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Scheuter, Karl R.; Fischer, Gerhard

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FREQUENCY MODULATED PICTURE RECORDING WITH RANDOM PIXEL DISTRIBUTION

Karl R. Scheuter and Gerhard Fischer
Institut für Druckmaschinen und Druckverfahren der Technischen Hochschule Darmstadt

Graphic arts' imaging processes generally make use of a halftone mode, which is a kind of amplitude modulation, to reproduce photographs. Photographs, however, may be understood as frequency modulated pictures because the local density is formed by appropriate distances between the silver grains or ink clouds. An electronic technique using the very same modulation principle was developed. The pixel size is constant. Their local density and their distributation is calculated from the density signal, combined with random numbers.
Tests proved that frequency modulation improves the quality of printed pictures considerably. The advantages are high detail rendering, high density range and freedom of moirèe. Further, it is fully reproducible.

The concern of the graphic arts industry is not to create original pictures, but to reproduce such originals by means of printing. Nowadays, the input of graphic arts processes is a photograph of very high quality in most cases. The photographic picture taken from a natural scene, for instance, plays the role of the first original in the graphic arts process. This means that the photograph has to reproduced as accurately as possible.

The best way to reproduce an original of any kind is to reproduce closely its characteristic peculiarities. This fact leads to a point of view, from which the photograph is not seen as a picture but as the result of a photochemical process showing specific peculiarities.

In the case of a black and white film halogen silver grains of constant average size in a random arrangement are exposed. The number of the exposed grains in a certain area increases with the exposure. After development the picture shows only a few silver crystals in areas of low exposure and many crystals in areas of high exposure. Their local frequency, defined as the reciprocal value of the local distances of the silver crystal, is not a picture constant but depends on the local density, i.e. photographic pictures are frequency modulated pictures.

The frequency modulation of the tone rendering is the main characteristic peculiarity of a photographic original. There are, however, two different kinds of noise superimposed over the frequency modulation. The actual sizes of the silver crystals are responsible for noise in very high local frequencies. This noise is not of interest because the human eye shows typical low-pass characteristics and cannot resolve any single crystal. The actual distances between the crystals on the other hand are responsible for lower frequency noise, which sometimes causes a visually resolvable granularity.

In the case of colour pictures there are little ink clouds instead of silver grains. Therefore the characteristic peculiarities, namely the frequency modulation with noise superimposed, are the same for all kinds of photographic pictures, colour pictures as well as black and white ones.

The nature of screen printed halftone pictures is quite different. The distances between the dot centres are constant. In this screen of constant local frequency the dot diameters are variable. They are small in areas of low density. With increasing density the dots get bigger until they link in the middletone region. Negative, white dots are now visible between the linked positive, black dots. The white dots get smaller with increasing density. In conclusion, the percentage dot area is locally variable like an amplitude. Therefore, the halftone pictures are amplitude modulated.

This modulation mode is responsible for the peculiarities of halftone pictures. First of all the modulation range is, in principal, limited. The very minimum dot area of the single black and of the single white dot is believed to be about 100 μm^2 /1/. On low quality paper this very minimum dot size becomes 300 μm^2 or even more. The practical minimum dot sizes of today tend to be between 300 μm^2 and 700 μm^2. The resulting minimum of the percentage dot area φ_{min} depends on the minimum dot area A_{MD} and on the screen element area A_{SE}, which is the square of the reciprocal value of the screen frequency F_S, i.e.

$$\varphi_{min} = \frac{A_{MD}}{A_{SE}} = A_{MD} \cdot F_S^2$$

The resulting maximum of the percentage dot area will then be

$$\varphi_{max} = 1 - \varphi_{min} = 1 - A_{MD} \cdot F_S^2$$

Obviously, the minimum percentage dot area φ_{min} increases and the maximum percentage dot area φ_{max} decreases with the square of the screen frequency F_S. In consequence, the density modulation range, and in colour prints the colour gamut as well, is not only limited by the density D_0 of the white paper and density D_S of the solid ink layer but furthermore by the screen frequency F_S. Moreover the gradation γ_{AM} decreases with the modulation range.

$$\gamma_{AM} = \frac{D(\varphi_{max}) - D(\varphi_{min})}{D_S - D_0}$$

As a first peculiarity of the amplitude modulation of halftone prints we find that only pictures with low contrasts can reach a high resolution power. consequence, the density modulation range of a screen print, i.e. the gradation γ_{AM},, and in colour prints the colour gamut as well, is not only limited by the density D_0 of the white paper and the density D_S of the solid ink layer but furthermore by the screen frequency F_S. As a first peculiarity of the amplitude modulation of halftone prints we find that only pictures with low contrasts can reach a high resolution power.

