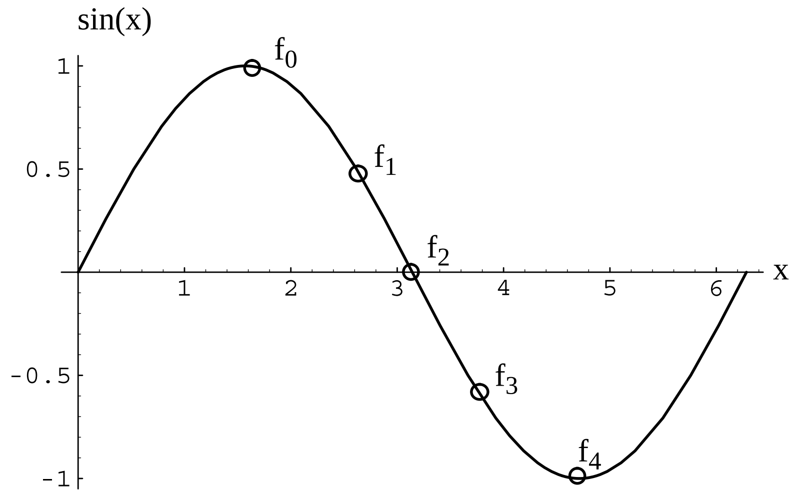

Fig. 5. Subintervals selected for analysis of dot gain.

Dot gain compensation on a given target printer requires the selection of a corrected input intensity level P'(x,y) in order to obtain the desired intensity level P(x,y). This correction can be obtained by printing patches at all desired intensity levels (for example 256 intensity levels), for each of the selected discrete frequency values f_0, f_1, f_2, f_3, *and* f_4. The density D of all patches can be measured and corresponding white surface coverage percentages C computed according to the formula

$$C = 1 - \frac{10^{-D_{white}} - 10^{-D}}{10^{-D_{white}} - 10^{-D_{black}}} = \frac{10^{-D} - 10^{-D_{black}}}{10^{-D_{white}} - 10^{-D_{black}}}$$

where D_{white} and D_{black} are respectively densities of the white paper and the solid black ink.

The experimental data we show below (Figs 6 and 7) is based on measurements made on a 600 dpi Apple LaserWriter II printing engine.

According to Fig. 6, the curve for frequency f_0 has the strongest dot gain since the corresponding screen element has the lowest period (4 pixels in the x-direction). The larger the screen element, the smaller the dot gain (f_0: 4 pixels wide, f_1: 5 pixels wide, f_2: 6 pixels wide, f_3: 7 pixels wide, f_4: 8 pixels wide).

Once that for all discrete frequencies f_i, the tables establishing the relationship between input intensities and white surface coverage are known, one may establish one inverse table per discrete frequency giving for each desired intensity level the corrected input intensity value (Fig. 7). Desired output intensity values for frequencies not present in the set of measured patches are obtained by interpolation between neighbouring values.

In order to obtain a perceptually balanced greywedge, the desired output intensity levels (light gray curve in Fig. 6) were determined by fitting a cubic polynomial function through the default greyscale surface coverage values of an Apple LaserWriter II 600 dpi printer, using the default screening of the printer.