The commonly used screen ruling of about 60 L/cm is a not very satisfactory compromise between a sufficient gradation and a sufficient resolution power /2/. By further optimizing the printing process the minimum dot area might get smaller in time, so that this relativly low screen frequency could become a little higher /3/. But even if today's very minimum dot sizes of about 100 μm^2 were to become practical, the screen frequencies could hardly exceed 100 L/cm (Fig. 1), because of the loss of graduation.

Another peculiarity of amplitude modulation is easily visible in colour prints. The combination of the screens of the colour separations causes an interferential phenomenon called "moirée". The moirée frequencies are lower than the screen frequencies and therefore clearly visible.

To summarize, the amplitude modulated pictures are known to be of lower quality than the photographic originals. In general the printed pictures look unsharp /4/, the rendition of details is not sufficient /5/ and they show moirée /6/. In fact, the amplitude modulation mode does not seem to be suitable for the reproduction of frequency modulated originals. The frequency modulation mode with superimposed noise, as known from the photographic process, promises fundamental advantages for the printing process, too. Because of the frequency modulation the colour gamut is independent of the resolution power. The colour gamut is only defined by the optophysical characteristics of the materials combined in printing, namely ink and paper. The resolution power is limited by the printing process only in so far that the dots must be printable. Furthermore, the superimposed noise promises freedom of moirée. The reasons described indicate that the highest possible standard of reproduction quality may be expected, when the main peculiarities of photographic images are simulated in the printed pictures. This idea produced a great number of investigations with the aim to establish screenless printing techniques /7/. However, none of these techniques prooved to be reproducible and generally practicable. All the sophisticated proceedures such as collotype or photo-lithographic printing have only been used in extreme cases and are very expensive.

A simple way to get a fully reproducible technique is to make it work in a digital mode. This possibility becomes available in picture processing when a very fine digital recording screen is used. The pixel size is constant in this case, whether the printed dots are positive (black) or negativ (white) ones. The electronic system has to calculate which of the fine-screen elements has to show a positive and which one a negative dot. The frequency of this fine-screen depends only on the printability of the dots and was 480 Lines/cm in most of our experiments. The resulting dot area was 440 μm^2. Printing tests showed that this digital fine screen is fully reproducible. It turned out to be even easier to reproduce than a conventional halftone print.

With the existence of this recording fine-screen and of the scanning screen there are two screens to be adapted in picture processing. The scanning screen is responsible for detail rendition and sharpness. The elements of the scanning screen may be called picture elements. In as much, one can say that the resolution power of the following picture processing is given by the scanning screen. It is clearly evident, therefore, that the scanning screen should be very fine, too. There is no need, however, to exceed the resolution power limit of ink and paper.

With respect to the light diffusion in the paper /8/ and furthermore to the physical spreading of ink /9/ on the paper we chose a scanning screen of 160 L/cm for our experiments.

The adaption of the screen-frequencies for scanning and for recording allows a certain number of tonal value steps per picture element. If the recording frequency is F_R and the scanning frequency is F_S, the number N_T of tonal value steps is given by

$$N_T = F_R^2 / F_S^2 + 1$$

It is well-known that the number of visually resolvable tonal steps in printing products may be about 50 or even more. But tonal differences of such a little amount are resolvable only in big areas of mainly constant tonal value. In this case all the picture elements within such an area have about the same tonal value. So these picture elements, which are local neighbours and are characterized by their nearly identical tonal values, are perceived as one single detail of a certain area and of a certain tonal value. If the whole detail consisting of N_P picture elements is processed in one step, then the available number N_T' of tonal values becomes

$$N_T' = N_P \cdot (F_R^2 / F_S^2) + 1$$

The number of available tonal steps can obviously exceed the number of visual resolvable tonal steps when the picture elements are processed not one by one but in larger groups. In consequence, the input of frequency modulated picture processing is a matrix consisting of the scanned density levels of a little picture area and the output is another matrix showing the appropriate positive and negative dot distribution /10/.

Even if the number of available tonal steps is large enough in every picture detail the problem has been solved, until now, only for the single details. Because the tonal values are in general scanned and recorded in tonal value steps there is nearly always a little difference between the scanned value and the recorded value. Especially in granular pictures and in scenes showing a lot of details these errors are not negligible. These little errors might be compensated accidentally in a matrix of picture elements but usually they are not. So we developed a special filter to compensate these errors automaticly /11/. The accumulated error of a certain picture area is minimized by this filter, whereby the errors of the single details may become enlarged a little. That is why the filter characteristic should be adapted to the low-pass-characteristics of the human eye. Furthermore, this filter may be used to subdivide large details consisting of a lot of picture elements into handy pieces each with a minimum accumulated error.

The next step in frequency modulated picture processing is the transformation of tonal values of the single details into the appropriate frequency modulated pixel arrangements. The basic idea is the following: The mean distances between the dots are variable and in consequence the surrounding areas of every single dot are variable, too. For every tonal value these surrounding areas of the dots are of constant size. In case of low density the dots are positive, that is printed, and the surrounding is not printed. At a high density value the dot is a negative one and its surrounding area is printed. The surrounding area, however, is digitalized by the recording fine screen. So the mean surrounding areas have to approach the tonal values at their best /12/. Every single dot and its surrounding area gives a certain number N_R of recording-screen elements.

A calculation program has to choose one out of these, N_R elements for the positive or negativ dot. This calculation is based on random numbers to achieve the desired random dot distribution. The position of every single dot is calculated in this way (Fig. 2).

Finally, the area of the detail is superimposed by a logical matrix, wherein the detail's screen elements are each of a different value from the others. By processing one detail after another in this way the output matrix is calculated (Fig. 3).

It is now evident that frequency modulated picture processing enables the lithographic printing of pictures that match far better the photographic original than does the traditional halftone printing process. A typical example is given in Figure 4.

At present the state of the art in frequency modulated processing is characterized by the use of a scanner-recorder station of the CHROMACOM-System, which was first loaded with the system software. Then the software for the frequency modulation was added to the existing programs. Consequently, the calculation time is impractical.

Yet modern fast processors, which are already in use in computer tomography for instance, could reduce the calculation time so immensly that the frequency modulation of the colour separations could be processed in line with the recording. There is no need for a spezialized hardware.

In summary, frequency modulation has, at last, proved to be practical in picture processing. The main advantages are the high resolution power and the freedom of moirée /13/. Furthermore, the digital mode of picture processing results in a high reproducibility not only with regard to recording but, as well, with regard to printing /14/.

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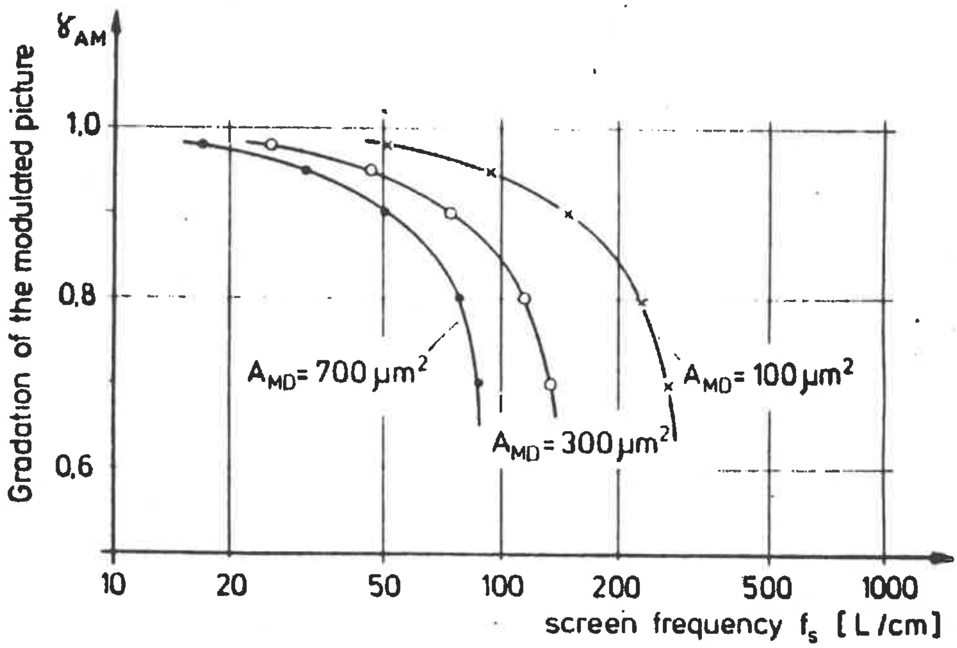