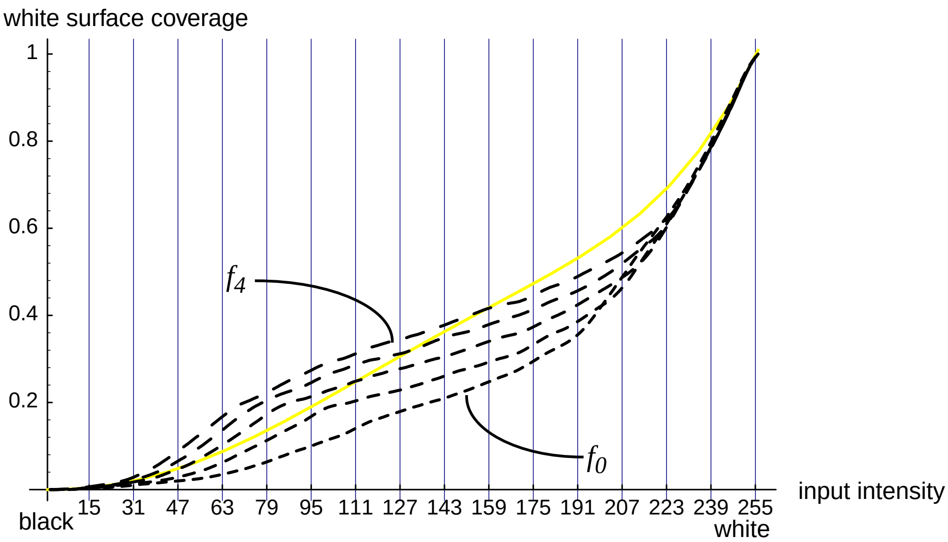

Fig. 6. Equivalent white surface coverage as a function of input intensity for 5 different screen element frequencies

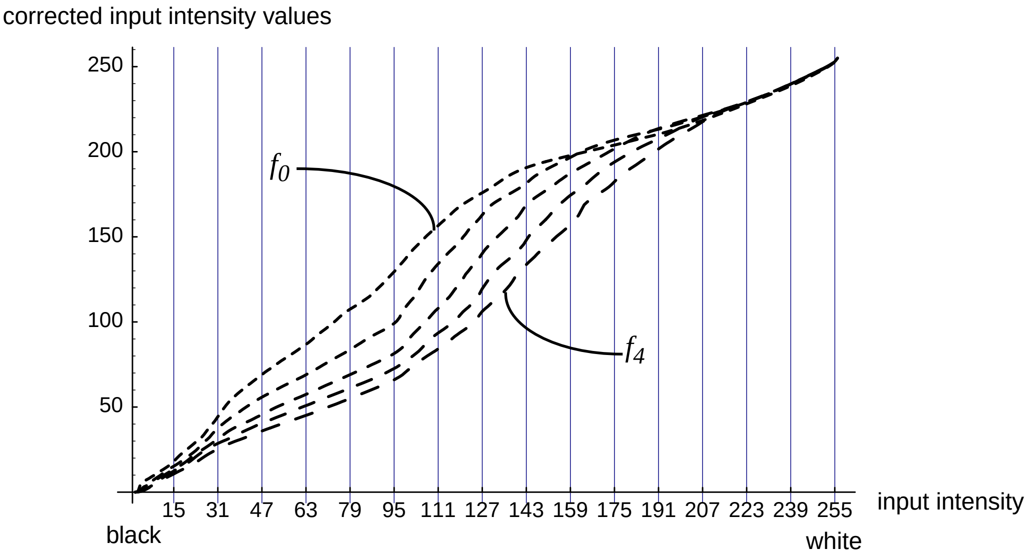

Fig 7. Correction tables for the 5 discrete frequencies f_0, f_1, f_2, f_3, and f_4.

4. Results

Figure 8 shows a greyscale image produced with the method described in the previous section. The printer's non-linear intensity behaviour has been compensated by the correction tables, shown in Figure 7. Due to the impossibility of reproducing faithfully in this proceedings book a dot-gain compensated printed image, only the enlarged part of the figure shows the described feature. The true full-scale image viewed at appropriate distance looks smooth, without significant artifacts or visual perturbations.

In order to define an appropriate viewing distance, one can consider that the human visual cut-off frequency is about 30 cycles per degree, under good light conditions (photopic vision). The viewing distance will depend therefore on the lowest screen frequency present in the image. For example, the lowest screen frequency in Figure 8b is 150/8 = 18.75 lpi. Since tan(1) = 1/57.2896..., we can conclude that in order to achieve the cut-off frequency of the human visual system, one has to see the image (Fig. 8b) at about 2.5 meters (57.2896 * 30 / 18.75 = 91.68 inches   2.33 m).

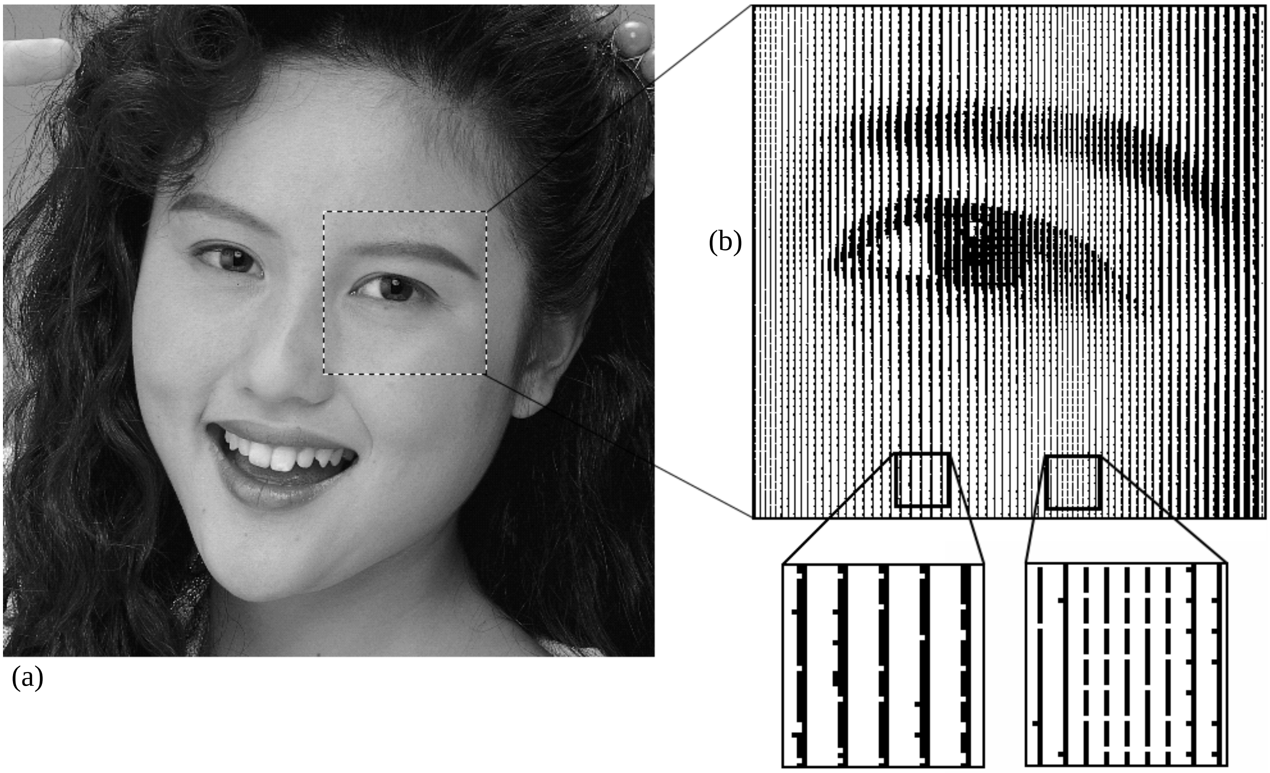

Fig. 8. Principle of generation of a greyscale image with the frequency-modulated screening. The enlarged part (b) of the image has been reproduced at 150 dpi.

When the image generated using the method described in the previous section is scanned by a desktop scanner, moiré fringes appear, no matter how the scanner has been adjusted. The strongest moiré fringes appear when the ratio between the scanner's frequency and the central frequency of the frequency-modulated set present in the image is close to an integer number. Fig. 9a shows an example where an image reproduced with an Apple LaserWriter II laser printer at 600 dpi has been scanned at 300 lpi. In this example, the frequencies which have been used by the frequency-modulated method vary between 75 lpi (period = 8 pix) and 150 lpi (period = 4 pix); the cental frequency equals to 100 lpi (period = 6 pixels).

On the other hand, the same image copied with a standard, analog xerographic copying machine shows very similar intensity beatings (Fig. 9b). Therefore, the same frequency-modulated feature can be used as a protection against counterfeiting, by both digital and analog devices.