Fig. 1: The modulation gradation of halftone prints as a function of the screen frequency calculated for different minimum dot areas

0	0	0	5	6	0	0	0	0	0	3	1	0	0	0	6	0	0
2	7	6	0	0	0	0	0	5	7	0	0	0	0	0	3	5	7
0	0	0	0	0	0	3	6	0	0	0	0	0	3	8	0	0	0
0	0	0	2	4	9	0	0	0	0	0	5	7	0	0	0	0	0
0	3	1	0	0	0	0	0	0	3	4	0	0	0	0	0	8	1
2	0	0	0	0	0	4	7	2	0	0	0	0	0	6	4	0	0
0	0	0	0	4	1	0	0	0	0	0	0	2	1	0	0	0	0
0	0	9	3	0	0	0	0	0	1	8	6	0	0	0	0	0	3
4	2	0	0	0	0	0	9	8	0	0	0	0	0	0	5	6	0
0	0	0	0	0	2	6	0	0	0	0	0	3	7	2	0	0	0
0	0	0	5	6	0	0	0	0	0	2	4	0	0	0	0	0	0
7	4	1	0	0	0	0	0	7	1	0	0	0	0	0	8	1	2
0	0	0	0	0	0	1	3	0	0	0	0	0	8	9	0	0	0
0	0	0	7	3	5	0	0	0	0	0	6	7	0	0	0	0	0
0	8	1	0	0	0	0	0	0	1	7	0	0	0	0	0	2	9
6	0	0	0	0	0	7	4	8	0	0	0	0	0	5	3	0	0
0	0	0	0	5	1	0	0	0	0	0	0	6	1	0	0	0	0
0	0	2	8	0	0	0	0	0	7	6	4	0	0	0	0	0	3

Matrix with 3 random numbers in 10 elements (φ = 10 %)

0	0	0	0	L	0	0	0	0	0	0	0	0	0	0	0	0	0
0	L	0	0	0	0	0	0	0	L	0	0	0	0	0	0	L	0
0	0	0	0	0	0	0	L	0	0	0	0	0	0	L	0	0	0
0	0	0	0	0	L	0	0	0	0	0	L	0	0	0	0	0	0
0	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	L	0
0	0	0	0	0	0	0	L	0	0	0	0	0	0	L	0	0	0
0	0	0	0	L	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	L	0	0	0	0	0	0	0	L	0	0	0	0	0	0	0
0	0	0	0	0	0	0	L	0	0	0	0	0	0	0	0	L	0
0	0	0	0	0	0	0	0	0	0	0	0	0	L	0	0	0	0
0	0	0	0	L	0	0	0	0	0	0	L	0	0	0	0	0	0
L	0	0	0	0	0	0	0	L	0	0	0	0	0	0	L	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	L	0	0	0
0	0	0	L	0	0	0	0	0	0	L	0	0	0	0	0	0	0
0	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	L
0	0	0	0	0	0	0	0	L	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	L	0	0	0	0	0
0	0	0	L	0	0	0	0	0	L	0	0	0	0	0	0	0	L

Dot distribution with noise superimposed (φ = 10 %)

Fig. 2: The distribution of pixels by frequency modulation with noise superimposed by random numbers