5. Conclusions

In this contribution, we show that frequency modulated screen dots exhibit a strongly position-dependent reproduction behaviour, which is difficult to compensate with devices capable of applying a simple gamma correction curve to the whole image. We present a method for multidimensional gamma-correction, where the dot gain compensation is both dependent on the intensity and on the period of the screen element. This position-dependent dot gain correction can be embedded into any halftoning process capable of generating variable frequency screen elements.

Position-dependent dot gain correction ensures the correct appearence of continuous tone images on the target printer for which the compensation tables have been established. Attempts to reproduce the image by electrophotographic means will fail due to the position dependent dot gain induced by the variable frequency screen dots. Correction of position-dependent dot gain would require a tremendous effort from potential counterfeiters.

5. References

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[Ostromoukhov95] V. Ostromoukhov, R.D. Hersch, Artistic Screening, Proceedings of SIGGRAPH'94, *ACM Computer Graphics*, Annual Conference Series, 1995, pp. 218-228.

[Spannenburg91] S. Spannenburg, “Frequency Modulation of Printed Gratings as a Protection against Copying”, Conf on Holographic Optical Security Systems, SPIE Vol 1509 (W.F. Fagan, Ed.), 1991, 88-103

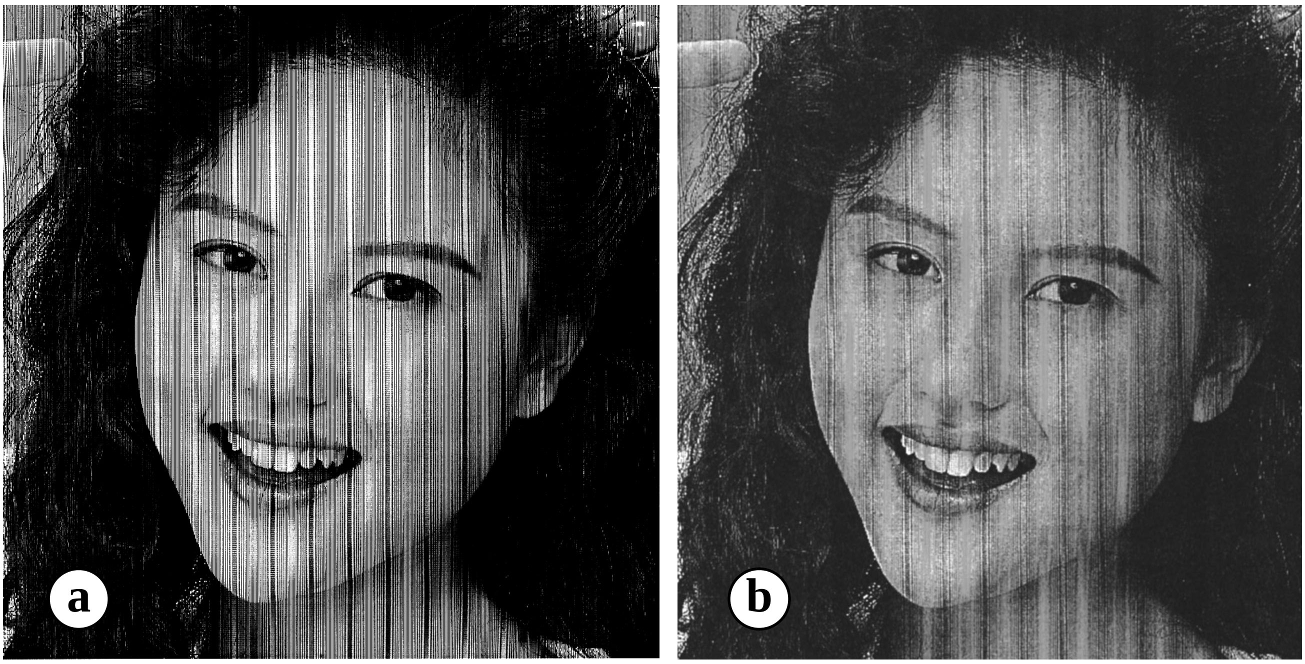

Fig. 9. The frequency-modulated image shown in Figure 8, after scanning (a) and analogical copying (b)