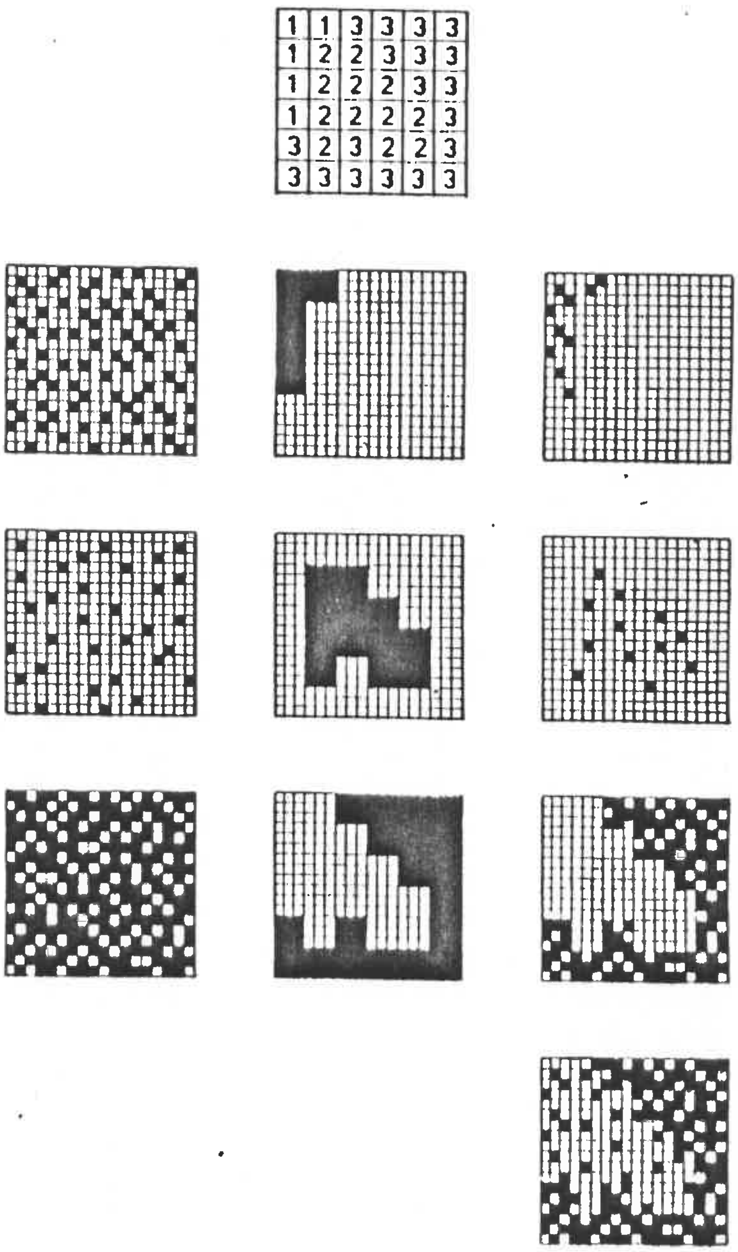

Fig. 3: The calculation of the output matrix by means of details areas and their tonal values

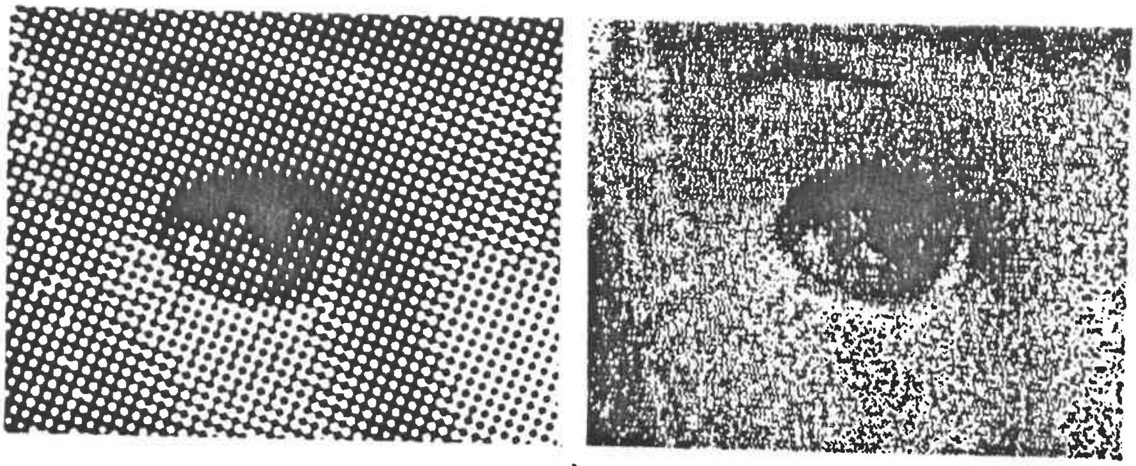

Fig. 4: A conventional amplitude modulated colour seperation (left) in comparison with a frequency modulated one (right)